Red Stag CLT Design Guide

Make it better

Red Stag CLT Design Guide V1.3
September 2022

RED STAG®
WOOD SOLUTIONS

Document Disclaimer

The Red Stag CLT Design Guide is intended to provide an overview of the structural design principles associated with a simple CLT building, which may include Red Stag CLT floor, wall, and roof panels. A series of indicative span tables for Red Stag CLT has been provided in the guide to support consulting engineers with an indication of CLT panel sizes for various applications.

Currently there is no New Zealand or internationally structural code covering the design of the CLT. As such, it is necessary for consulting engineers to design and certify the design as part of a performance solution.

It is responsibility of Red Stag CLT users to ensure that this CLT Design Guide is appropriate and exercise their own professional judgment when using the Red Stag documents. Full responsibility for design and compliance with the New Zealand Building Code (NZBC) and all relevant New Zealand standards, rests with the design professional specifying the product. Red Stag will not accept any liability for the failure of the any other elements of the building which cause a subsequent failure of a Red Stag CLT products.

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Section 1

Cross Laminated Timber Overview & Introduction

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1. Factory Overview

Red Stag Wood Solutions Limited (Red Stag) is a speciality Engineered Wood Product (EWP) manufacturer focusing on the integration of timber solutions into traditional, mid and high-rise construction. Red Stag is focused on developing new products and solutions to enhance productivity, cost effectiveness and the environmental impact associated with the construction sector. *Figure 1* shows the Red Stag EWP site in Rotorua.

Figure 1: Red Stag's primary EWP site in Rotorua.

Red Stag is the legal entity within the Red Stag Group focusing on structural EWP, including but not limited to Cross Laminated Timber (CLT), Glue Laminated Timber (GLT), Frame and Truss (F&T), advanced stick panelisation and cassette systems. Red Stag has constructed the first phase of New Zealand's largest and most advanced CLT plant. The scale facility has the ability to manufacture panels up to 16.5 x 4.5 x 0.42 m (Length × Width × Depth). *Figure 2* shows panoramic views of the Red Stag EWP manufacturing process in Rotorua.

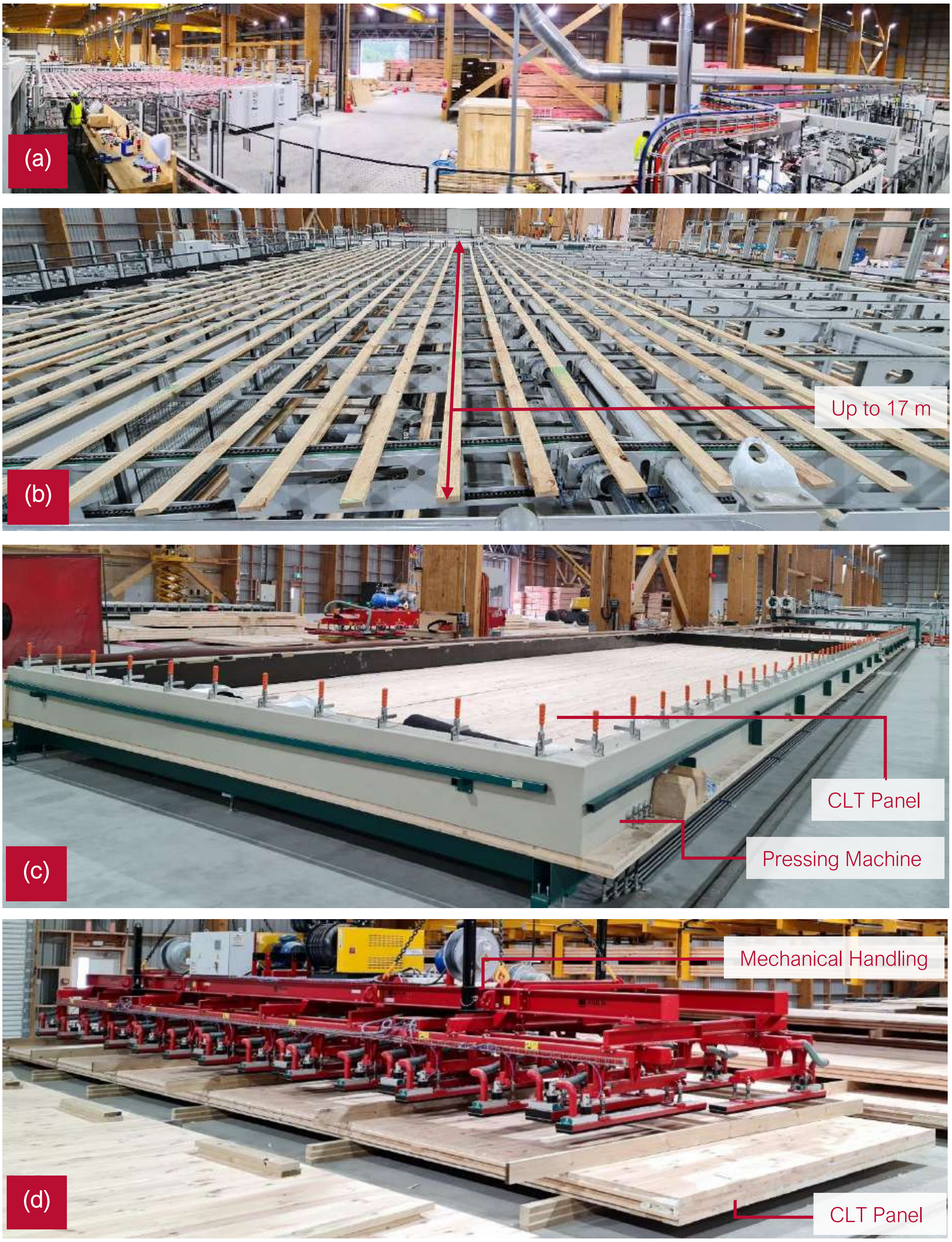


Figure 2: Red Stag's EWP manufacturing facility a) panoramic view of the Red Stag remanufacturing line; (b) 16.5 meter lamella out of the Finger Jointing (FJ) line; (c & d) CLT laminating equipment.

CLT is fundamentally changing the way buildings are designed, manufactured, and constructed. Red Stag's investment and innovation will help CLT to become the backbone for future generations of high performance, low carbon construction, in traditional, mid and high-rise buildings.

New Zealand and the Pacific regions are in the early stages of a CLT construction boom, driven by increasing demand and expanded building code acceptance of mass timber structures. CLT allows developers, designers, and builders to move beyond traditional construction trade-offs to create buildings that are sophisticated, efficient, rapidly assembled, structurally sound, affordable, and aesthetically stunning. As access to high-quality CLT continues to expand in New Zealand, Red Stag is confident that it will become the material of choice across a broad range of market sectors, building types, and geographies.

2. Red Stag's CLT Research &

Red Stag's goal is to develop the most advanced mass timber building systems in New Zealand, making them more widely available, more efficiently produced, compliant to New Zealand standards (including treatment), more cost-effective and of higher quality than ever before (Refer to *Figure 3*).

CLT is much more than simply a structural building material. It is an opportunity to evolve building design and construction, making it easier to create buildings that are elegantly designed, efficiently built, and environmentally responsible, all while providing increased investment returns. To achieve these lofty goals, Red Stag has taken an integrated approach and applied technology to every step in the process. Red Stag is establishing end-to-end mass timber expertise and making unprecedented investment in CLT Research & Development (R&D), testing, manufacturing, design, engineering, and construction. With this level of control and innovation, Red Stag can provide its partners with the most advanced building systems currently available.

Figure 3: Red Stag's CLT Research Projects (Scion, Crown Research Institute focusing on wood products and materials).

Red Stag CLT is a building material that offers a unique combination of efficiency, strength, safety, aesthetics, and environmental benefits to deliver value across the entire construction ecosystem.

2.1 For Developers

The efficiency and accuracy of digital design, combined with Computer Numerical Control (CNC) machined EWP significantly reduces:

- Construction time (reduced holding costs and labour hours).
- On site construction and processing.
- Site nose, dust, and debris.
- Site waste.
- Site health and safety incidents (reduced labour units required on site, reduced hazards, reduced construction time).

2.2 For Owners/Operators

The superior aesthetics and operational efficiencies of mass timber buildings present unique opportunities for design differentiation, high occupancy demand, and long-term asset value growth. The option for exposed CLT generates a robust, aesthetically pleasing substrate that has significantly lower maintenance issues compared to plaster board. Timber buildings have proven to generate higher sales and lease rates compared to traditional construction materials due to the physiological and psychological benefits that exposed timber provides occupants.

2.3 For Architects & Engineers

Red Stag's CLT inherent structural, aesthetic, and biophilic characteristics offer unique design possibilities that blend form, function, user experience, and sustainability. Combining CLT and GLT with large scale five-axis CNC'ing allows for the most complex, advanced designs, and associated Building Information Modelling (BIM) to be seamlessly converted from concepts on paper or screen into reality.

2.4 For Builders

As a prefabricated material, Red Stag CLT moves labour upstream and offsite, reduces site waste and logistics, significantly speeds up site build times, reduces site noise and debris, improves safety (reduced labour units, less time at height, less processing on-site), reduces the impact of weather, and generally mitigates many of the other risks associated with traditional construction on site.

2.5 For Tenants & Citizens

Mass timber buildings are at the forefront of healthy and dynamic communities, providing physiological and psychological benefits to the people who live and work in them, and reducing the environmental impact of construction. The health benefits [1],[20] include, but are not limited to:

- Reduced blood pressure.
- Reduced stress levels.
- Improved attention and focus.
- Greater creativity.
- Faster recovery.
- Reduced pain perception.

3. Environmental & Sustainability

The recent Emissions Gap Report 2020 from the UN Environment Programme (UNEP) found that buildings generate nearly 40 percent of the global annual Carbon Dioxide (CO_2) emissions [2]. Of those total emissions, building materials and construction generates 11 percent of the world's CO_2 emissions annually from embodied carbon emissions, or 'upfront' carbon that is associated with materials and construction processes throughout the whole building lifecycle [3].

Two of the most conventional building materials, concrete and steel, are among the most carbon-intensive to produce, therefore contribute to the majority of the construction sector's CO_2 emissions. Switching to lower carbon footprint alternatives such as CLT can significantly reduce a building's negative environmental impact. Steel and concrete are each responsible for between 5 – 8 percent of global CO_2 emissions, the most significant greenhouse gas causing global warming [4].

In contrast to concrete and steel, CLT is a renewable material that sequesters carbon during its life cycle. CLT is a lighter, stronger, more sustainable alternative to concrete and steel structures. The environmental and sustainability advantages of building with CLT compared with concrete and steel are derived from the inherent qualities of wood as a carbon-capturing material, reduced transportation costs (lighter and less loads as compared to traditional materials), and expedited construction time to further reduce the net CO_2 for associated builds (Refer to *Figure 4*).

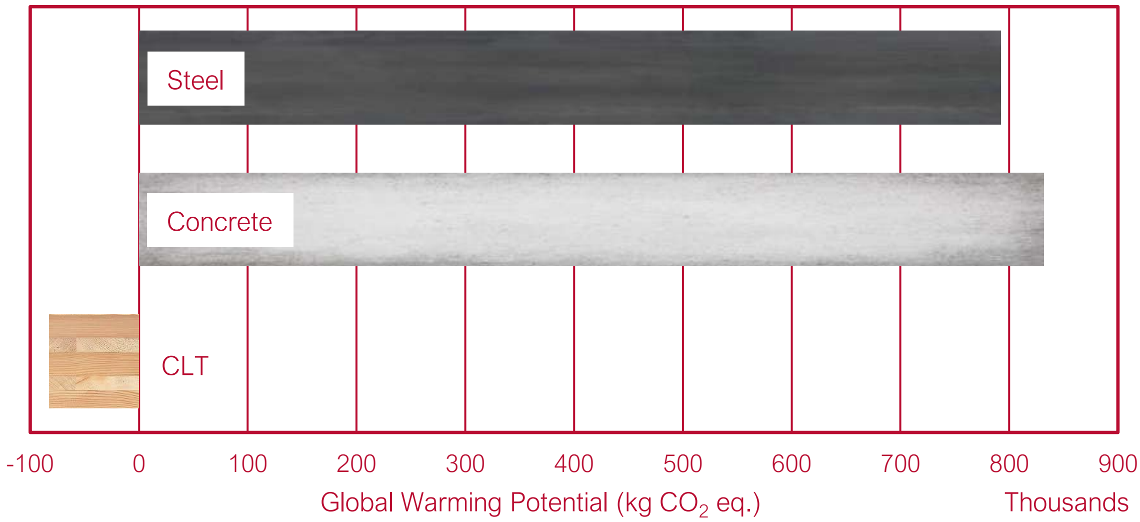


Figure 4: Embodied Carbon of Timber Building Versus Concrete and Steel Building.

3.1 Environmental Advantage of CLT versus Plywood and LVL

Other EWP such as plywood and LVL utilise approximately 10 percent adhesive (glue), often urea-formaldehyde, which can produce hazardous chemicals during recycling or incineration [5]. In contrast, CLT has less than one percent adhesive, and typically uses a bio-based polyurethane. For CLT, the lamella or boards are bonded together with a comparatively smaller amount of adhesive due to the supporting chemical reaction between the natural moisture in the timber and pressure.

4. Cross Laminated Timber

CLT is a high-performance mass timber product that comprises treated, graded boards, which are glued together in a cross-layered manner, where each layer is orientated 90 degrees to each other. Red Stag CLT is manufactured from New Zealand renewable Forest Stewardship Council ® (FSC® Licence Code: FSC-C172039) [6] certified forestry, typically in three to eleven layers, with a total thickness ranging from approximately 126 mm to 420 mm depending on the structural requirements (Refer to *Figure 5* to *Figure 7*).

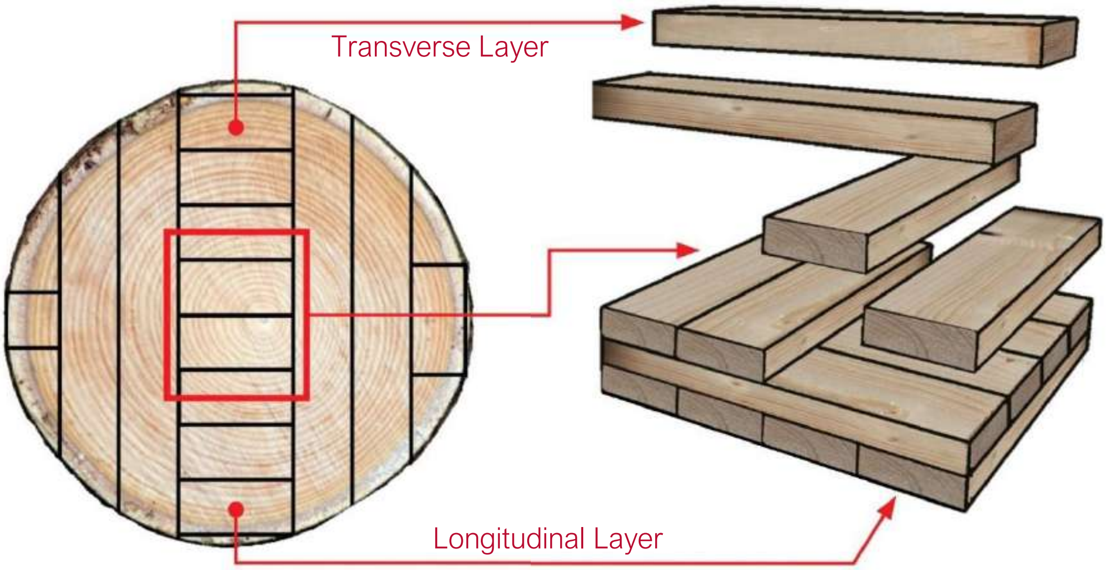


Figure 5: Arranging Boards. ***Figure 6:*** Sawn Log.

4.1 Characteristics

CLT panels gain most of their stiffness from the outer structural layers (defined as longitudinal laminates regardless of length). Transverse laminates help to bind the structural layers, but do not require the same structural properties. Red Stag manufactures panels using specified layer properties, defining the Modulus of Elasticity (MoE in GPa) to align with the performance criteria of the panel (Refer to *Table 1*). Red Stag panels are glued together using Polyurethane Reactive (PUR) adhesive.

The benefits of CLT include design flexibility, rapid installation, reduced mass loading and foundation requirements, exceptionally structural properties, outstanding seismic performance, and a very good fire rating. CLT is a highly cost-effective material compared to concrete and steel and a significant sequester of carbon, making it an environmentally friendly solution for mid to high-rise construction.

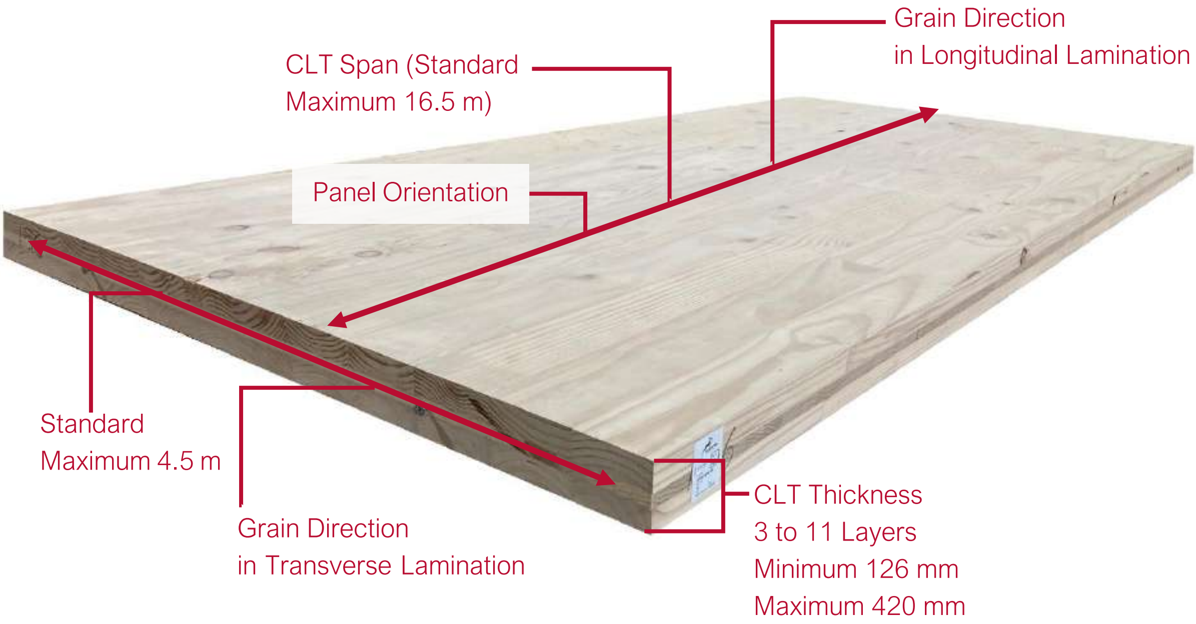


Figure 7: Red Stag CLT panel.

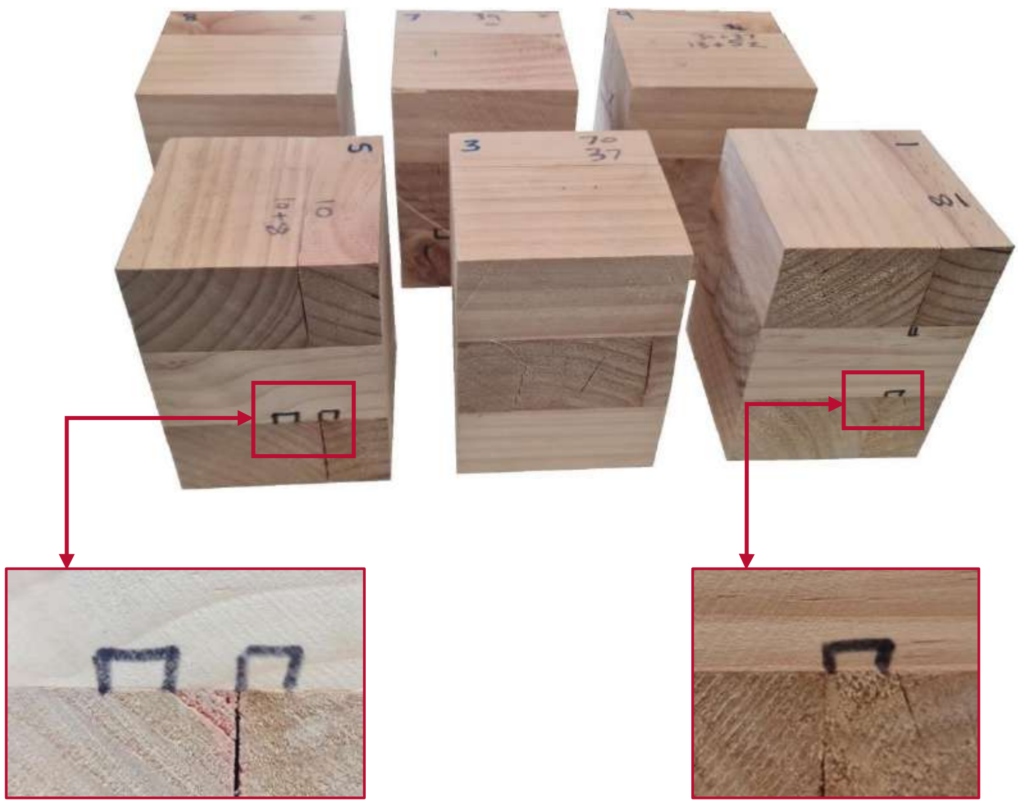
Table 1: Red Stag CLT Structural Material Strength Properties.		
Structural Properties	Longitudinal Laminates	Transverse Laminates
Modulus of Elasticity (MoE)	8.0 GPa	6.0 GPa
Bending Strength	14 MPa	10 MPa
Compression Parallel to Grain	18 MPa	15 MPa
Compression perpendicular to Grain	8.9 MPa	8.9 MPa
Tension Strength	6.0 MPa	4.0 MPa
Normal Shear	3.8 MPa	3.8 MPa
Available lamella thickness	42 mm & 20 mm	42 mm & 20 mm
Refer to NZS 3603:1993 [7]		

4.2 CLT Performance Testing

Red Stag manufactured CLT panels and associated feedstock have been tested by professional third parties to ensure the durability, mechanical strength, and fire resistance. As shown in *Figure 8 - Figure 10*, a series of large-scale experimental tests have been conducted on Red Stag CLT products to verify the quality and performance. Destructive large-scale four-point bending tests conducted by SCION [8] confirmed that the Red Stag CLT panels have a sufficient level of stiffness and strength to carry applied structural loads (Refer to *Figure 8*). Testing on short, intermediate, and long-span CLT panels showed their exceptional structural performance under large pure shear forces, pure bending moments, and the combination of both. The SCION test results confirmed that the CLT panels outperformed the theoretical design calculations and associated numerical modelling.

Figure 8: Large scale mechanical testing conducted by SCION; (a) Long span testing, (b) Median span testing, (c) Short span testing.

The glue bond quality and durability of the CLT layers have been assessed by delamination testing. The reported delamination test results by a third-party specialist company showed an average delamination percentage [9] under the standard allowable limit, confirming the glue line bonds are sufficiently durable (Refer to *Figure 9*). In addition to the delamination testing, the large-scale bending experimental tests conducted by SCION verified that there were no adverse issues associated with glue line performance. No glue line failure or board separation was observed during all deflection testing.



Test specimens after delamination test [9]

Figure 9: Delamination test specimens confirming the quality of Red Stag glue line bonds.

The Fire Code is formulated to permit time for occupants to safely leave a burning building before structural collapse or succumbing to heat or smoke inhalation. The code stipulates that the safe evacuation period of up to 60 minutes in New Zealand will cover the vast majority of building types and uses. Large-scale CLT panel fire testing has been conducted by Red Stag to determine the overall fire resistance and fire performance of the panels under structural loads (Refer to *Figure 10*). CLT test specimens were installed in a furnace to investigate a number of parameters such as the structural performance during a fire event, temperature profile and deflection. The third-party fire test report confirmed no structural, integrity or instability failure after more than 60 minutes at 900 degrees Celsius.

Figure 10: Large-scale fire test specimen set-up for the fire testing on Red Stag CLT; (a) Red Stag CLT floor test specimen after fire testing, (b) Red Stag CLT wall test specimen before fire testing.

In addition to the experimental test results and confirming reports from third-party specialists, Red Stag tested and investigated its products numerically. A typical 3D design and associated finite element mesh model for the CLT panels are shown in *Figure 11*.

Red Stag's technical team can provide a comprehensive technical statement, including CLT design calculations, experimental test reports and numerical analysis for each project separately if required by the client [i].

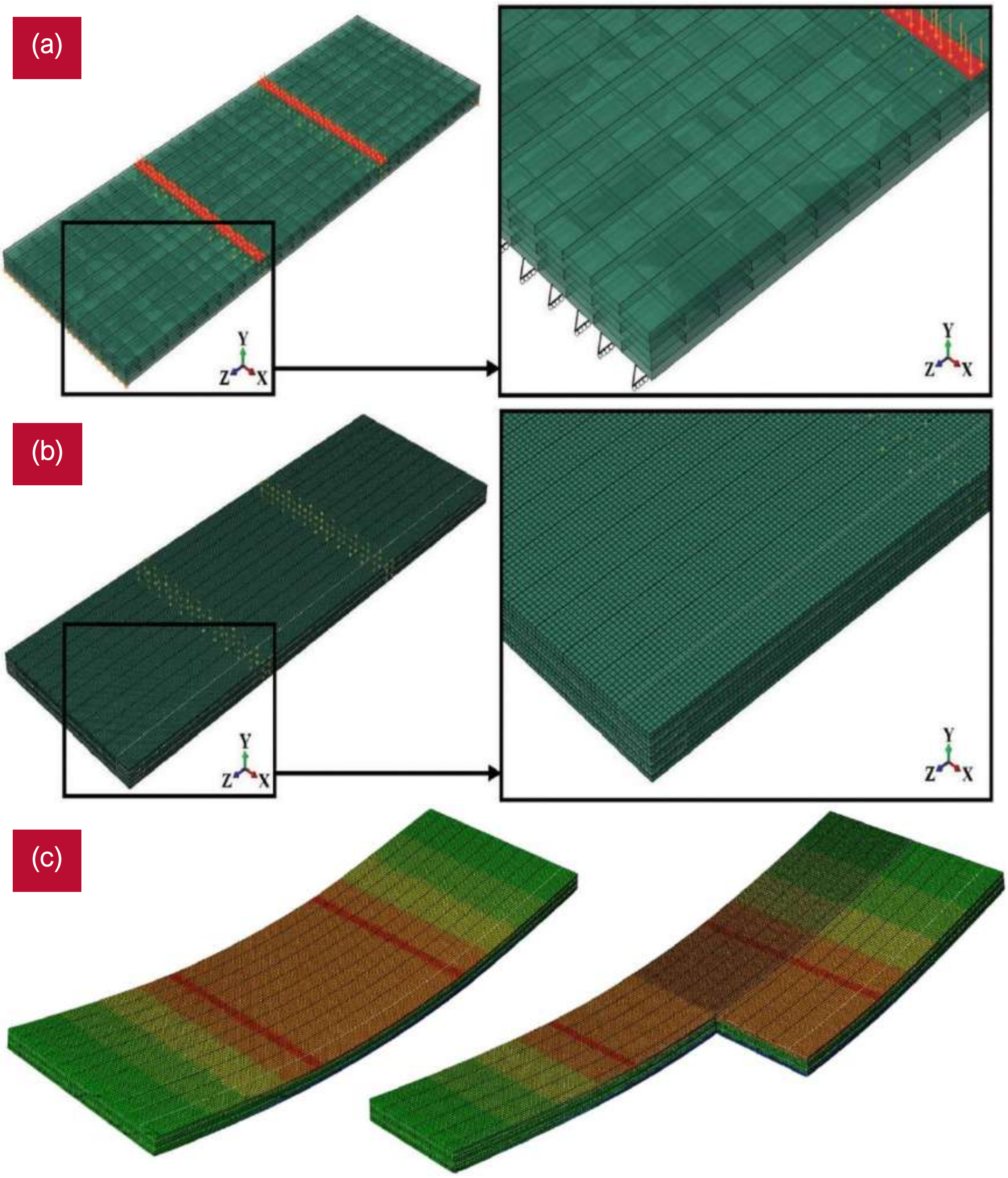


Figure 11: Typical boundary conditions and Finite Element (FE) mesh numerical model using ABAQUS [19] software; (a) FE model boundary conditions (Load and support); (b) FE mesh; (c & d) CLT panel numerical model to determine the deflection and stresses under various load conditions.

[i] Client requests can be assessed and supported, but the client will need to have their engineering team sign off on all Red Stag modelling and associated calculations. Red Stag will charge all services out at its defined rates.

4.3 Red Stag Testing Facilities

Red Stag regularly checks the quality of the manufactured CLT panels via inhouse testing equipment. Red Stag has invested in the most advanced delamination testing equipment to analyse the glue bond quality between lamellas (Refer to *Figure 12*). Red Stag also confirms the quality of its Finger Joints (FJ) and shear block testing using a high-capacity hydraulic press with integrated load cell (Refer to *Figure 12*). To test beams and EWP sections, Red Stag uses calibrated, third party verified four point bending equipment for routine component analysis and internal Research and Development (Refer to *Figure 12 – Figure 14*).

Figure 12: Delamination testing machine.

Figure 13: Finger joint test equipment and setup.

Figure 14: CLT beam bending testing machine and setup; (a) Isometric end elevation; (b) Front elevation.

Section 2

Cross Laminated Timber Application & Products

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Red Stag manufactures CLT panels from locally grown radiata pine for a wide range of structural components. Applications for CLT panels include floors, walls, beams, stairs, and roof/ceiling systems. CLT can resist large forces and loads, making it an effective, cost-effective structural option for multistorey applications.

5.1 Red Stag CLT Floors

Red Stag CLT panels are ideally suited for floor systems, with the ability to span in one or two directions (Refer to *Figure 15)*. Offsite manufacturing allows for panels to be shipped to site as ready-to-install structural components, greatly simplifying the building assembly process and increasing job site productivity and construction speed. The scale of Red Stag's EWP manufacturing plant allows for optimised structural solutions with fewer large format panels, providing the opportunity to install up to 75 square meters per crane lift (Refer to *Figure 16*).

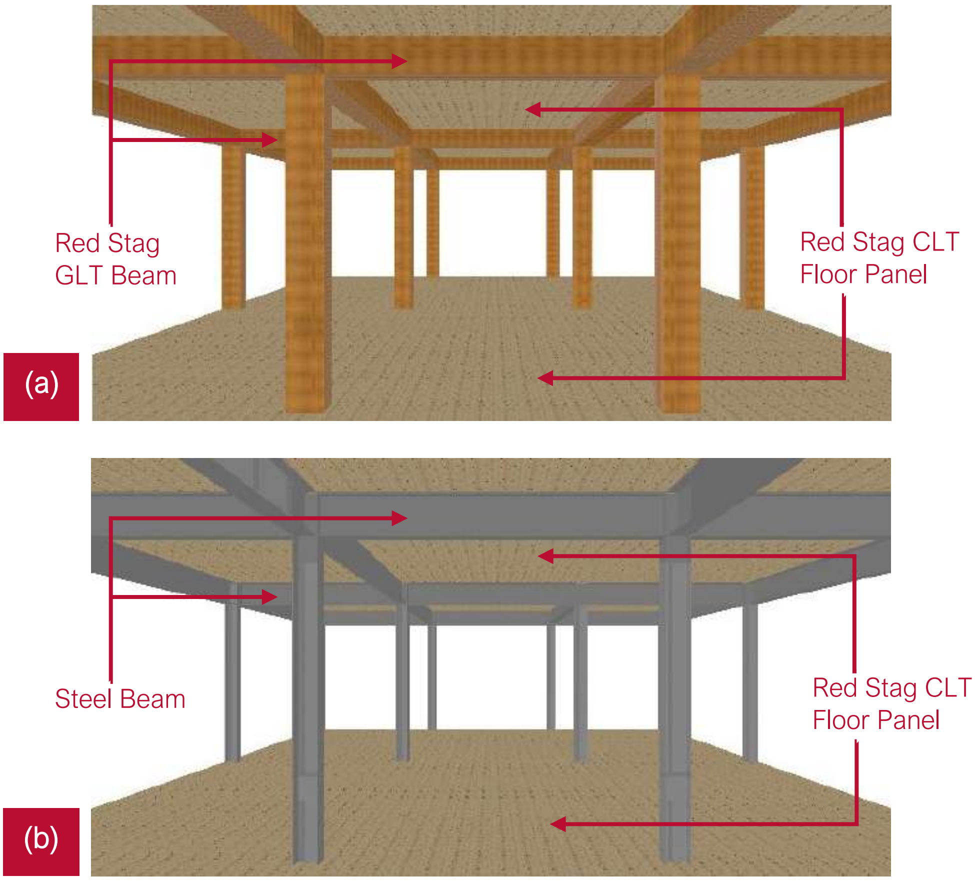


Figure 15: Red Stag CLT floor panel applications in timber or composite structures; (a) Timber system structure; (b) Steel-timber composite structure.

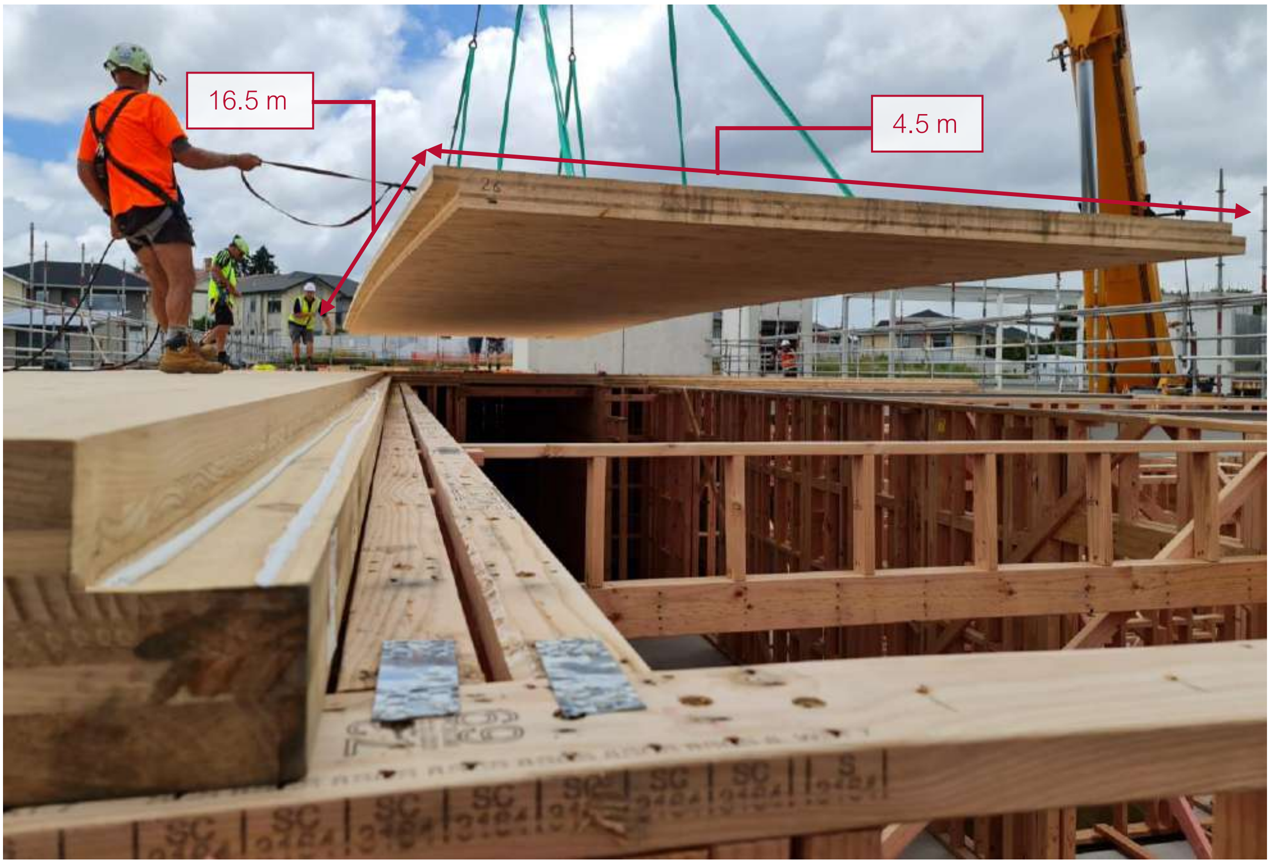
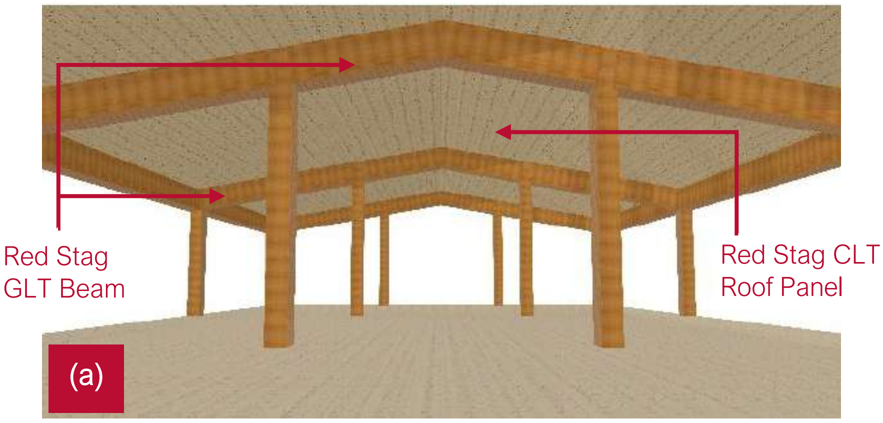


Figure 16: Red Stag CLT floor panels being installed onto Red Stag frames. Installation shows an example of a 75 square meter Red Stag CLT panel being effortlessly installed on site.

5.2 Red Stag CLT Roofs

Red Stag CLT roof panels provide a solution to expediently enclose a building from the weather, while providing the option for a natural timber sarking finish in the interior. CLT roof panels support in providing improved thermal properties (refer to section 5), when combined with secondary insulation [22] (Refer to *Figure 17).*



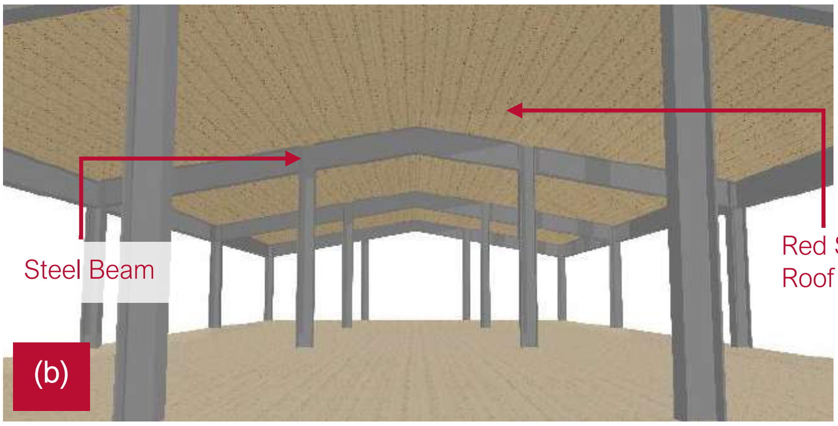


Figure 17: Red Stag CLT roof panel applications in timber or composite structures; (a) Timber system structure; (b) Steel-timber composite structure.

5.3 Red Stag CLT Walls

Red Stag CLT wall panels are a cost-competitive alternative to pre-cast concrete systems. CLT is lighter than pre-cast concrete, simplifying material handling and installation. Red Stag CLT wall panels can be designed for both tradition platform, and balloon wall systems (Refer to *Figure 18*).

Red Stag CLT walls provide improved gravitational load resistance and significant bracing to the structure. CLT walls are especially well suited to internal load bearing walls, lift shafts and stair wells. For mid and higher rise structures, CLT exterior walls provide the benefit of speed and structural performance.

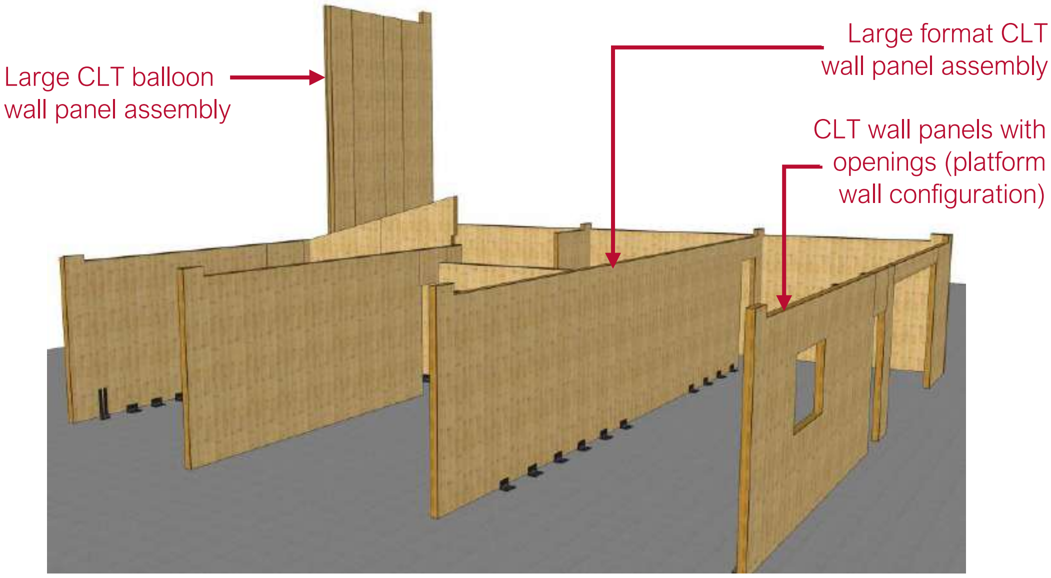


Figure 18: Red Stag CLT Wall panel applications.

5.4 Red Stag CLT Lift Shafts

Red Stag CLT lift shaft panels can be erected faster and easier than similar steel and concrete options, while providing exceptional lateral bracing for the building. Elevator and stair shafts can comfortably achieve a one hour fire resistance rating when using a 126 mm thick (or greater) three layer Red Stag CLT panel (Refer to *Figure 19*).

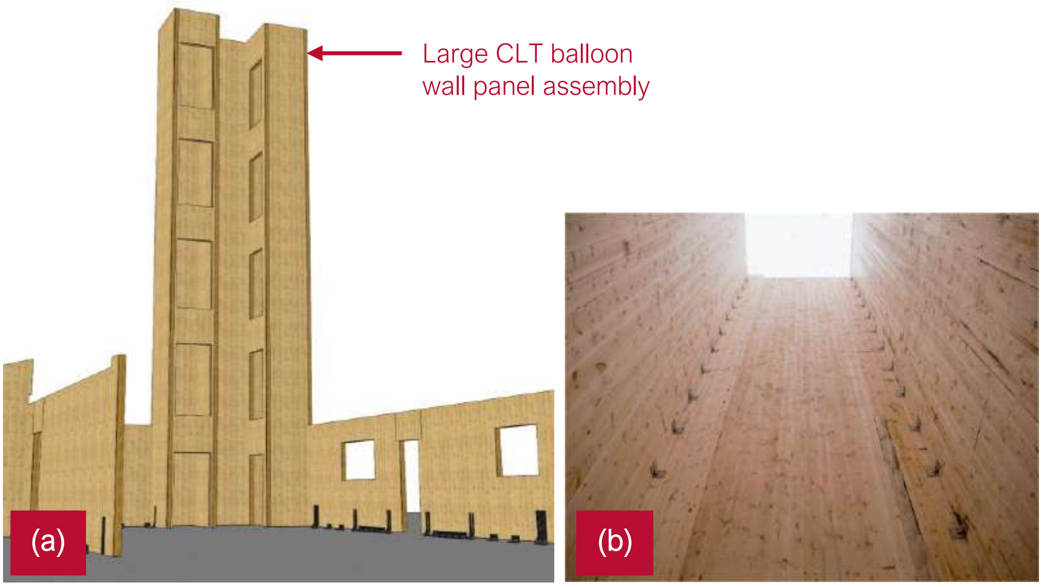


Figure 19: CLT Lift shaft (a) Multi-storey building with CLT lift shafts; (b) Interior view of a CLT lift shaft.

5.5 Red Stag CLT Shear Walls and Diaphragms

Red Stag CLT panels offer a great structural solution for timber and hybrid building designs to resist lateral loads generated by earthquakes and wind. Shear transfer between adjacent Red Stag CLT panels is achieved through a variety of metal connector systems and other high-density wood products that are attached with screws or nails (*Figure 20*).

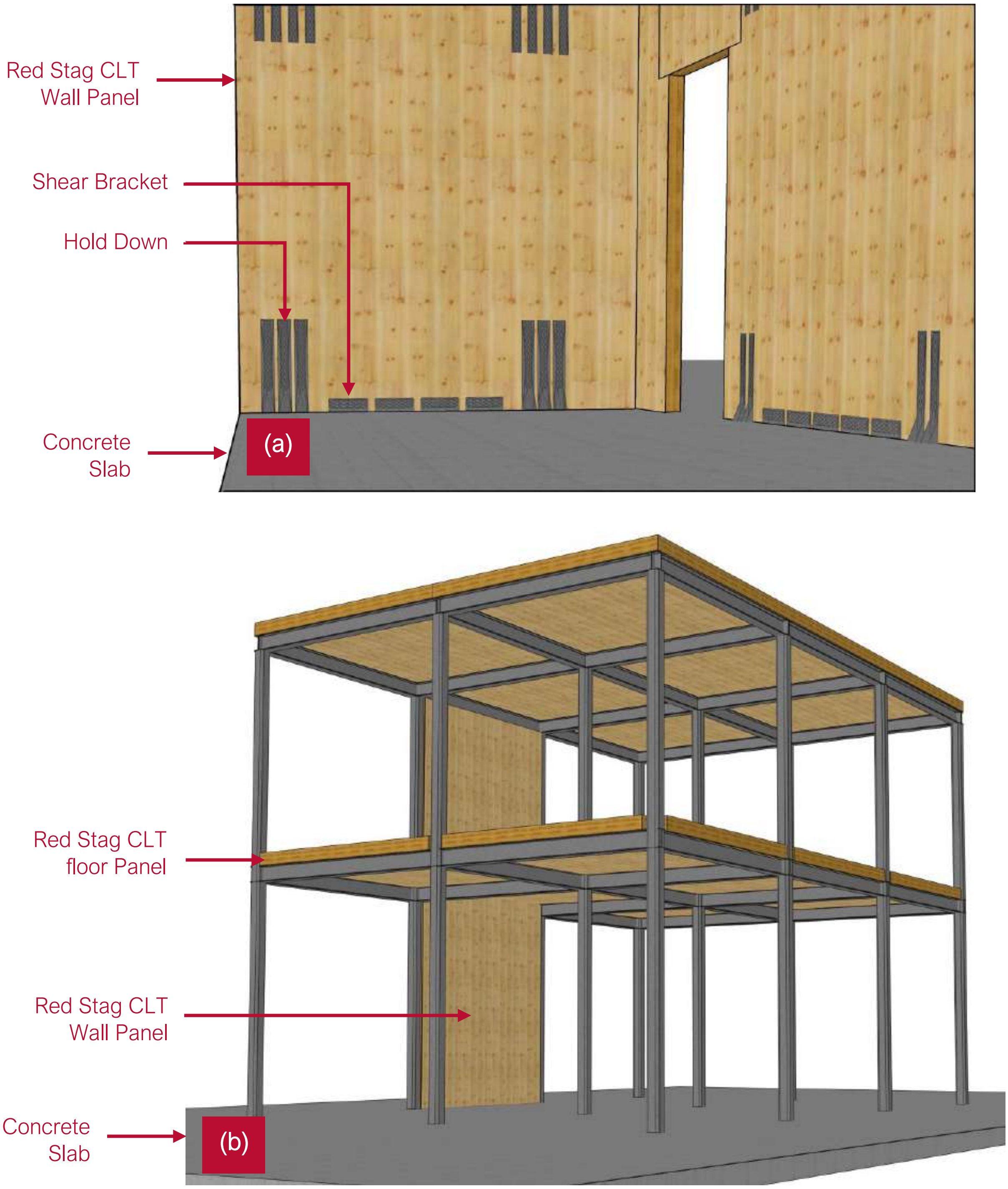


Figure 20: (a) CLT shear wall hold down system; (b) CLT panel diaphragm.

6. Red Stag CLT Panel Configuration Option

Red Stag can create a range of CLT configurations or recipes, including 3, 5, 7, 9 and 11-layer panels in visual and standard grades. A simplified range of CLT panel configurations for floor, roof and wall applications is summarised in *Table 2 to Table 6.* Additional CLT configurations beyond those presented in the tables below may be available based on the client's requirements; however, feedstock references will determine the availability, viability, and cost position of alternate recipes. A significant benefit of CLT and timber is its ability to lock up carbon. For every cubic meter (1 m^3) of timber utilised in a building, it removes 486 kg/m^3 of CO_2 [10] from the atmosphere. The CO_2 is absorbed by the timber and the carbon is stored/sequestered. For every 1 m^3 of CLT, it will sequester 250 kg of locked-in carbon [12-15] (*Figure 21*). To highlight this exceptional environment advantage, Red Stag has calculated the CO_2 benefits for its CLT products and summarised in the CLT panel specification tables below (*Table 4 - Table 6*). *Table 7 – Table 13* present the maximum span for cantilevered, simply supported, and continuous CLT floors and roofs based on the FPInnovations [11] CLT design guide and the New Zealand design action standard (AS/NZS 1170.0) [12].

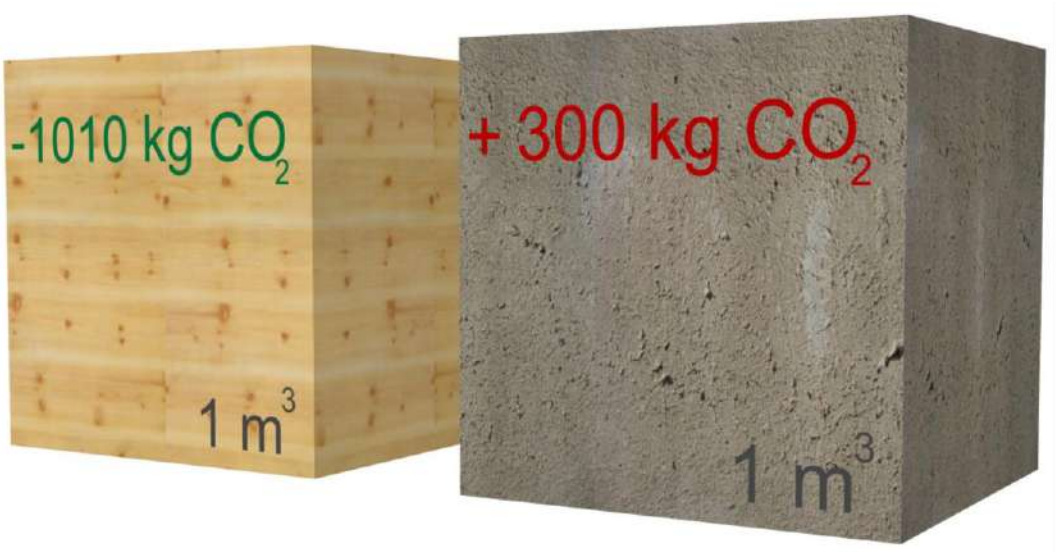


Figure 21: CLT versus Concrete [14-17].

7. Red Stag Lamella Specifications

The Red Stag Timber sawmill focuses on structural timber gauges 45 mm thick with finished board widths between 70 – 290 mm. To produce 140x45 gauged timber, Red Stag Timber cuts 150x50 Rough Sawn (RS), which is then further processes to create the final 140x45 gauging.

Red Stag's CLT plant utilises three primary feedstock thicknesses: 45 mm gauged, 50 mm RS, and 25 mm RS. Subject to the CLT recipe requirements, wherever practically possible, 45 mm thick feedstock will be used to make the processed CLT as economical as possible (reduced price point).

To optimise the utilisable fibre, Red Stag has refined its remanufacturing line to generate 42 mm thick lamella from 45 mm feedstock. *Table 3* details the primary feedstock and finished planed gauges.

The second feedstock option is 25 mm RS, used to create 20 mm lamella. Red Stag tries to limit the use of 20 mm lamellas as it generates the largest cross-sectional wastage through planing and requires the largest volume of defecting to ensure the lamellas run smoothly through the process.

The third primary feedstock option is 50 mm RS, used to create lamella gauges 45 mm thick. 50 mm RS is the least available and most expensive feedstock as it is the pre-MSG feedstock for Red Stag Timber structural timber.

The input raw material price calculations are based on the feedstock gauge; therefore, the price will not decrease if the Client selects a thinner gauge (i.e. 42 mm thick lamellas will be less expensive than 35 mm lamellas due to secondary planing requirements). As Red Stag Timber is a structural mill, predominantly servicing the New Zealand market, the largest majority of the feedstock will have an average MoE of 8 GPa. As such, the longitudinal layers of the Red Stag CLT will generally be specified as 8 GPa, with the majority of the transverse layers being specified up to 6 GPa. Red Stag will have some 10 GPa (and potentially higher) feedstock available; however, will focus its designs around 8 GPa and 6 GPa feedstock to make CLT as economic as practically possible relative to the properties of New Zealand Radiata Pine in the Central North Island.

Red Stag Timber is providing Red Stag with pre-treated feed stock for its EWP. To ensure the quality of the glue bond on the processed EWP, Red Stag minimises the time between final planing, glue application and pressing. To maximise the retained treatment, Red Stag planes as little timber as possible from lamellas. This aligns with the three primary finished gauge options in order of priority/preference: 42, 20, 45 mm.

Table 2: Material Strength Properties

Structural Properties	Longitudinal Laminates		Transverse Laminates
Modulus of Elasticity (MoE)	8 GPa	10 GPa	6.0 GPa
Bending Strength	14 MPa	20 MPa	10 MPa
Compression Parallel to Grain	18 MPa	20 MPa	15 MPa
Compression perpendicular to Grain	8.9 MPa	8.9 MPa	8.9 MPa
Tension Strength	6.0 MPa	8.0 MPa	4.0 MPa
Normal Shear	3.8 MPa	3.8 MPa	3.8 MPa
Refer to NZS 3603:1993 [7]			

Table 3: EWP Feedstock Gauge Priority and Associated Commonly Available Post Processed Gauges.

Gauge Priority [a]	Primary Raw Gauges (mm)	Gauged Width (+/- 2 mm)	Gauged Thickness (+/- 1 mm)
1	140x45	137	42
2	100x25	93	20
3	150x50	140	45

a. Gauge priority defines the most cost effective and readily available feedstock gauge.
b. Client accepts treatment retention based on volume of post planning below 42 mm in thickness.

Table 4: Three (3) Layer CLT Panel Specifications

Recipe Priority [a]	1	2
Panel Recipe	CLT 3/126	CLT 3/104
Layer 1, MoE 8 GPa	42 mm	42 mm
Layer 2, MoE 6 GPa	42 mm	20 mm
Layer 3, MoE 8 GPa	42 mm	42 mm
Panel Self Weight (Static Load)	0.63 kPa	0.52 kPa
Panel Thickness	126 mm	104 mm
Removed CO_2 from Atmosphere [14]	- 100 kg/m^3	- 83 kg/m^3
Created CO_2 by Equivalent Concrete Slab	+ 51 kg/m^3	+ 43 kg/m^3
CLT CO_2 Benefit Compared to a Concrete Slab	151 kg/m^3	126 kg/m^3

a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.

Table 5: Five (5) Layer CLT Panel Specifications

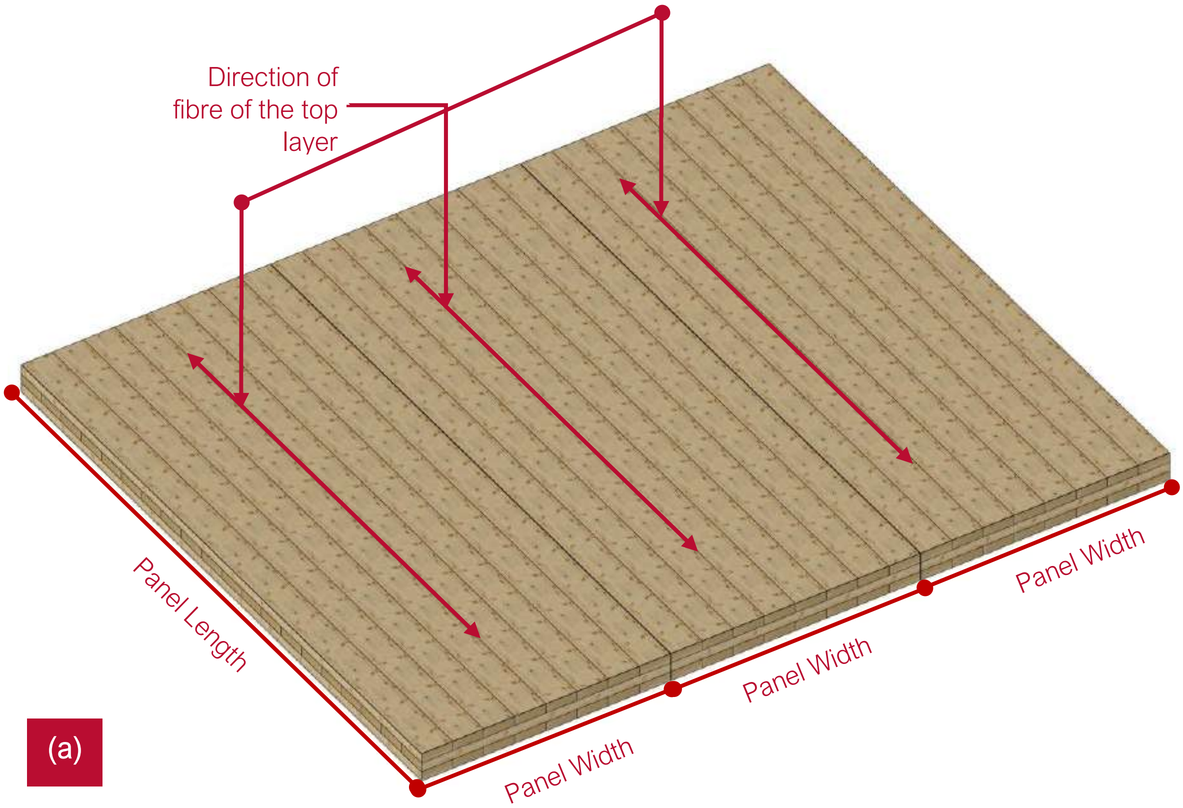
Recipe Priority [a]	1	2
Panel Title	CLT 5/210	CLT 5/166
Layer 1, MoE 8 GPa	42 mm	42 mm
Layer 2, MoE 6 GPa	42 mm	20 mm
Layer 3, MoE 8 GPa	42 mm	42 mm
Layer 4, MoE 6 GPa	42 mm	20 mm
Layer 5, MoE 8 GPa	42 mm	42 mm
Panel Self Weight (Static Load)	1.05 kPa	0.83 kPa
Panel Thickness	210 mm	166 mm
Removed CO_2 from Atmosphere [14]	- 161 kg/m^3	- 127 kg/m^3
Created CO_2 by Equivalent Concrete Slab	+ 82 kg/m^3	+ 64 kg/m^3
CLT CO_2 Benefit Compared to a Concrete Slab	242 kg/m^3	191 kg/m^3

a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.

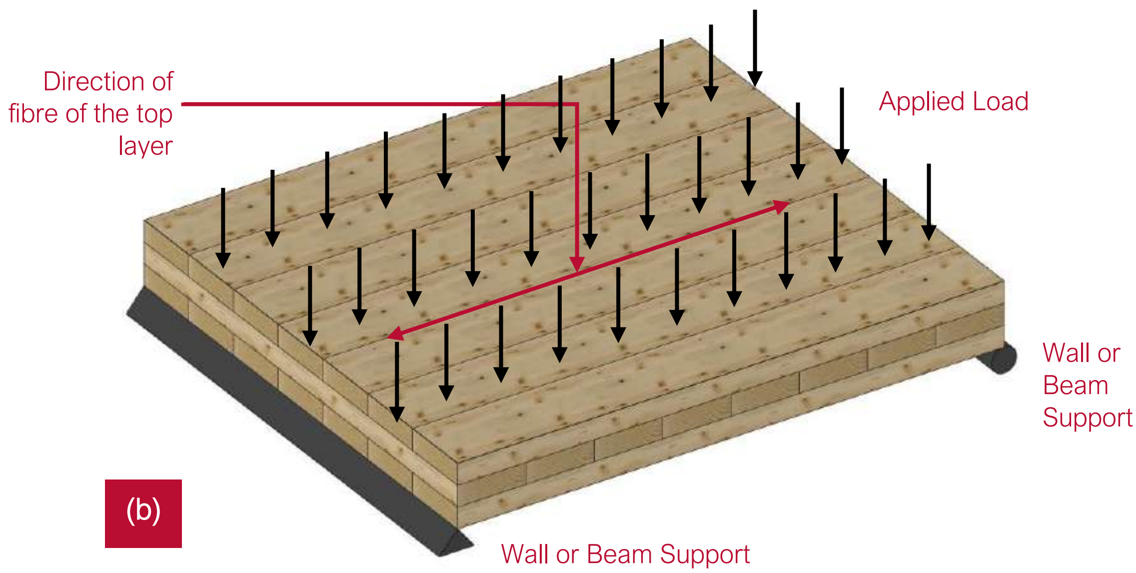
Table 6: Seven (7) Layer CLT Panel Specifications.		
Recipe Priority [a]	1	2
Panel Title	CLT 7/294	CLT 7/228
Layer 1, MoE 8 GPa	42 mm	42 mm
Layer 2, MoE 6 GPa	42 mm	20 mm
Layer 3, MoE 8 GPa	42 mm	42 mm
Layer 4, MoE 6 GPa	42 mm	20 mm
Layer 5, MoE 8 GPa	42 mm	42 mm
Layer 6, MoE 6 GPa	42 mm	20 mm
Layer 7, MoE 8 GPa	42 mm	42 mm
Panel Self Weight (Static Load)	1.47 kPa	1.14 kPa
Panel Thickness	290 mm	228 mm
Removed CO_2 from Atmosphere [14]	- 419 kg/m^3	- 325 kg/m^3
Created CO_2 by Equivalent Concrete Slab	+ 213 kg/m^3	+ 166 kg/m^3
CLT CO_2 Benefit Compared to a Concrete Slab	633 kg/m^3	490 kg/m^3
a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.		

IMPORTANT: If a project is less than 200 m^3, Red Stag can only provide recipe priority 1 options unless agreed prior with the client. Recipe priority 2 or alternates are only available based on available feedstock and production capacity. If a project requires an alternate recipe to priority 1 options, please coordinate with Red Stag in advance.

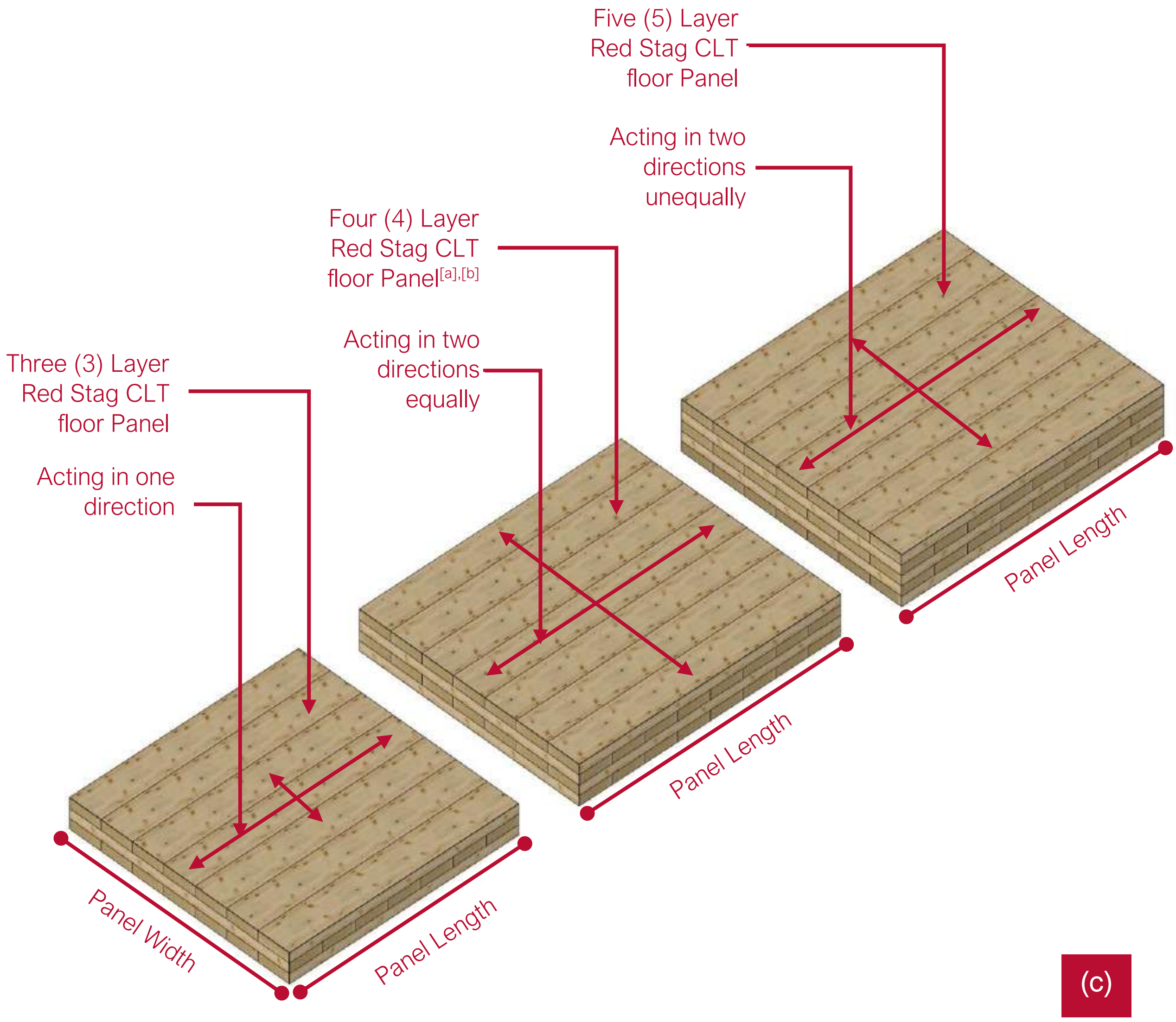
In roof and floor applications, CLT panels are usually placed next to each other in the same direction (Refer to *Figure 22a* and *Figure 22b*), acting as single directional CLT slab. The width of Red Stag CLT panels can be customised but is generally up to 4.5 m wide. Most floor and roof systems are simply supported on two or more walls or beams. In some cases, CLT roof and floor configurations can be built with CLT panels acting in two directions (Refer to *Figure 22c*). Please note that the three (3) layer CLT panel in *Figure 22c* is for illustration purposes only, as at least four layers are required for a two-way action.



(a)



(b)



[a] Performs in two directions equally, similar to the main direction action of a three-layer CLT panel.
[b] Lighter weight compared to the five-layer panel, with comparable structurally performance.

Figure 22: CLT Floor assemblies (a & b) for three (3) layer CLT panels acting in one direction; (c) one five (5) layer CLT panel acting in both directions. Minimum of five layers of lamella are required to guaranty the CLT performs as a two-way CLT system. "Panel width" depends on the manufacturer and properties of the lamella in each layer. Two acting directions in three (3) layer and five (5) layer asymmetrical CLT panels compared with a four (4) layer symmetrical CLT panel.

Red Stag have utilised the Gamma method presented in the FPInnovations CLT design guide to design its CLT panels for roof or floor applications. The Gamma method takes rolling shear deformation in the transverse laminate(s) into account (Refer to *Figure 23*). Dissimilar to the long spans in CLT roof or floor panels, shorter spans have a higher proportion of rolling shear deformation.

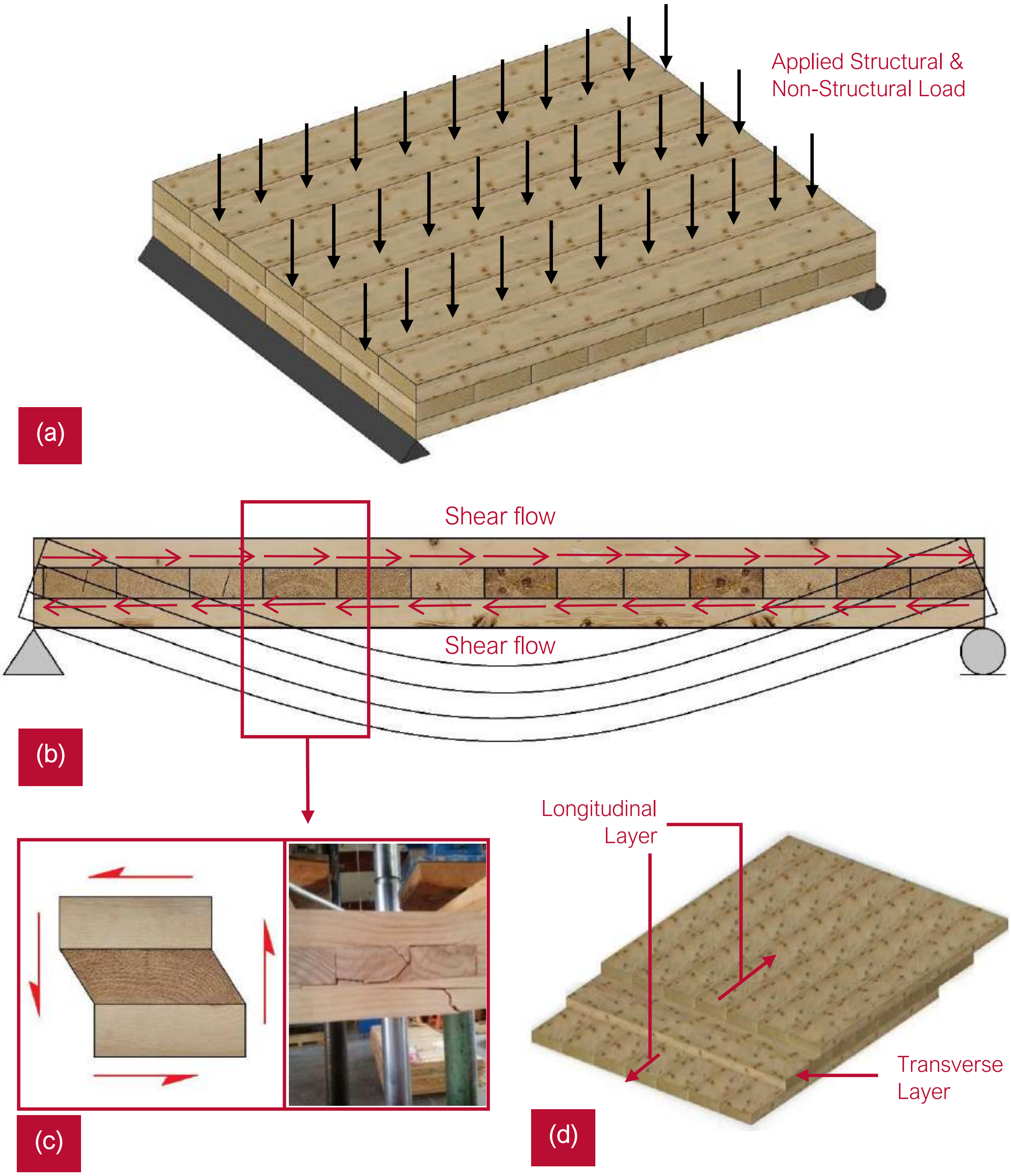


Figure 23: Rolling shear phenomenon; (a) Loaded CLT panel; (b) Shear flow through the panel; (c) Effect of rolling shear; (d) Rolling shear translation to transverse layer.

Red Stag's design guide has calculated bending strength and midspan deflection of the CLT panels for short-term and long-term loading under various load combinations for strength (ultimate), limit state design, and serviceability limit state design (further design details are summarised below).

Strength limit state:

For Long Term Loading:	1.35 G
For Medium Term Loading:	1.2 G + 1.5 Q

Serviceability limit state:

For Short Term Loading:	G + 0.7 Q
For Long Term Loading:	G + 0.4 Q

G: Gravitational weight of the CLT panel (Refer to *Table 4 - Table 6*).

$G_{add\text{-}DL}$: Additional dead load on the CLT floor. Assumed as 0.1 kPa for roof applications and 0.5 kPa, 1 kPa or 1.5 kPa for floor applications.

Q: Live load. Assumed as 0.25 kPa for roof applications and 2 kPa, 3 kPa, or 5 kPa for floor applications.

K_2*: Long-term creep factor. 2.0 or 3.0 for the serviceability limit state deflection check for simply supported and cantilever floors, respectively.

*Assumed that the CLT roof and floor remains dry during its service life.

Δ: Midspan deflection calculation result under $k_2(G+G_{SDL}+0.4Q)$. The result should be lower than Span/300 for a simply supported floor/roof and Span/200 for cantilevers.

9.1 Red Stag CLT Floor Vibration Design

Vibration (e.g. harmonics created during the walking/movement across the floor) is another important factor that needs to be taken into account during the design of CLT floor systems. The test results in the FPInnovations CLT design guide [11] shows that the vibrational behaviour of CLT floors is different from lightweight joist floors. The vibrational impact on the span of CLT floors is calculated based on the FPInnovations [11] and Euro Code [13] design methods. These two methods have been verified experimentally by a series of laboratory tests performed by FPInnovations [11] and the European Timber Standards.

- **FP Innovations [11] Vibration Calculation Method:**

Limited Vibration Span (L) ≤ $\frac{1}{9.15} \times \frac{(EI)_{eff}^{1m^{0.293}}}{(\rho A)^{0.123}}$

L = Maximum CLT floor span (m).

$(EI)_{eff}$ = Effective stiffness for a 1 m wide panel (N-m^2).

ρ = Density of CLT (kg/m^3).

- **Euro Code 5 [13], Section 7 Vibration Calculation Method:**

Limited Vibration Span (L) ≤ $0.11 \times \frac{(\frac{(EI)_{eff}}{10^6})^2}{m^{0.12}}$

L = vibration-controlled span limit (m). Clear span measured from face to face, of the two end supports.

$(EI)_{eff}$ = Effective stiffness for a 1 m wide panel (N-m^2).

m = Density of CLT (kg/m^3).

Floor vibration is a very complex phenomenon, therefore, to minimise the issue, it is recommended for the midspan deflection of CLT floors be restricted to 1 - 2 mm under 1 kN load based on New Zealand Design Action Standards (AS/NZS 1170) [12].

9.2 Continuous Red Stag CLT Floors and Roof Systems

Red Stag's large scale EWP plant can manufacture very large CLT panels for continuous roof or floor applications. A continuous CLT roof or floor has structural advantages compared to simply supported systems. Continuous CLT roof or floor systems have less deflection under similar loading conditions (Refer to *Figure 24* - *Figure 25*) and provide much larger spans or distance between supports as compared to simply supported CLT floors. Continuous systems may also allow roof or floor members to have a smaller overall depth or bending stiffness as the maximum bending stress and deflection are reduced.

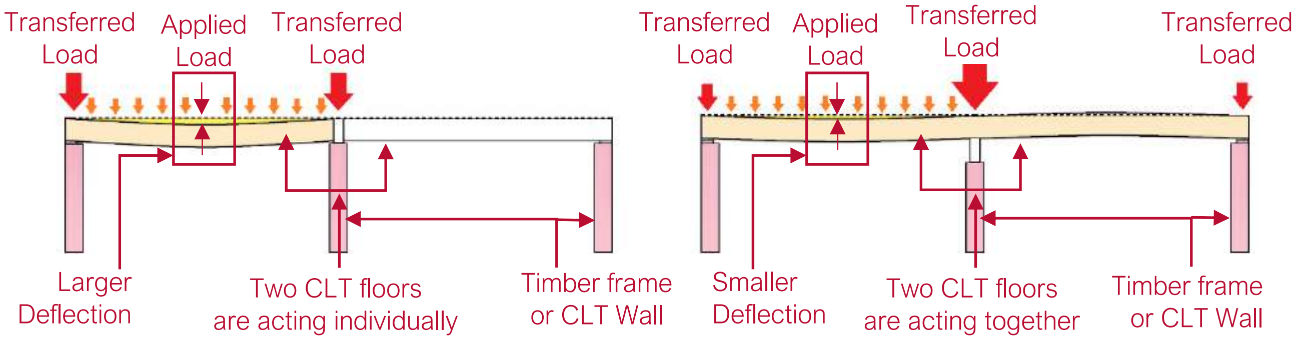
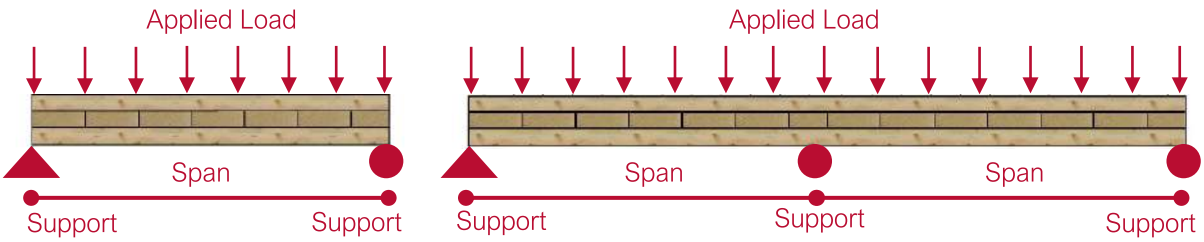


Figure 24: Comparison of deflections between single and double span CLT panels for roof or floor applications.[21]



Single span CLT floor panel

$$\Delta = \frac{5 \times w \times L^4}{384 \times E \times I}$$

W = Applied Load
L = Span
E = Elastic modulus
I = Moment of Inertia

Continuous double span CLT floor panel

$$\Delta = \frac{w \times L^4}{185 \times E \times I}$$

Figure 25: Comparison of deflection calculations for single and double span CLT panels for roof or floor applications [21].

9.3 Red Stag CLT Panel Specifications for Roof and Floor Applications

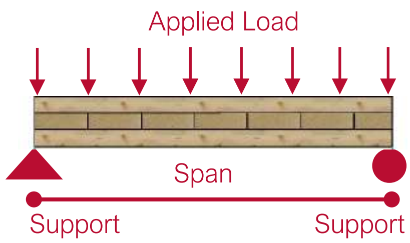
Red Stag can produce a range of CLT configurations or recipes, including 3, 5, 7, 9 and 11-layer panels in visual and standard grades. Red Stag CLT panels incorporate specified layer properties, defining the MoE to align with the performance criteria of each panel design.

An optimised list of CLT panel configurations for floor and roof applications are summarised in *Table 4* to *Table 6*. The maximum span for cantilever, simply supported and continuous CLT floors and roofs based on the FPInnovation CLT design guide, and the New Zealand design action standard (AS/NZS 1170) [12] are summarised in *Table 8* to *Table 13*. Additional CLT configurations beyond those presented in the following tables may be available based on the client's requirements; however, feedstock requirements will determine the availability, viability, and cost position of alternate configurations.

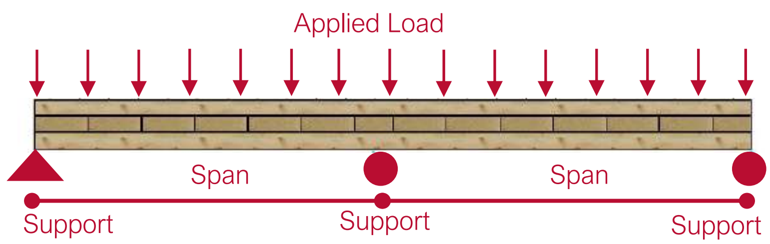
Table 7: Material Strength Properties of lamella for Roof/Floor Applications		
Structural Properties	Longitudinal Laminates	Transverse Laminates
Modulus of Elasticity (MoE)	8.0 GPa	6.0 GPa
Bending Strength	14 MPa	10 MPa
Compression Parallel to Grain	18 MPa	15 MPa
Compression perpendicular to Grain	8.9 MPa	8.9 MPa
Tension Strength	6.0 MPa	4.0 MPa
Normal Shear	3.8 MPa	3.8 MPa
Refer to NZS 3603:1993 [7]		

9.3.1 Three (3) Layer CLT Roof Panel

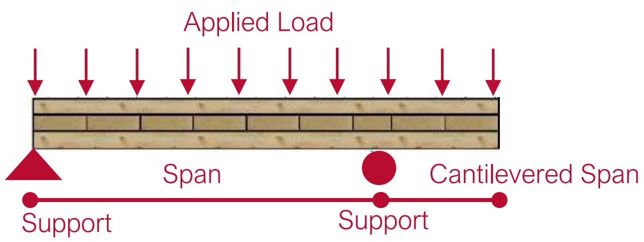
- Applied Loads: Imposed Load = 0.25 kPa, Snow Load = 0 kPa or 3 kPa, CLT Dead Load, Refer to *Table 4.*
- Vibration calculation not considered for roof applications.



Single span (Simply Supported) CLT panel



Double Span (Continuous Two Spans) CLT panel



Cantilevered CLT panel

Table 8: Three (3) Layer CLT Roof Specification for No Snow Zones [a, b, c, d]					
Recipe Priority [e]	Panel Title	Thickness	Single Span (Simply Supported)	Double Span (Continuous Two Spans)	Cantilevered
1	CLT 3/126	126 mm	5.18 m	7.01 m	1.69 m
2	CLT 3/104	104 mm	4.57 m	6.15 m	1.35 m

a) Not designed for floor applications.
b) Designed for 0.25 kPa live load, 500 kg/m^3 for CLT, 0.1 kPa additional dead load for non-structural elements.
c) Did not design for vibration.
d) Roofs are designed for 500 kg/m^3 for CLT only (Refer to *Table 4*).
e) Recipe priority defines the most cost-effective Red Stag CLT recipe option.

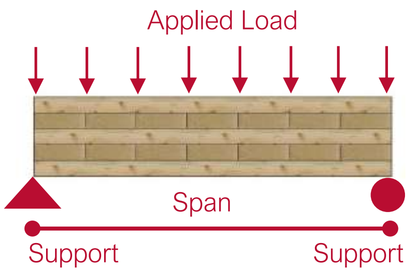
Table 9: Three (3) Layer CLT Roof Specification for Snow Zones [a, b, c, d, f]					
Recipe Priority [e]	Panel Title	Thickness	Simply Supported	Double Span (Continuous Two Spans)	Cantilevered
1	CLT 3/126	126 mm	3.00 m	4.12 m	1.45 m
2	CLT 3/104	104 mm	2.85 m	3.51 m	1.10 m

a) Not designed for floor applications.
b) Designed for 0.25 kPa live load, 500 kg/m^3 for CLT, 0.1 kPa additional dead load for non-structural elements.
c) Did not design for vibration.
d) Roofs are designed for 500 kg/m^3 for CLT only (Refer to *Table 4*).
e) Recipe priority defines the most cost-effective Red Stag CLT recipe option.
f) Snow load assumed as the dead load in the calculation.

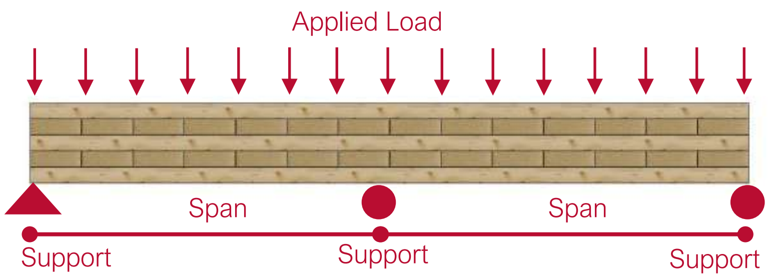
IMPORTANT: If a project is less than 200 m^3, Red Stag can only provide recipe priority 1 options unless agreed prior with the client. Recipe priority 2 or alternates are only available based on available feedstock and production capacity. If a project requires an alternate recipe to priority 1 options, please coordinate with Red Stag in advance.

9.3.2 Five (5) Layer CLT Roof Panel

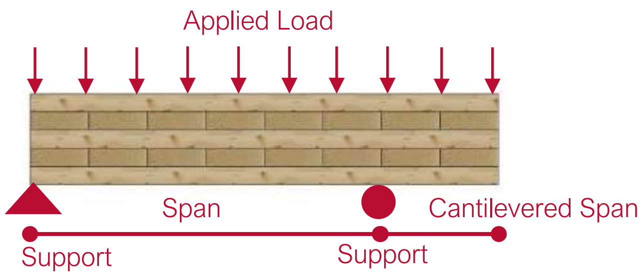
- Applied Loads: Imposed Load = 0.25 kPa, Snow Load = 0 kPa or 3 kPa, CLT Dead Load, Refer to *Table 5*.
- Vibration calculation not considered for roof applications.



Single span (Simply Supported) CLT panel



Double Span (Continuous Two Spans) CLT panel



Cantilevered CLT panel

Table 10: Five (5) Layer CLT Roof Specification for No Snow Zones [a, b, c, d].

Recipe Priority [e]	Panel Title	Thickness	Single Span (Simply Supported)	Double Span (Continuous Two Spans)	Cantilevered
1	CLT 5/210	210 mm	7.04 m [f]	9.93 m [f]	2.15 m
2	CLT 5/166	166 mm	6.25 m	8.36 m	1.85 m

a) Not designed for floor applications.
b) Designed for 0.25 kPa live load, 500 kg/m^3 weight for CLT, 0.1 kPa additional dead load for non-structural elements.
c) Vibration calculation not considered for roof applications.
d) Roofs are designed for 500 kg/m^3 for CLT only (Refer to *Table 5*).
e) Recipe priority defines the most cost-effective Red Stag CLT recipe option.
f) Refer to *Section 10* for three (3) Layer Red Stag CLT Roof design example.

Table 11: Five (5) Layer CLT Roof Specification for Snow Zones [a, b, c, d, f].

Recipe Priority [e]	Panel Title	Thickness	Single Span (Simply Supported)	Double Span (Continuous Two Spans)	Cantilevered
1	CLT 5/210	210 mm	4.54 m	6.23 m	1.95 m
2	CLT 5/166	166 mm	3.96 m	5.28 m	1.60 m

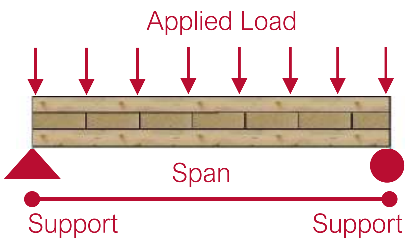
a) Not designed for floor applications.
b) Designed for 0.25 kPa live load, 500 kg/m^3 weight for CLT, 0.1 kPa additional dead load for non-structural elements.
c) Vibration calculation not considered for roof applications.
d) Roofs are designed for 500 kg/m^3 for CLT only (Refer to *Table 5*).
e) Recipe priority defines the most cost-effective Red Stag CLT recipe option.
f) Snow load assumed as the dead load in the calculation.

IMPORTANT: If a project is less than 200 m^3, Red Stag can only provide recipe priority 1 options unless agreed prior with the client. Recipe priority 2 or alternates are only available based on available feedstock and production capacity. If a project requires an alternate recipe to priority 1 options, please coordinate with Red Stag in advance.

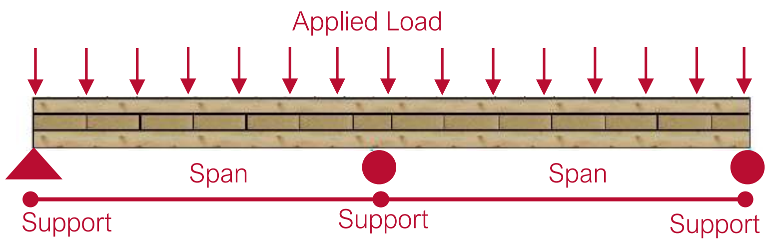
9.3.3 Three (3) Layer CLT Floor Panel

- Applied Loads: Imposed Load = 2 kPa, 3 kPa and 5 kPa,

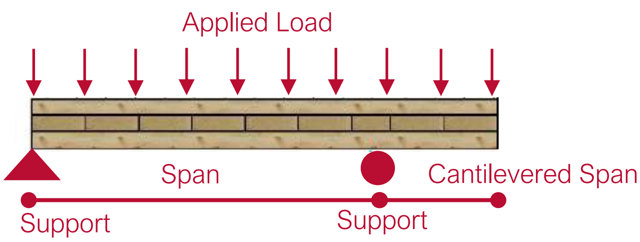
  CLT Dead Load = Refer to *Table 4*.
- Vibration calculation considered in span performance.



Single span (Simply Supported) CLT panel



Double Span (Continuous Two Spans) CLT panel



Cantilevered CLT panel

Table 12: Three (3) Layer Simply Supported Single Span, Double Span and Cantilevered CLT Floor Specifications [a, b, c].

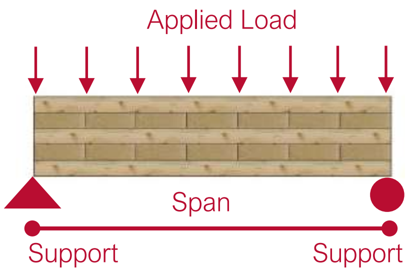
	Recipe Priority [a]	Panel Title	Thickness	Applied Load (kPa)								
				Super Imposed Dead Load 0.5 kPa			Super Imposed Dead Load 1 kPa			Super Imposed Dead Load 1.5 kPa		
				Live Load (Imposed Load)			Live Load (Imposed Load)			Live Load (Imposed Load)		
				2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa
Single span (Simply Supported)	1	CLT 3/126	126 mm	3.85 m [g, f, k]	3.60 m [g, e]	3.23 m [g, e]	3.85 m [g, f,]	3.60 m [g, e]	3.23 m [g, e]	3.85 m [g, f,]	3.60 m [g, e]	3.23 m [g, e]
	2	CLT 3/104	104 mm	3.32 m [g, f]	3.10 m [g, e]	2.78 m [g, e]	3.32 m [g, f]	3.10 m [g, e]	2.78 m [g, e]	3.32 m [g, f]	3.10 m [g, e]	2.78 m [g, e]
Double Span (Continuous Two Spans)	1	CLT 3/126	126 mm	5.21 m [h, f, k]	4.91 m [g, e]	4.43 m [g, e]	4.84 m [g, f]	4.59 m [g, e]	4.20 m [g, e]	4.53 m [g, f]	4.33 m [g, e]	4.01 m [g, e]
	2	CLT 3/104	104 mm	4.49 m [g, f]	4.19 m [g, e]	3.77 m [g, e]	4.13 m [g, f]	3.91 m [g, e]	3.58 m [g, e]	3.86 m [g, f]	3.69 m [g, e]	3.42 m [g, e]
Cantilevered	1	CLT 3/126	126 mm	0.38 m	0.32 m	0.21 m	0.28 m	0.25 m	0.20 m	0.22 m	0.20 m	0.15 m
	2	CLT 3/104	104 mm	0.30 m	0.28 m	0.20 m	0.25 m	0.23 m	0.19 m	0.20 m	0.18 m	0.14 m

a) Recipe priority defines the most cost-effective Red Stag CLT recipe option.
b) Floors are designed for 2 kPa, 3 kPa or 5 kPa Live Load (Imposed Load).
c) Floors are designed for 0.5 kPa, 1 kPa or 1.5 kPa addition Dead Load (Super Imposed Dead Load).
d) Floors are designed for 500 kg/m^3 for CLT (Refer to *Table 4*).
e) Floors are designed for vibration based on the recommended method in FPInnovation CLT design guide.
f) Floors are designed for vibration based on Eurocode 5 section 7.3.
g) Span limited by deflection.
h) Span controlled by vibration.
i) Red Stag design limits for floors are not constrained to this table. If specific floor designs are required, please contact Red Stag.
j) The maximum cantilever span is no less than 2.5 times of the cantilever length.
k) Refer to *Section 10* for three (3) Layer Red Stag CLT Floor design example.

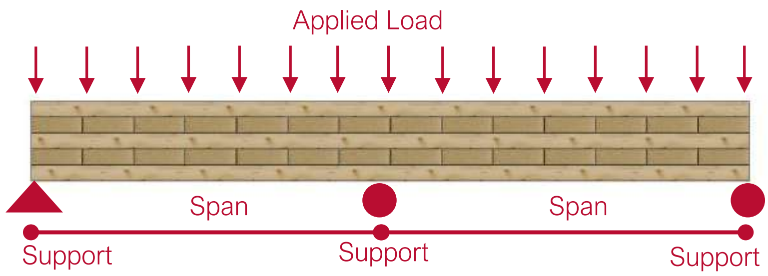
IMPORTANT: If a project is less than 200 m^3, Red Stag can only provide recipe priority 1 options unless agreed prior with the client. Recipe priority 2 or alternates are only available based on available feedstock and production capacity. If a project requires an alternate recipe to priority 1 options, please coordinate with Red Stag in advance.

9.3.4 Five (5) Layer CLT Floor Panel

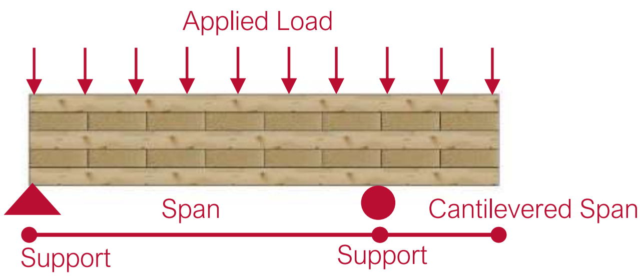
- Applied Loads: Imposed Load = 2 kPa, 3 kPa and 5 kPa,
  CLT Dead Load = Refer to *Table 5*.
- Vibration calculation considered in span performance.



Single span (Simply Supported) CLT panel



Double Span (Continuous Two Spans) CLT panel



Cantilevered CLT panel

Table 13: Five (5) Layer Simply Supported Single Span, Double Span and Cantilevered CLT Floor Specifications [a, b, c].

	Recipe Priority [a]	Panel Title	Thickness	Applied Load (kPa)								
				Super Imposed Dead Load 0.5 kPa			Super Imposed Dead Load 1 kPa			Super Imposed Dead Load 1.5 kPa		
				Live Load (Imposed Load)			Live Load (Imposed Load)			Live Load (Imposed Load)		
				2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa
Single span (Simply Supported)	1	CLT 5/210	210 mm	5.54 m [g, f]	5.33 m [g,e,k]	4.86 m [g, e]	5.26 m [g, f]	5.01 m [g, e]	4.63 m [g, e]	4.96 m [g, h]	4.76 m [g, e]	4.43 m [g, e]
	2	CLT 5/166	166 mm	4.86 m [g, f]	4.57 m [g, e]	4.15 m [g, e]	4.51 m [g, f]	4.29 m [g, e]	3.95 m [g, e]	4.24 m [g, h]	4.07 m [g, e]	3.78 m [g, e]
Double Span (Continuous Two Spans)	1	CLT 5/210	210 mm	6.37 m [h, f]	5.47 m [h,e,k]	5.47 m [h, e]	6.37 m [h, f]	5.47 m [h, e]	5.47 m [h, e]	6.37 m [h, f]	5.47 m [h, e]	5.47 m [h, e]
	2	CLT 5/166	166 mm	5.89 m [h, f]	4.81 m [h, e]	4.81 m [h, e]	5.89 m [h, f]	4.81 m [h, e]	4.81 m [h, e]	5.76 m [g, h]	4.81 m [h, e]	4.81 m [h, e]
Cantilevered	1	CLT 5/210	210 mm	0.71 m	0.65 m	0.36 m	0.54 m	0.50 m	0.26 m	0.41 m	0.36 m	0.22 m
	2	CLT 5/166	166 mm	0.50 m	0.47 m	0.29 m	0.39 m	0.37 m	0.21 m	0.31 m	0.26 m	0.17 m

a) Recipe priority defines the most cost-effective Red Stag CLT recipe option.
b) Floors are designed for 2 kPa, 3 kPa or 5 kPa Live Load (Imposed Load).
c) Floors are designed for 0.5 kPa, 1 kPa or 1.5 kPa addition Dead Load (Super Imposed Dead Load).
d) Floors are designed for 500 kg/m^3 for CLT (Refer to *Table 5*).
e) Floors are designed for vibration based on the recommended method in FPInnovation CLT design guide.
f) Floors are designed for vibration based on Eurocode 5 section 7.3.
g) Span limited by deflection.
h) Span controlled by vibration.
i) Red Stag design limits for floors are not constrained to this table. If specific floor designs are required, please contact Red Stag.
j) The maximum cantilever span is no less than 2.5 times of the cantilever length.
k) Refer to *Section 10* for five (5) Layer Red Stag CLT Floor design example.

IMPORTANT: If a project is less than 200 m^3, Red Stag can only provide recipe priority 1 options unless agreed prior with the client. Recipe priority 2 or alternates are only available based on available feedstock and production capacity. If a project requires an alternate recipe to priority 1 options, please coordinate with Red Stag in advance.

10. Red Stag CLT Wall Design

CLT walls are vertical structural members, typically designed to carry gravity loads. Prefabricated CLT walls are significantly lighter in weight compared with precast concrete, and are generally faster to install, and require less transportation and associated logistical management. CLT walls have excellent fire resistance and provide exceptional bracing attributes. The design calculations for CLT walls under axial loads are summarised in *Table 14 and Table 15.* Red Stag is capable of manufacturing both standard and visual grade CLT wall systems, allowing the timber to be exposed to reduced secondary lining costs, improve aesthetics and the occupants' health and well-being [18],[20].

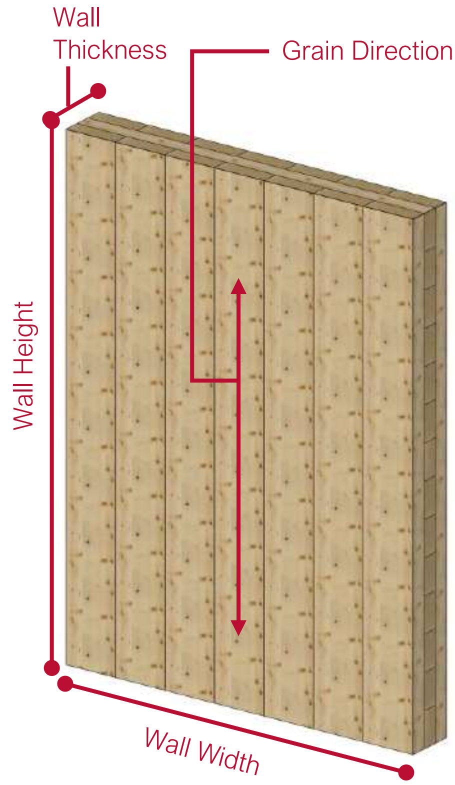


Table 14: Wall Load Carrying of the Three (3) Layer CLT Panel Under Uniformly Distributed Vertical Load.

Recipe Priority [a]	Panel Title	Thickness	Wall Height				Removed CO_2 from Atmosphere	CLT CO_2 Benefit Compared to Concrete Wall
			2.7 m	3.0 m	3.5 m	4.0 m		
1	CLT 3/126	126 mm	300 kN/m	235 kN/m	185 kN/m	140 kN/m	-100 kg/m^3	151 kg/m^3
2	CLT 3/104	104 mm	215 kN/m	190 kN/m	150 kN/m	105 kN/m	- 83 kg/m^3	126 kg/m^3

a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.

Table 15: Wall Load Carrying of the Five (5) Layer CLT Panel Under Uniformly Distributed Vertical Load.

Recipe Priority [a]	Panel Title	Thickness	Wall Height				Removed CO_2 from Atmosphere	CLT CO_2 Benefit Compared to Concrete Wall
			2.7 m	3.0 m	3.5 m	4.0 m		
1	CLT 5/210	210 mm	635 kN/m	590 kN/m	520 kN/m	440 kN/m	-161 kg/m^3	242 kg/m^3
2	CLT 5/166	166 mm	485 kN/m	420 kN/m	340 kN/m	255 kN/m	-127 kg/m^3	191 kg/m^3

a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.

11. Red Stag CLT Stair Design

Red Stag CLT stairs are a significantly more cost-effective, lighter, more versatile, and faster to install than alternate stair systems. The performance specifications of Red Stag CLT stairs, generally allow them to be installed early in a project to provide safe access during the construction phase. Typically machined out of a solid CLT panel, Red Stag CLT stairs provide a high strength, robust and visually appealing substrate that generally only requires supporting at both ends to create a clean, clear span (Refer to *Figure 26*). Red Stag CLT stairs have an excellent fire rating due to the mass of the solid timber system.

The performance characteristics of the Red Stag CLT stairs are created from the layers under the plane generated from the underside of the treads and risers (the stringer). The machined section to create the treads and risers is effectively non-structural but is still bonded as a homogenous system with the stringer section of the stair substrate. The CLT under the treads and risers forms the stair stringer, which is designed to be capable of handling the bending moment that is created with applied loads, and the self-weight of the stair system. The vibrational performance of the CLT stringer is also calculated to confirm the dynamic behaviour of the Red Stag CLT stairs is not creating an uncomfortable functional environment for the building occupants.

Red Stag can optimise CLT stair designs based on the architectural and structural requirements; however, standardised specifications are summarised in *Table 16*. There are a wide range of CLT connection methods, fasteners, and details to connect Red Stag CLT stairs to landing areas or floor assemblies. Two cost efficient examples of Red Stag stair connections are illustrated in *Figure 27* and *Figure 28*.

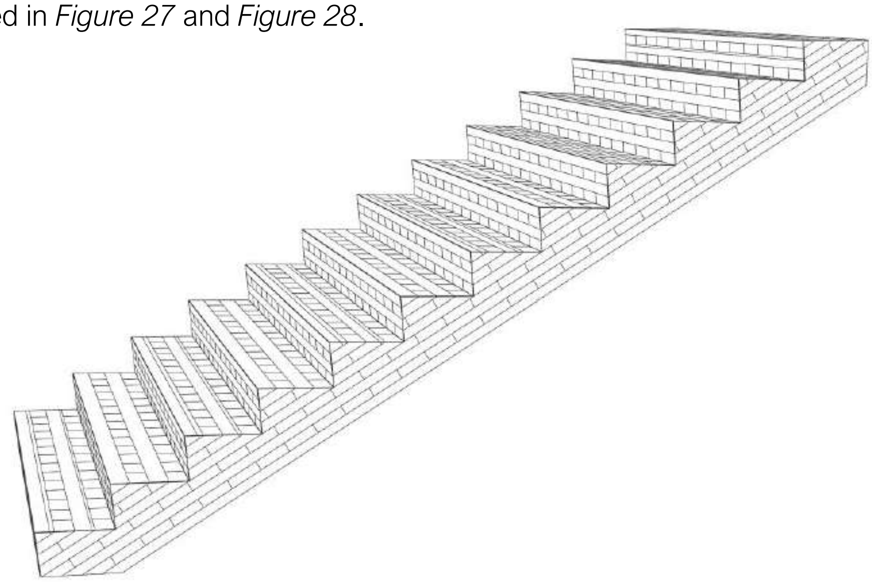


Figure 26: Example of the Red Stag CLT stairs

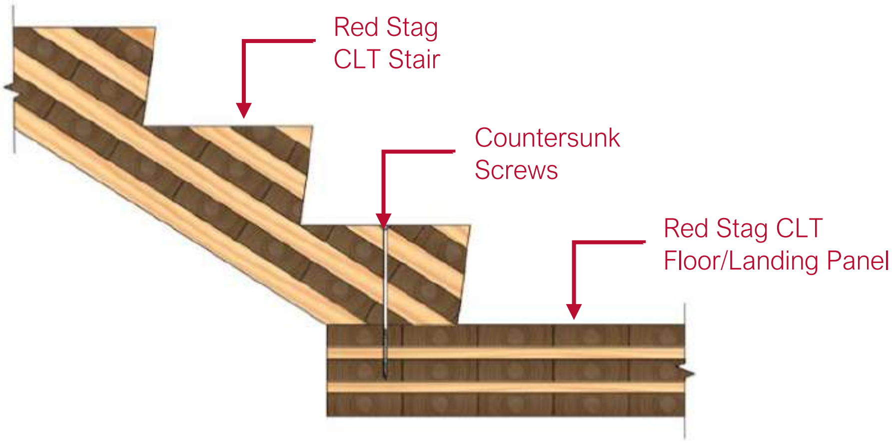


Figure 27: Example of Red Stag CLT stair panel base connection to CLT landing/floor panel.

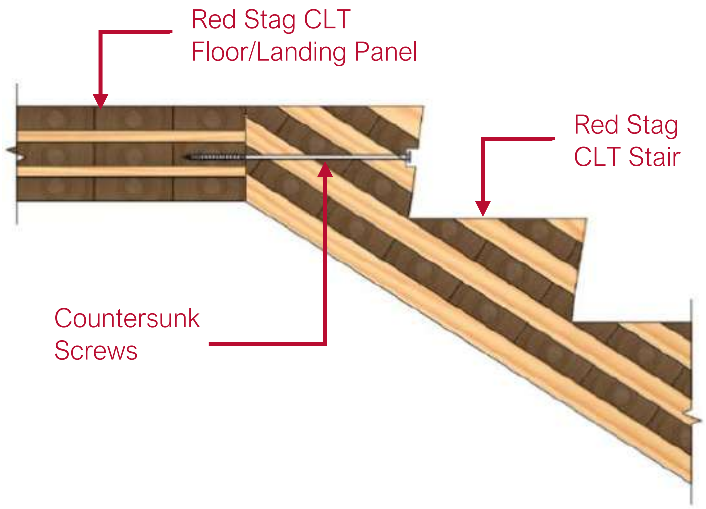


Figure 28: Example of Red Stag CLT stair panel upper connection to CLT landing/floor panel.

Table 16: Red Stag CLT Stair Spans [a, b, c, d, e, f, g]

Panel Title	CLT Panel Stringer	Stringer Thickness	Live Load (Imposed Load)				Removed CO_2 from Atmosphere	CLT Stairs CO2 Benefit Compare to Concrete Stairs
			2 kPa [b]	3 kPa [b]	4 kPa [b]	5 kPa [b]		
CLT7/126/294 [a]	CLT 3/126	126 mm	3.95 m[e]	3.73 m[f, h]	3.49 m[f]	3.31 m[f]	- 100 kg/m^3	151 kg/m^3
CLT9/210/378[a]	CLT 5/210	210 mm	5.47 m[e]	5.47 m[f]	5.19 m[f]	4.96 m[f]	- 161 kg/m^3	242 kg/m^3

a) CLTX/Y/Z, where X = Number of layers, Y = Stringer thickness, Z = Overall panel thickness.
b) Red Stag CLT Stairs are designed for a 2 kPa, 3 kPa, 4 kPa and 5 kPa Live Load (Imposed Load).
c) Red Stag CLT Stairs are designed based on 500 kg/m^3 for the CLT (CLT stringer & CLT Tread & Riser).
d) Red Stag CLT Stairs are designed for vibration based on the FPInnovation method.
e) Span limited by deflection.
f) Span controlled by vibration.
g) The maximum tread and riser dead load are generated by a 332 mm tread depth and 180 mm riser height, reflected in the calculation within *Figure 29*. All other tread/riser combinations reduce the dead loads incorporated in *Figure 29*.
h) Refer to *Section 10* for three (3) Layer Red Stag CLT Stair design example.

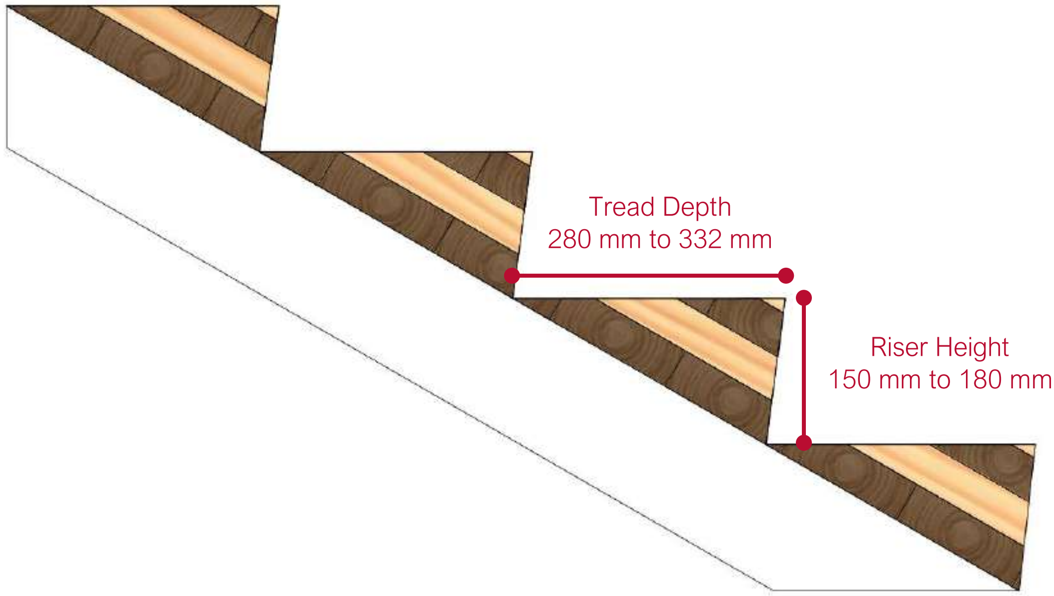


Figure 29: Pitch line, tread, and riser dimensions for common and main private stair ways.

Section 3

Cross Laminated Timber Connections

Make it better

Red Stag CLT Design Guide V1.3
September 2022

RED STAG WOOD SOLUTIONS

Screw connections play an essential role in maintaining the integrity of CLT structures by providing supporting strength, stiffness, stability, and ductility. The structural efficiency of a CLT flooring system acting as a rigid or flexible diaphragm, with walls in resisting lateral loads depends on the efficiency of the fastening systems and connection details used to interconnect individual panels and assemblies together. A wide range of partially and fully threaded self-tapping screw options are available from fixing providers (Refer to *Figure 30*). Short self-tapping screws are commonly used for connecting CLT floor panels together, and long self-tapping screws are generally used for connecting CLT floor panels to CLT wall panel assemblies (Refer to *Figure 31* and *Figure 32*). There are other types of traditional and innovative fasteners and fastening systems that can also be used in CLT assemblies.

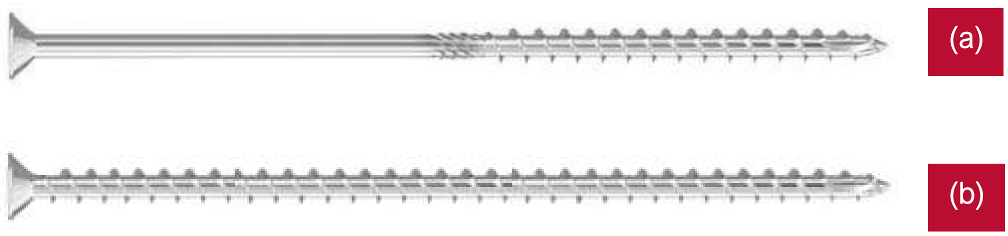


Figure 30: A partially threaded screw versus a fully threaded screw;
a) Partially threaded screw, b) Fully threaded screw.

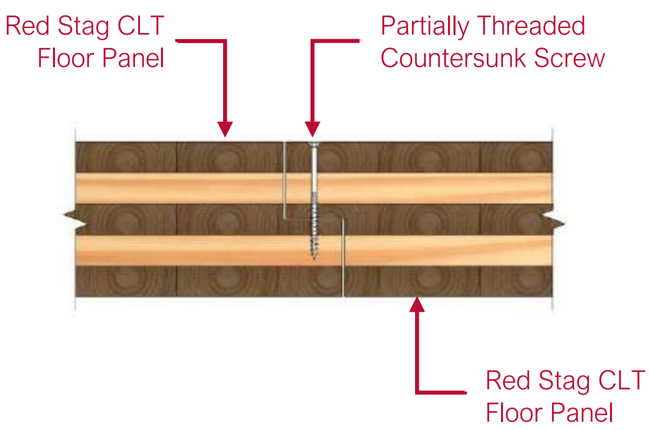


Figure 31: Red Stag CLT floor panel to Red Stag CLT floor panel connection.

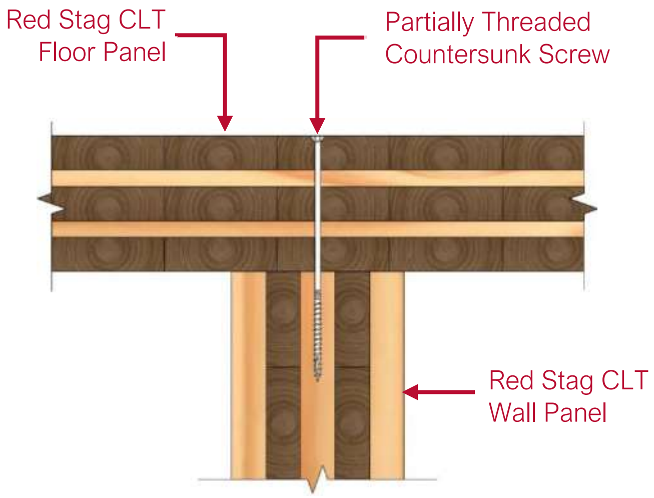


Figure 32: Red Stag CLT floor panel to Red Stag CLT wall panel connection.

13. Butt Joint Connection

The butt joint is the simplest connection type from a fabrication perspective, as the panels only have plumb cuts. Minor processing reduces both machine time and material waste to make it the most efficient joint in factory. But joints are connected via angled self-tapping screws, installed at precise angles. The screws typically penetrate the shear plane at half of the panel thickness, generally at a 45° angle. Intersecting the joint at half the panel thickness, the screws are loaded perpendicular to their longitudinal axis (Refer to *Figure 33* - *Figure 34*).

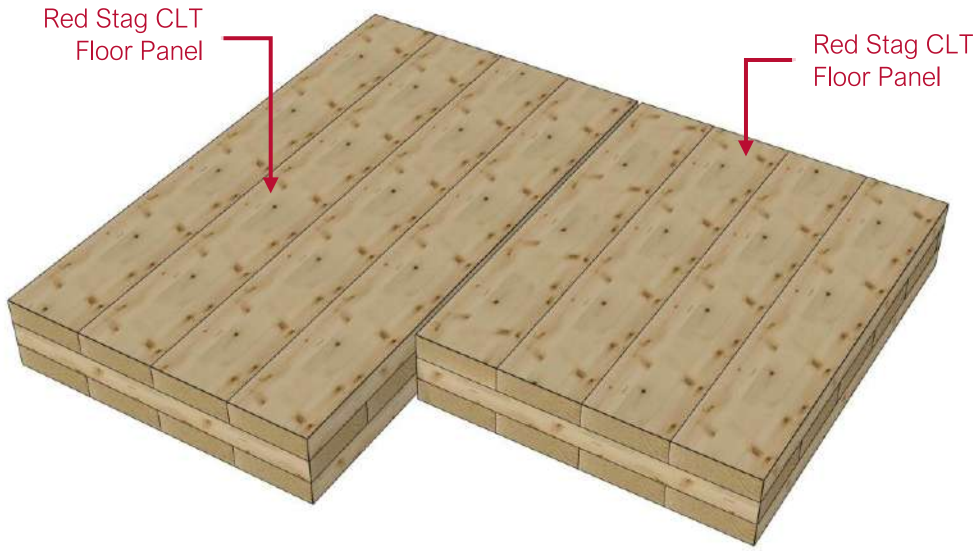


Figure 33: 3D view of butt joint connection.

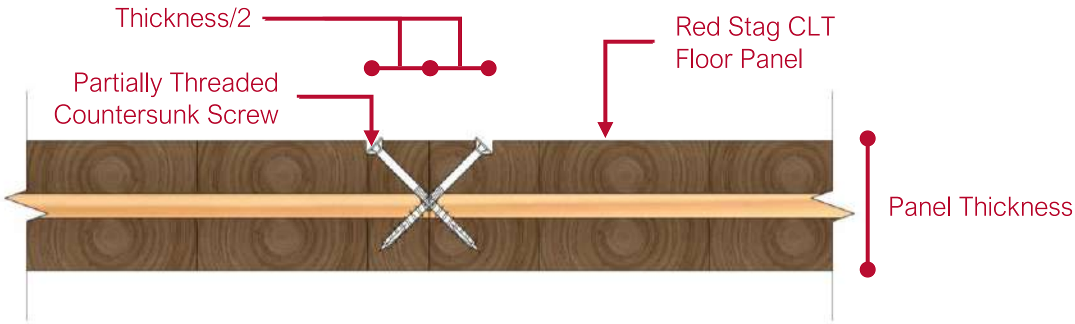


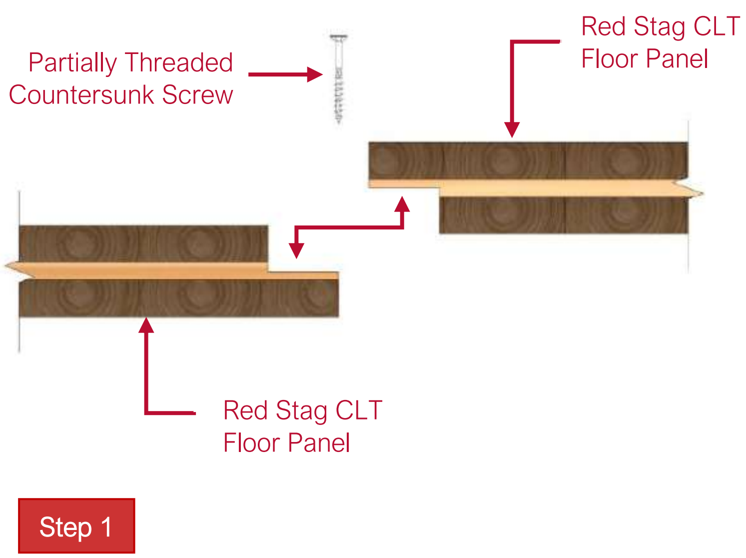
Figure 34: Cross-section detail of butt joint connection.

14. Half-Lap Joint Connection

Half-lap joints require more prefabrication than butt joints and increase the panel wastage for the overlap, but simplify the site installation time. The joints are connected via self-tapping screws, driven at a 90° angle, and act in pure shear at half the panel thickness. Assembly details of the half-lap joint are presented in *Figure 35*. Half-lap joints offer the largest variety of connection performances. Technically half-lap joints can resist in-plane shear and normal forces, but are not considered to be a moment resisting connection (Refer to *Figure 36*).

While the half-lap joint is a very simple connection that facilitates quick assembly, there is a risk of splitting of the cross-section due to the concentration of tension perpendicular to grain stresses in the rebated section.

If the load at the half-lap joint is substantial, there could be a tendency for the panel to split at or near the joint. To minimise the risk, reinforcing screws should be considered (refer to *Figure 37*). Another disadvantage is the loss of fibre and the reduced installed width of the panel in comparison with other types of connections such as butt and spline (refer below) joints. Red Stag offers an 80 mm half-lap to minimize the disadvantage of the fibre loss and balances the fire protection compared to narrower half-lap joint sizes, which transfer heat faster during a fire event (refer to *Figure 38*).



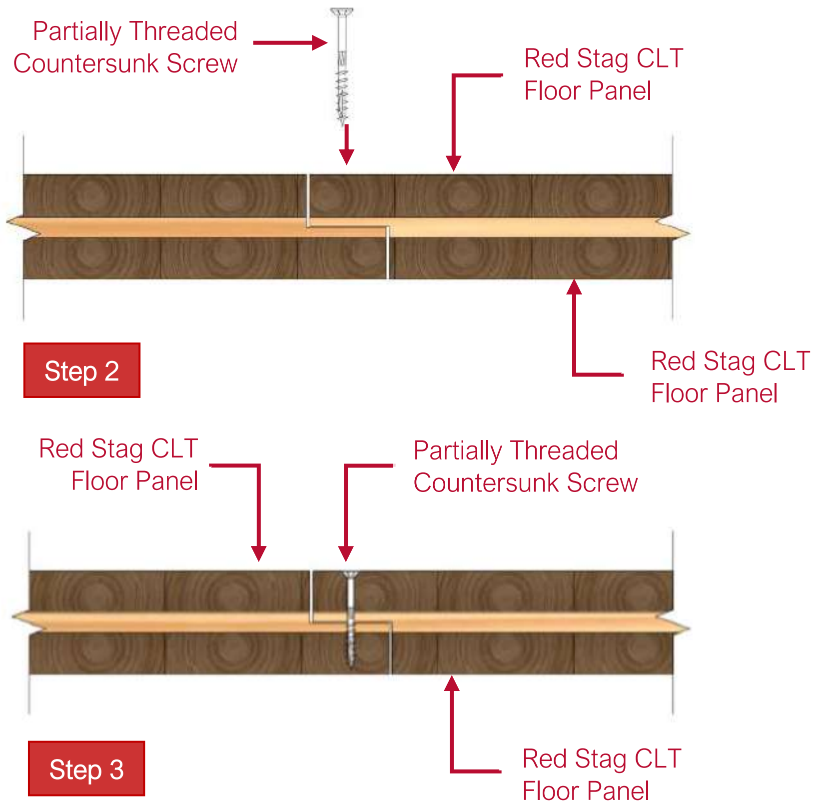


Figure 35: Assembly details of the half-lap joint.

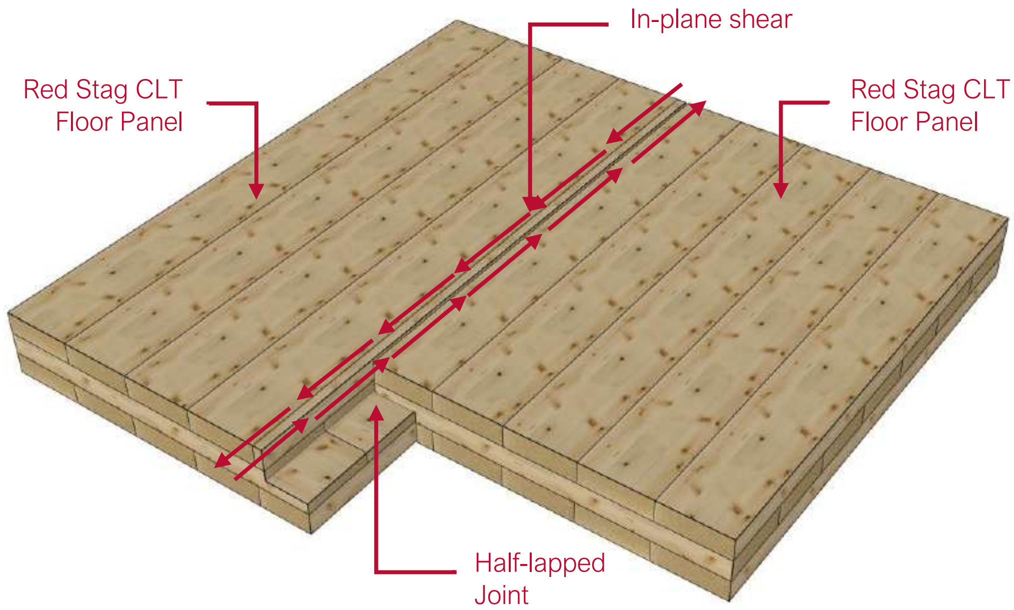


Figure 36: In-plane shear along the half-lap joint between two Red Stag CLT panels.

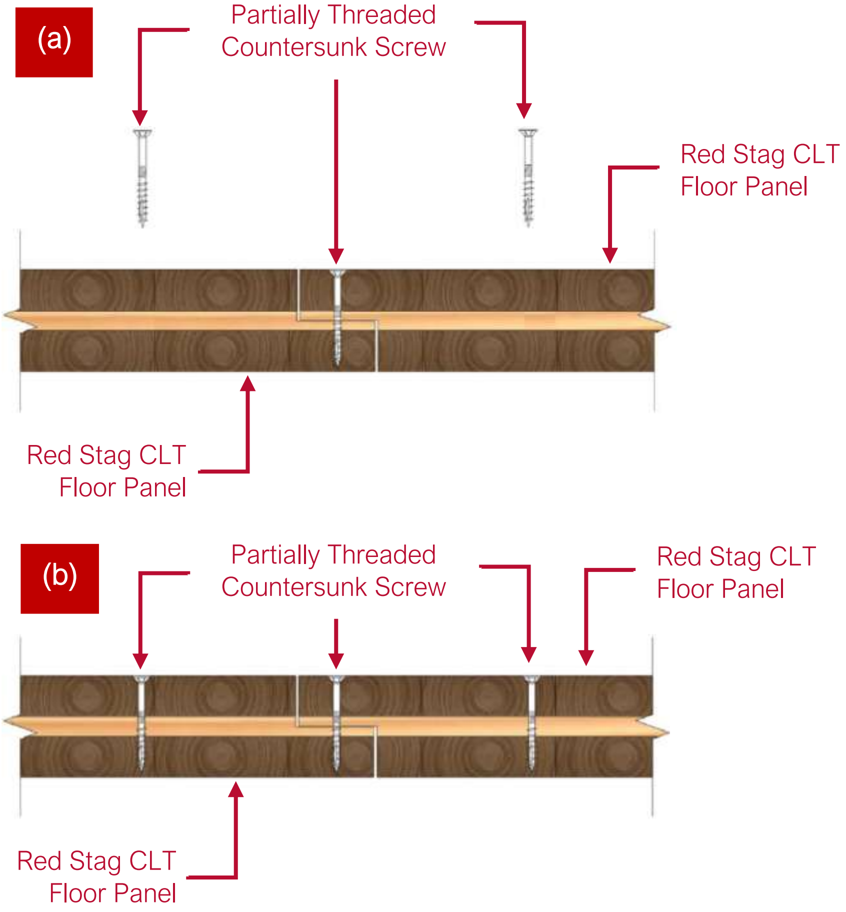


Figure 37: Reinforcing screws to reduce the risk of splitting.

a) Before Reinforcement, b) After Reinforcement.

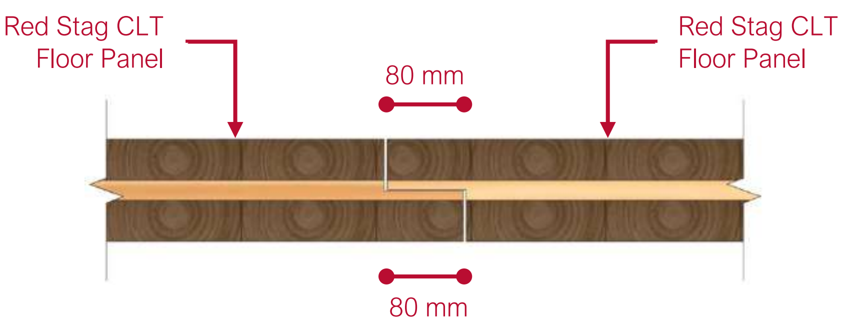


Figure 38: Optimum size half-lap joint (80 mm).

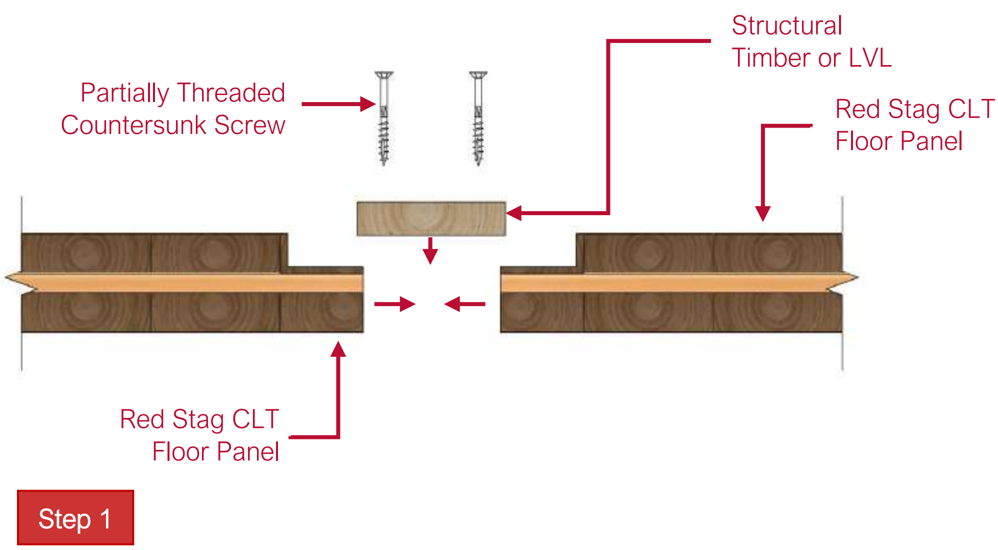
15. Spline Joint Connections

Spline joints are formed by rebating the edge of a butt joint to allow for a spline or board to bridge either side of the joint. Splines are typically made from solid structural timber, ply strips or Laminated Veneer Lumber (LVL) where longitudinal shear is more critical. Splines are fastened with a series of short self-tapping screws, creating a pure shear connection. Assembly details of a single spline joint is presented in *Figure 39*.

If the longitudinal shear along the connection line is very high, a double surface spline joint connection is recommended to increase the strength and stiffness of the connection (*Figure 40*). The four rows of fasteners support in double the number of shear planes resisting the load (Refer to *Figure 41 and Figure 42*).

To provide sufficient clearance between the upper and lower spline joint screw lines or to provide even larger shear resistance, it may be necessary to have one spline wider than the other as represented in in *Figure 43*.

A singe surface spline joint is the second most efficient (butt joints are the most efficient) and cost effective machined joint as it allows for all in factory machining to be processed without flipping panel and it maximises the utilisable panel area (overlaps in lap joints reduce utilisable surface area). Double surface spline joints require panels to be flipped, therefore when combined with dual screw lines on both sides of the panel, create a complex machine and labour-intensive connection detail.



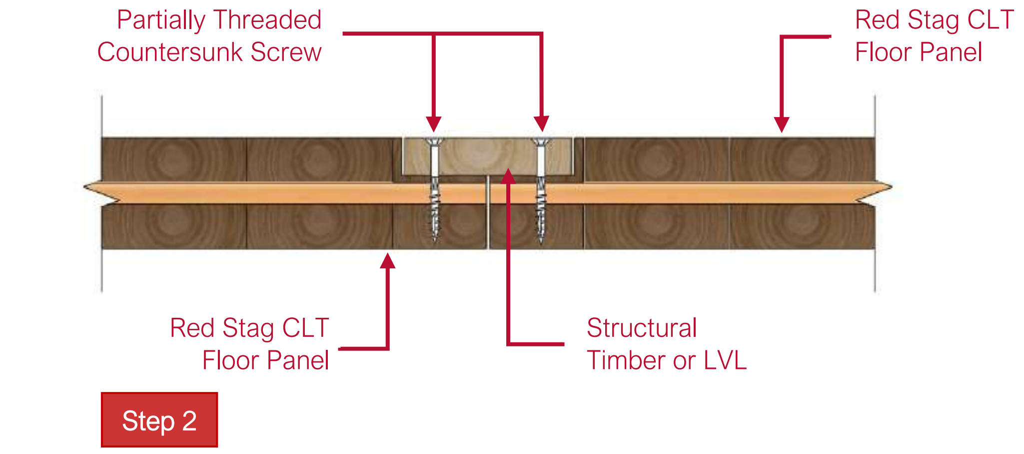


Figure 39: Assembly details of the single surface spline joint.

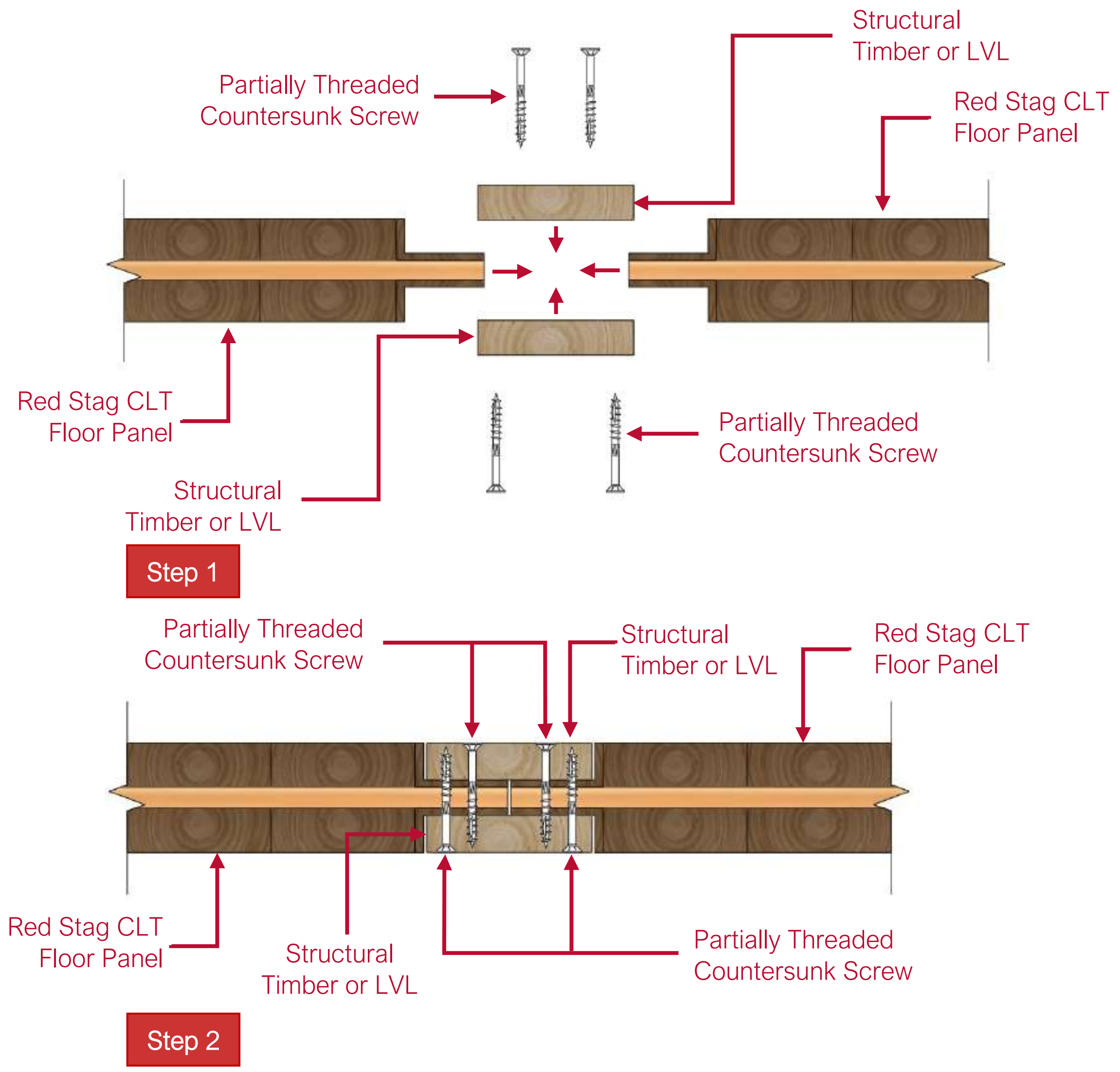


Figure 40: Assembly details of the double surface spline joint.

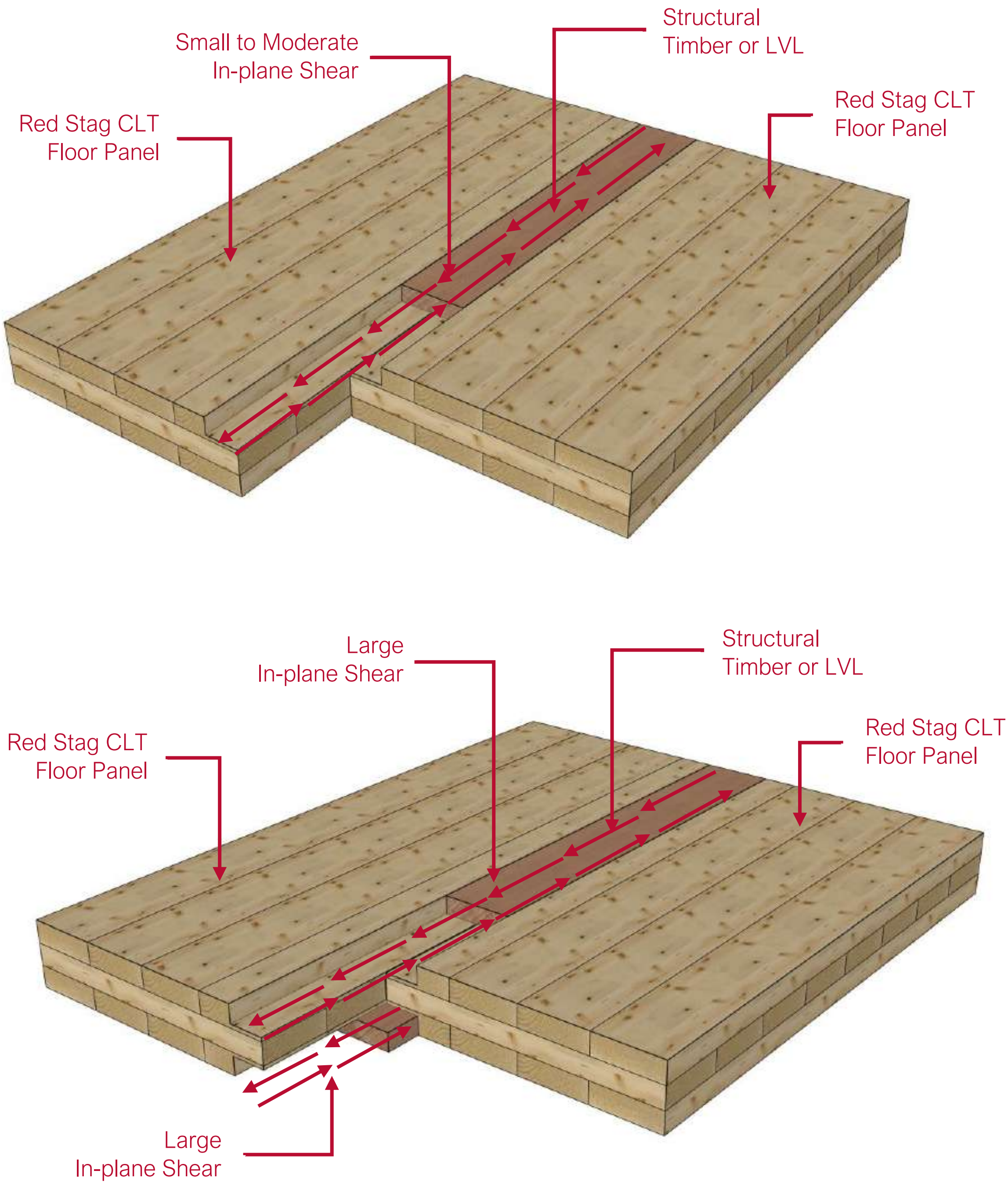


Figure 41: Longitudinal shear along the connection line in single and double surface spline joints.

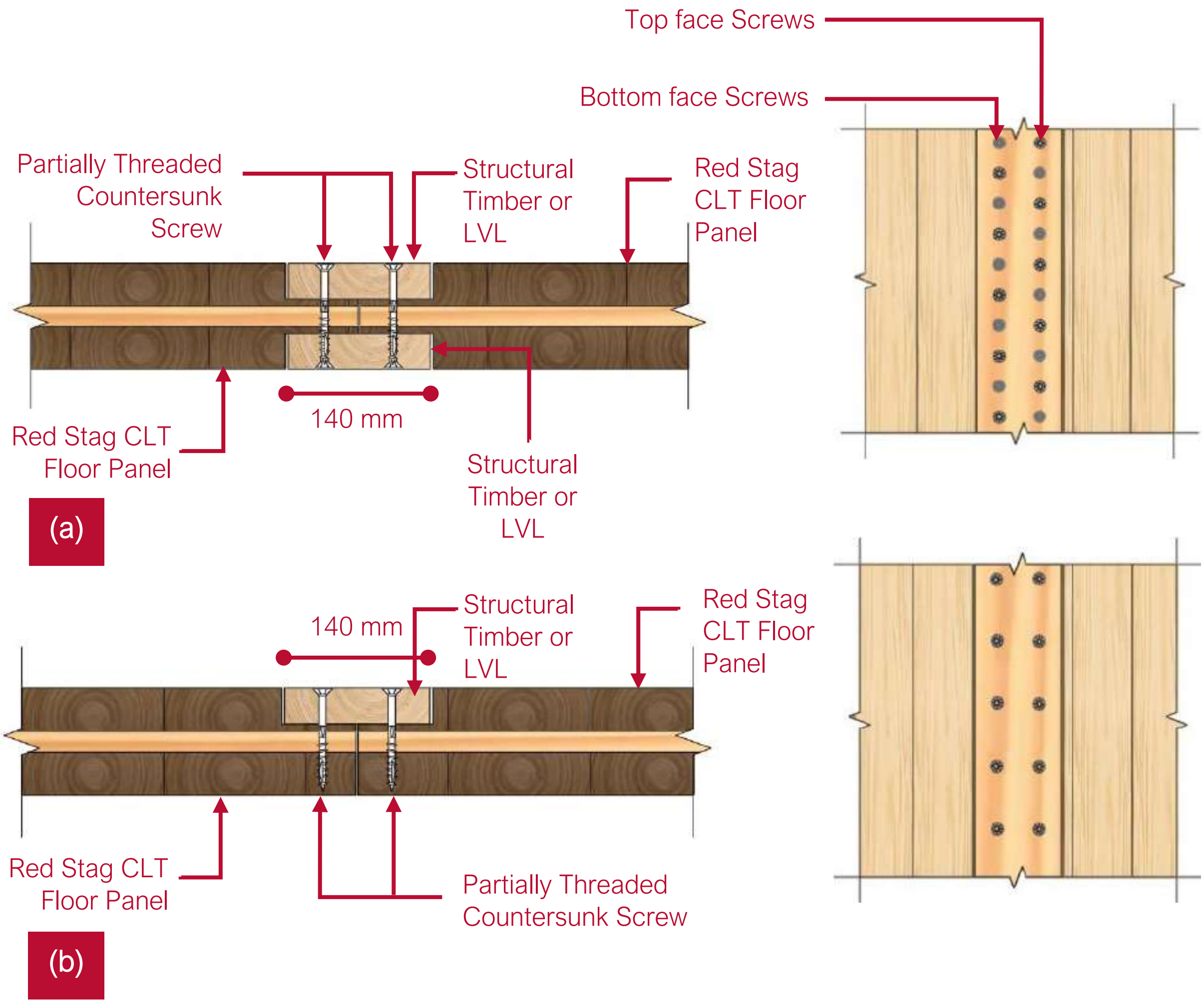


Figure 42: Screw spacing in a single surface spline joint versus a double surface spline joint. Double surface spline joints require sufficient space for double the number of fasteners. a) Double surface spline joint; b) Single surface spline joint.

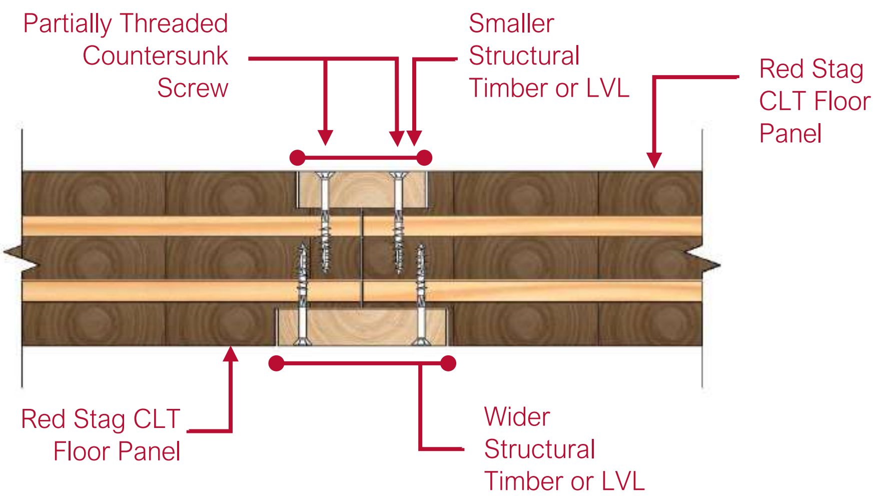


Figure 43: Screw layout for a double surface spline joint with an asymmetric timber spline plate.

There are a wide range of CLT connection methods and fasteners available to combine floor, wall, and roof assemblies. A series of some of the most common structural connection details in timber and hybrid buildings are illustrated below in *Figure 44* to *Figure 56*.

16.1 Red Stag CLT Wall Panel to Concrete Foundation/Floor Connection

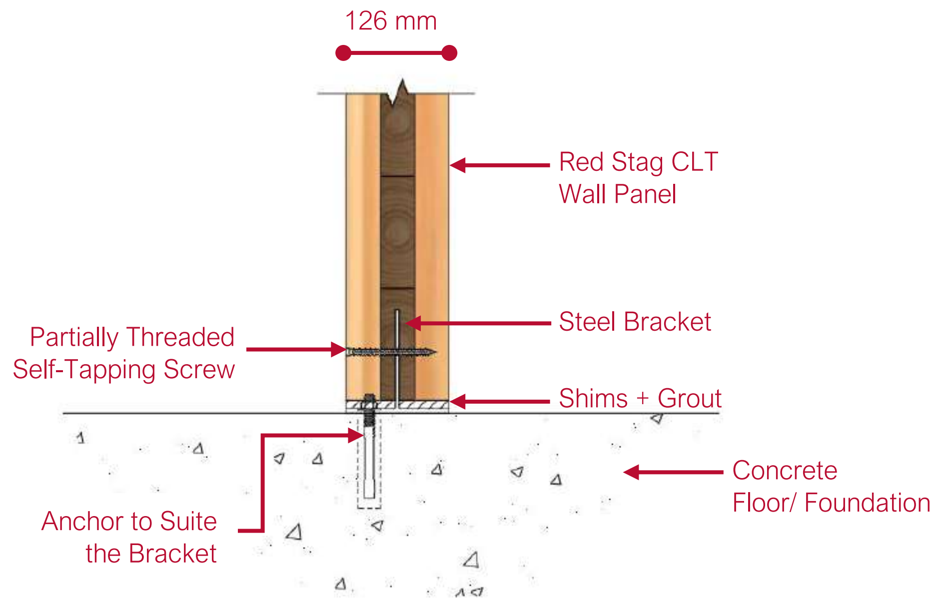


Figure 44: Internal Red Stag CLT wall to the concrete foundation/floor connection.

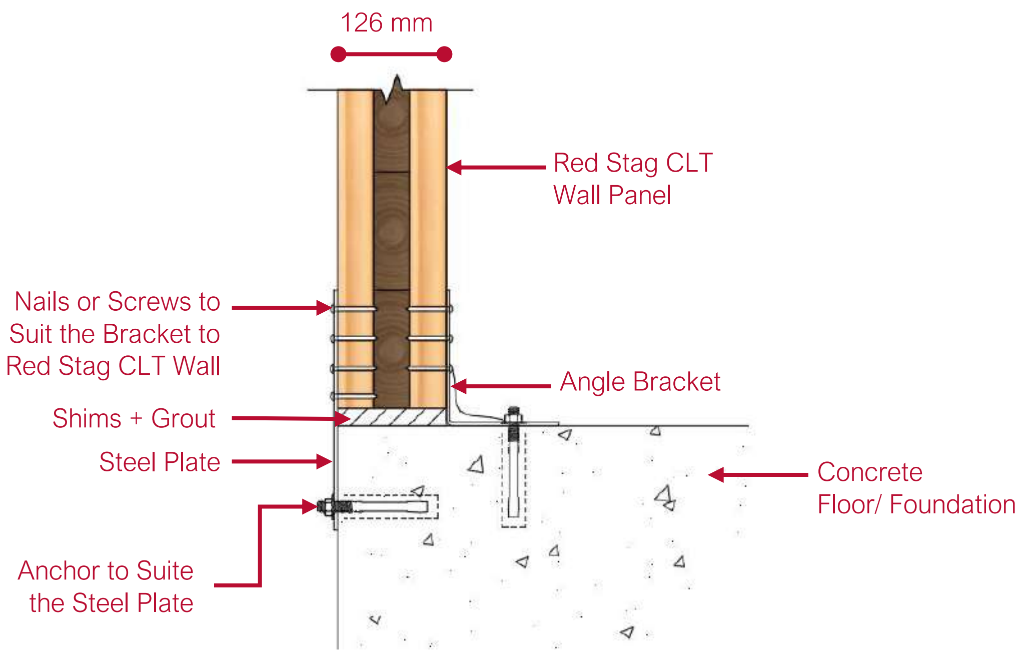


Figure 45: Red Stag CLT wall panel to the concrete foundation/floor (On edge of external walls of the building)

16.2 Red Stag CLT Wall Panel Connection

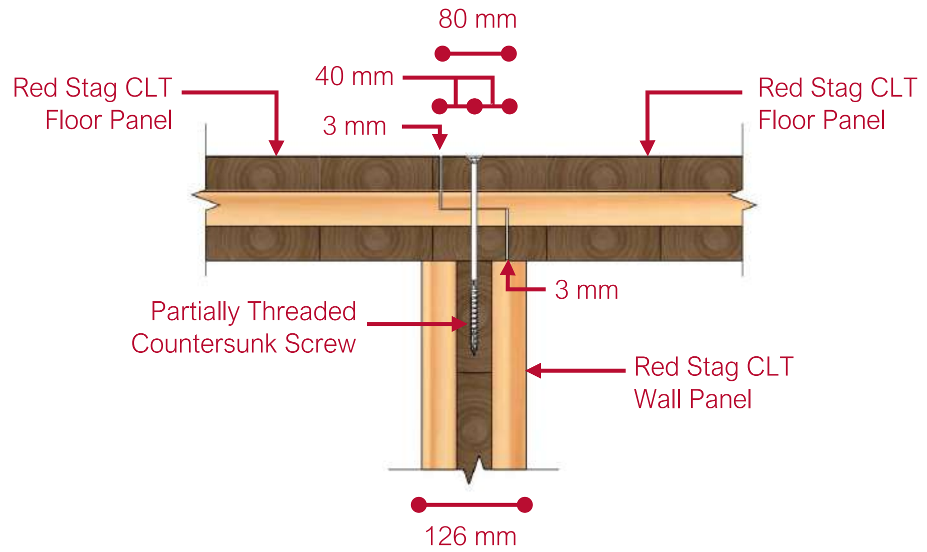


Figure 46: Red Stag three (3) Layer CLT wall panel to CLT floor panel half joint connection.

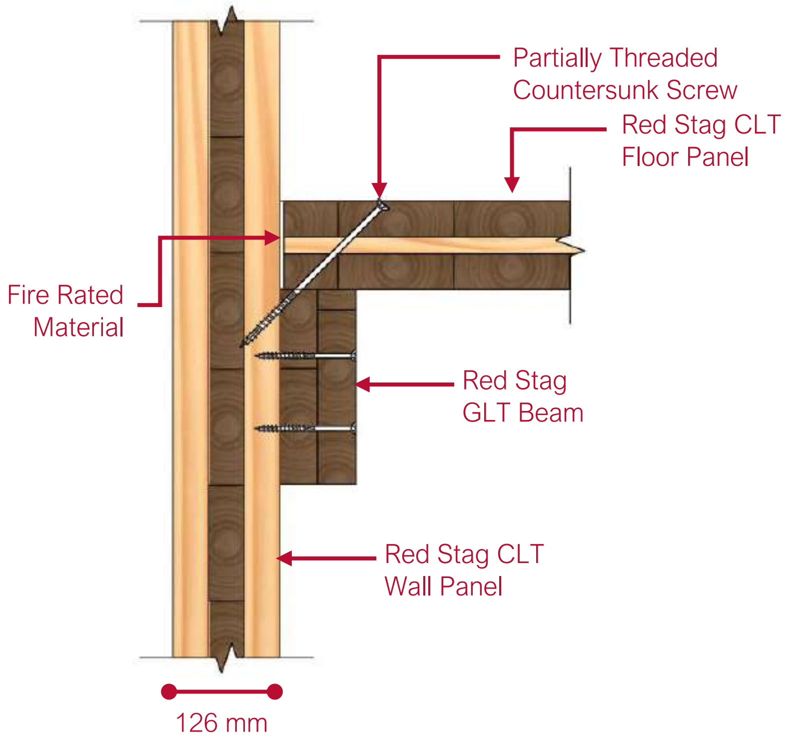


Figure 47: Red Stag CLT wall panel to CLT floor panel (On edge of external walls of building).

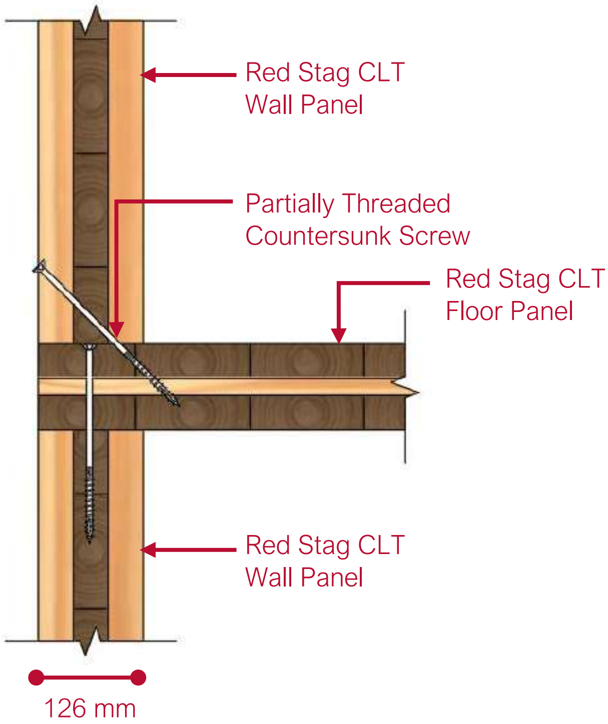


Figure 48: Red Stag CLT wall panel to CLT floor panel.

16.3 Red Stag CLT Roof Panel Connection

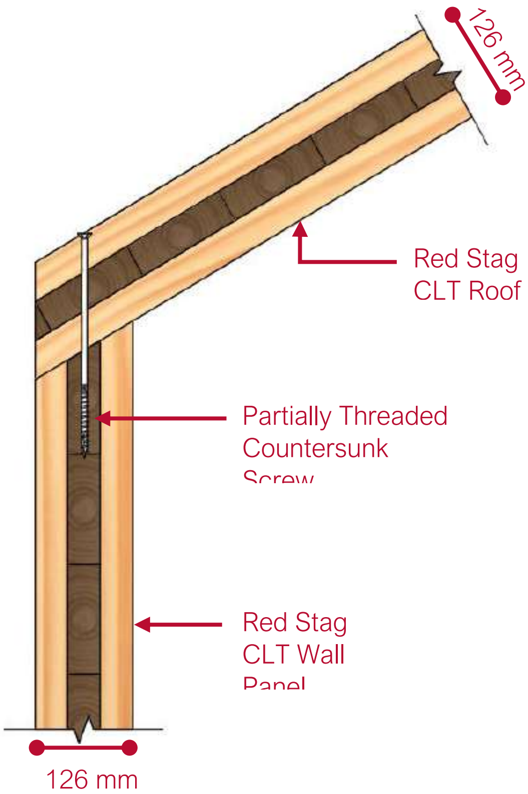


Figure 49: Red Stag three (3) layer CLT roof panel to CLT wall panel connection.

16.4 Mixed Timber Connection to Red Stag CLT Connections

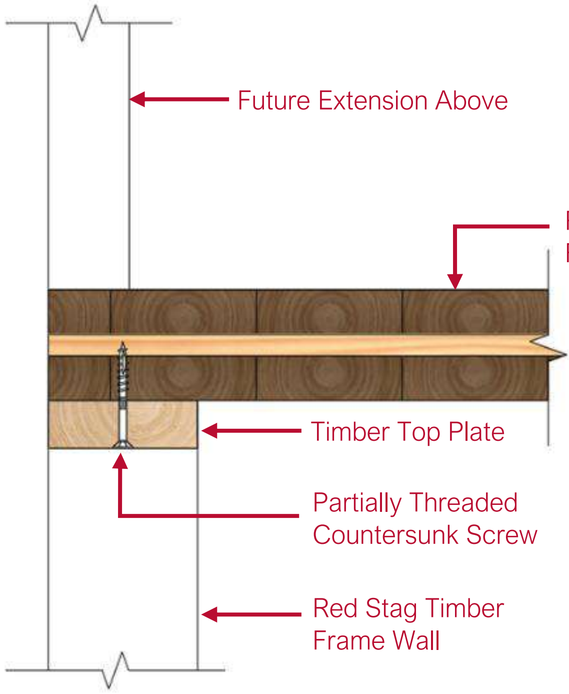


Figure 50: Timber frame wall to Red Stag CLT floor panel connection.

16.5 Red Stag CLT Floor Connection

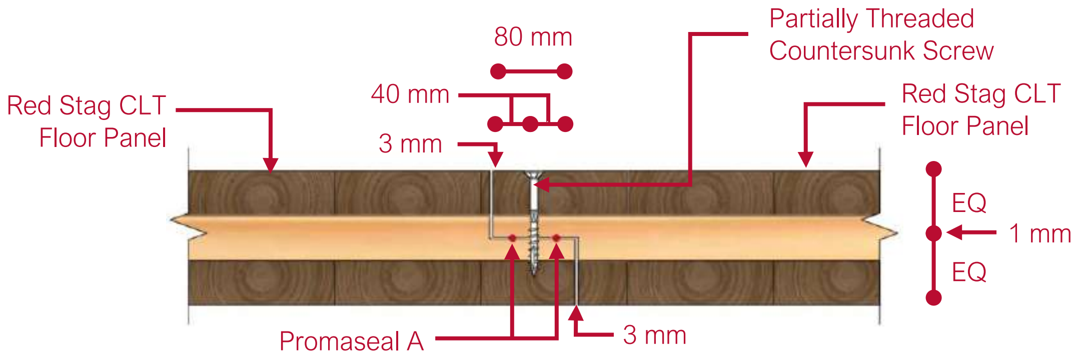


Figure 51: Red Stag three (3) layer CLT floor to floor half-lap joint connection.

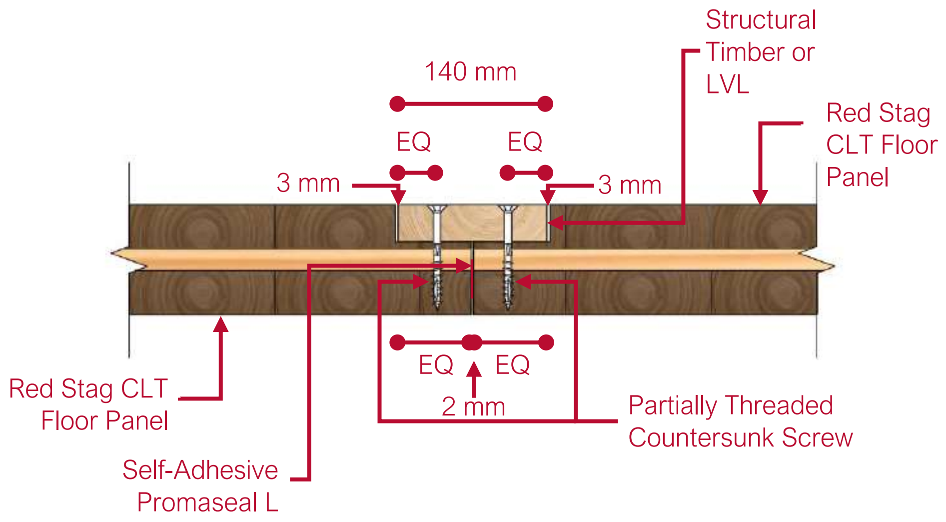


Figure 52: Red Stag three (3) layer CLT floor to floor with spline plate connection.

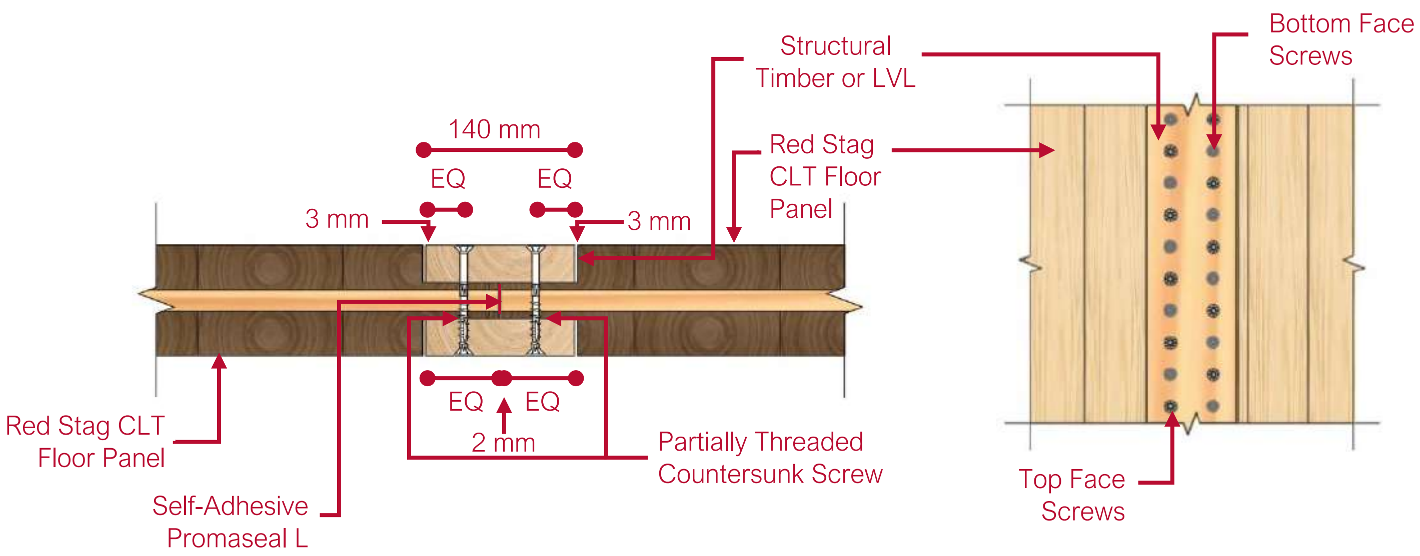


Figure 53: Red Stag three (3) layer CLT floor panel to floor panel with double spline plate connection.

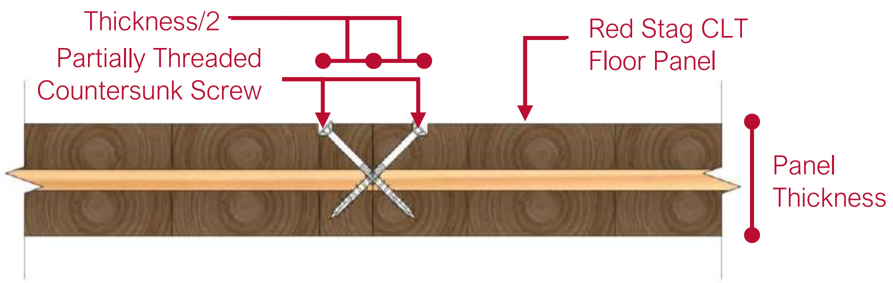


Figure 54: Red Stag three (3) layer CLT floor to floor butt joint connection.

16.6 Red Stag CLT Stair Connection Details

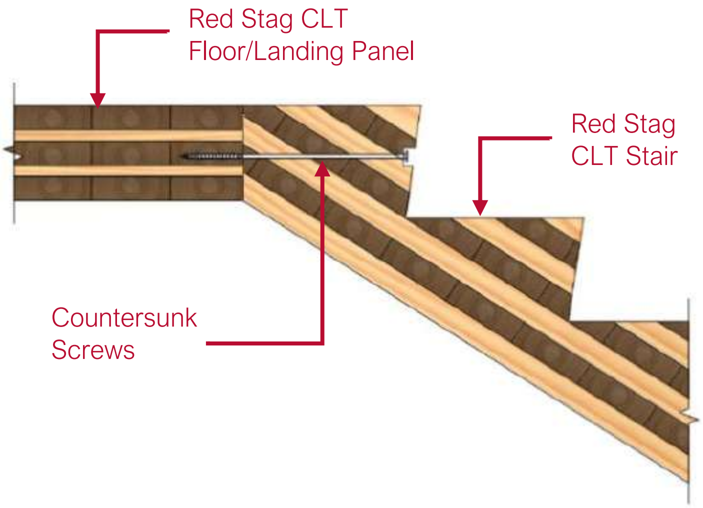


Figure 55: Red Stag CLT stair panel to CLT landing/floor panel connection.

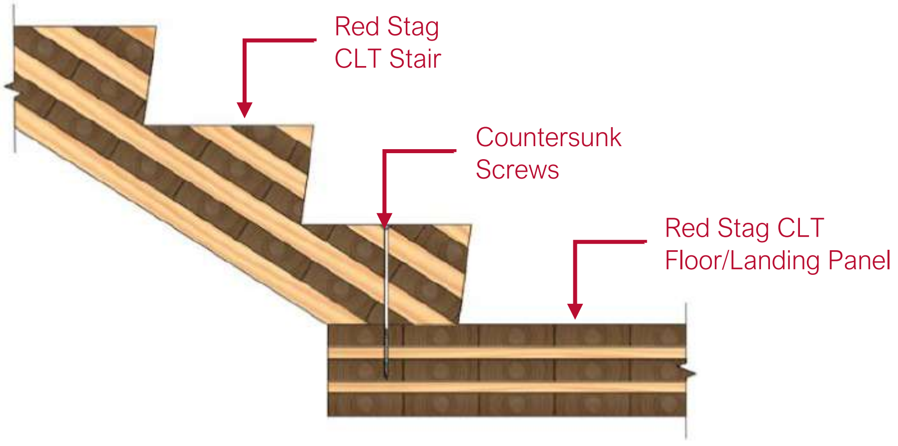


Figure 56: Red Stag CLT stair panel to CLT landing/floor panel connection.

17. Fastener Placement in CLT Panels

New clauses were introduced into the Canadian CLT standard to specify the minimum spacing of fasteners installed in the panel edge of CLT. The new requirements are intended to limit issues associated with splitting of timber. For bolts, lag screws, nails and self-tapping screws in the edge of CLT panels, the minimum fastener spacing should be in accordance with *Table 17* and *Figure 57* for three layer panels and , and *Figure 58* for five layer panels.

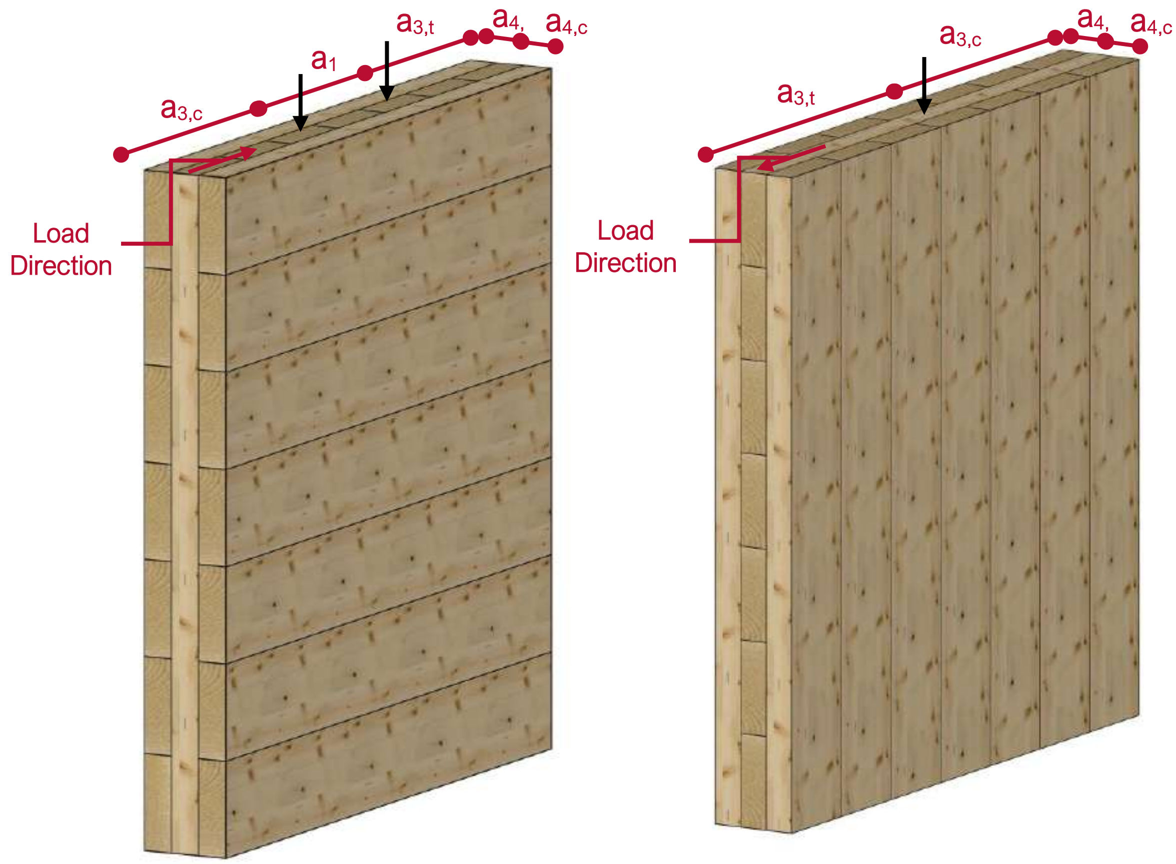


Figure 57: Spacing placement of fasteners on the edge of CLT panels.

Table 17: Spacing of self-tapping screws in CLT Panels [11]

Symbol	Minimum Spacing
a_1	10 × diameter
a_2	3 × diameter
$a_{3,t}$	12 × diameter
$a_{3,c}$	7 × diameter
$a_{4,c}$	5 × diameter

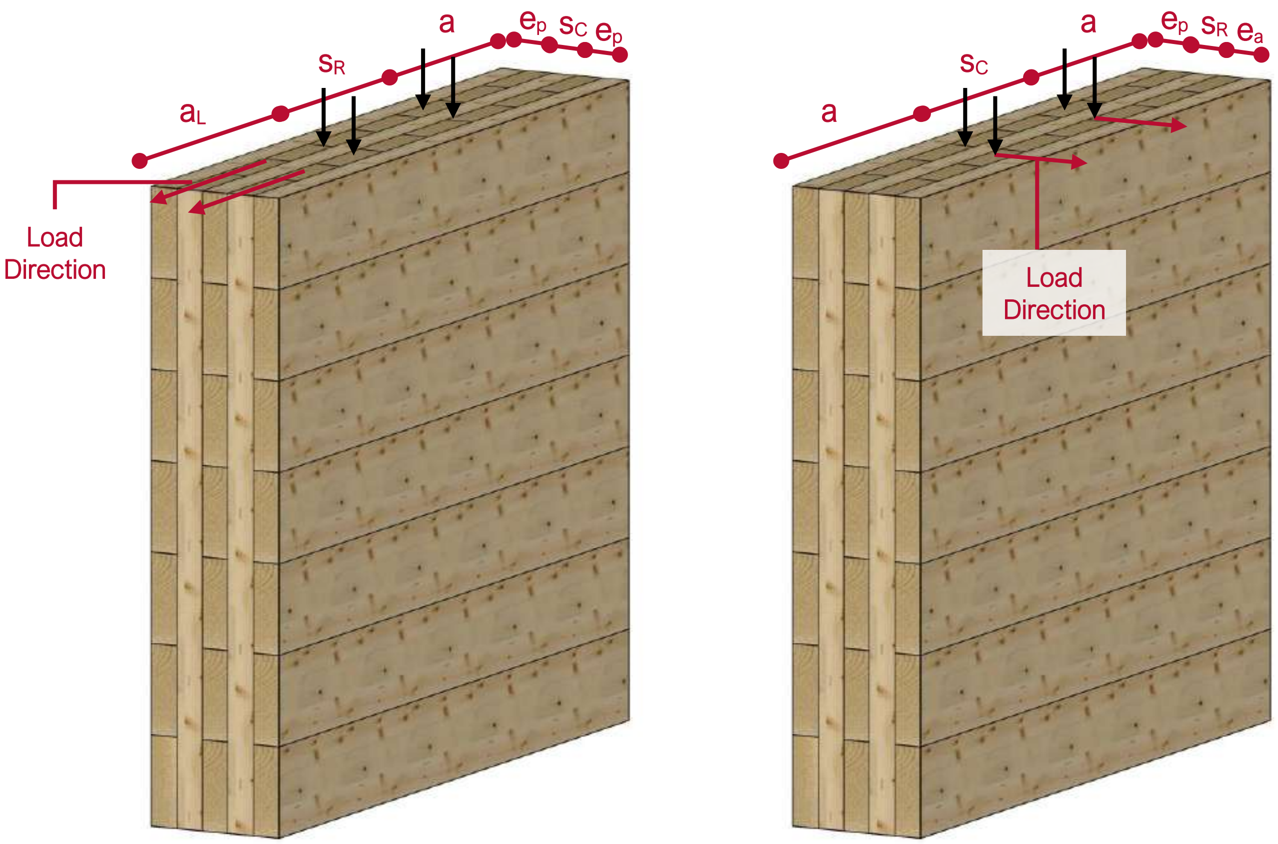


Figure 58: Spacing placement of the fasteners on the edge of CLT panels.

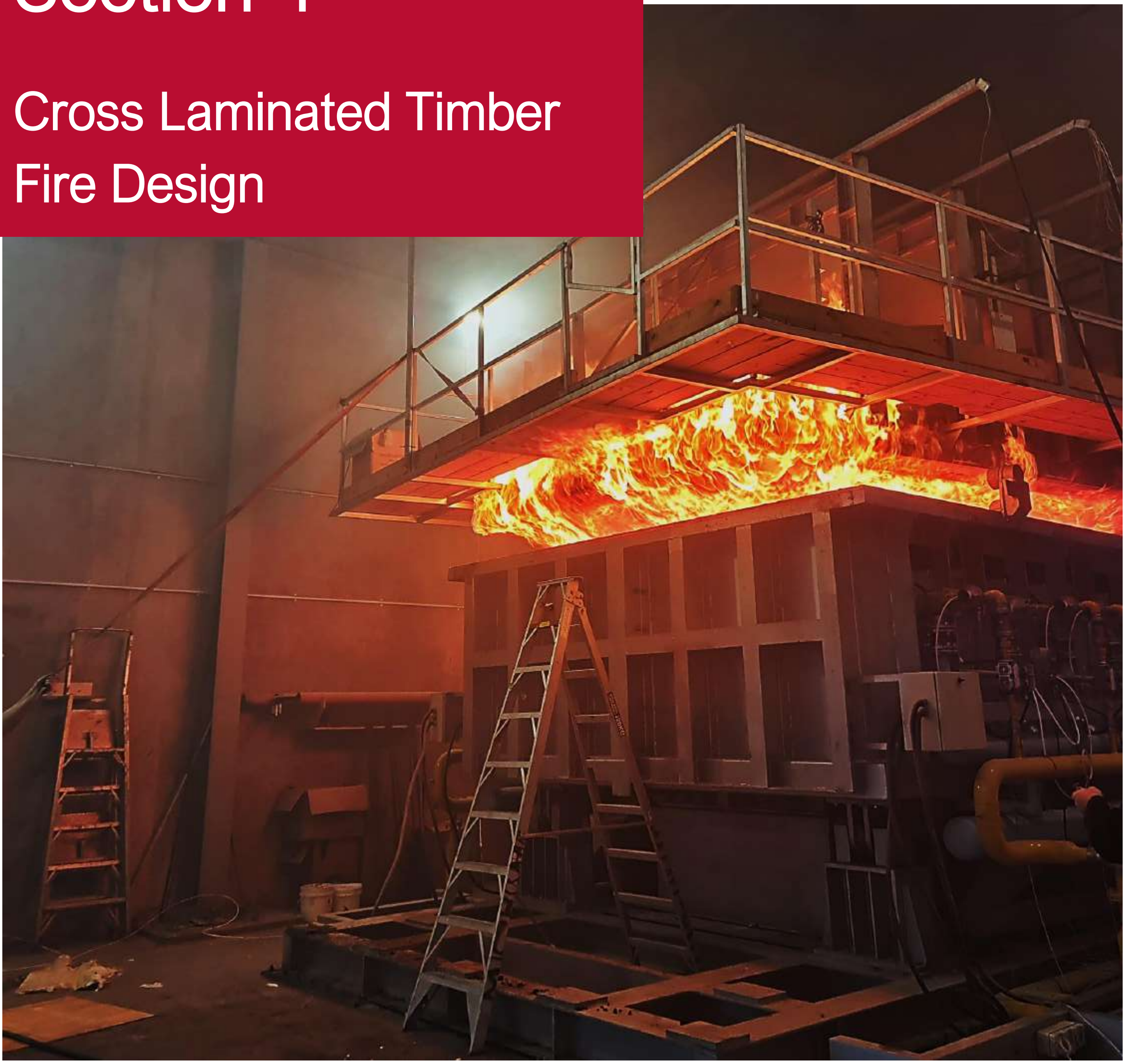
Table 18: Spacing of self-tapping screws and nails in CLT Panels [11]

Symbol	Dimension	Minimum Spacing
s_R	Spacing parallel to the load direction	10 × diameter
s_C	Spacing perpendicular to the load direction	4 × diameter
a	End distance	7 × diameter
a_P	Unloaded end distance	7 × diameter
a_L	Loaded end distance	12 × diameter
e	Edge distance	3 × diameter
e_P	Unloaded edge distance	3 × diameter
e_a	Loaded edge distance	6 × diameter

Table 19: Spacing of bolts and lag screws in CLT Panels [11]		
Symbol	Dimension	Minimum Spacing
s_R	Spacing parallel to the load direction	3 × diameter
s_C	Spacing perpendicular to the load direction	3 × diameter
a	End distance	Maximum (4 × diameter or 50 mm)
a_P	Unloaded end distance	Maximum (4 × diameter or 50 mm)
a_L	Loaded end distance	Maximum (4 × diameter or 50 mm)
e	Edge distance	1.5 × diameter
e_P	Unloaded edge distance	1.5 × diameter
e_a	Loaded edge distance	5 × diameter

Section 4

Cross Laminated Timber Fire Design



18. CLT Exposed to Fire

If CLT is exposed to fire or an elevated supply of energy, its temperature increases, and the water molecules embedded within the system start to evaporate at 100 °C. At 200 – 300 °C, the long-chain molecules in the cell walls split, producing gaseous and flammable compounds. The gas subsequently enters the surface of the wood where it reacts with oxygen in the air and combusts [23].

These chemical compounds decompose in a process known as "pyrolysis" (whereby gas emissions from combustible components in the wood burst into flame), gradually spreading along the wood, leaving a charring area behind it. This char layer is formed from the carbonaceous residue of pyrolysis, which burns, generating embers. This layer, which has low density and high permeability acts as heat insulation and protects the underlying, undamaged wood.

19. Fire Resistance Rating (FRR) of CLT

The primary objectives for CLT fire designs are to:

1. Maximise the resistance to fire.
2. Prevent the spread of fire.
3. Stop the building collapsing due to fire.
4. Support fire remediation if a fire event occurs.

Fire Resistance and Fire Reaction terms are used when referring to fire protection products:

- **Fire Reaction:** An indication of how CLT responds to fire, whether it flares or contributes to the spread of fire.
- **Fire Resistance:** Measures how well CLT performs in containing the fire, preventing it from spreading elsewhere.

Different construction elements are given a rating for how well they perform during fire testing. This is affected by their resistance to fire and their reaction to fire. Fire rating performance is referred to as FRR in the New Zealand fire safety Acceptable Solutions and Verification Methods (compliance documents).

FRR is described using three numbers that together refer to the structural adequacy (Structural resistance), integrity and insulation. It may be described differently in other jurisdictions (refer to *Figure 59a* to *Figure 59c*).

Common representations of FRR ratings are as follows:

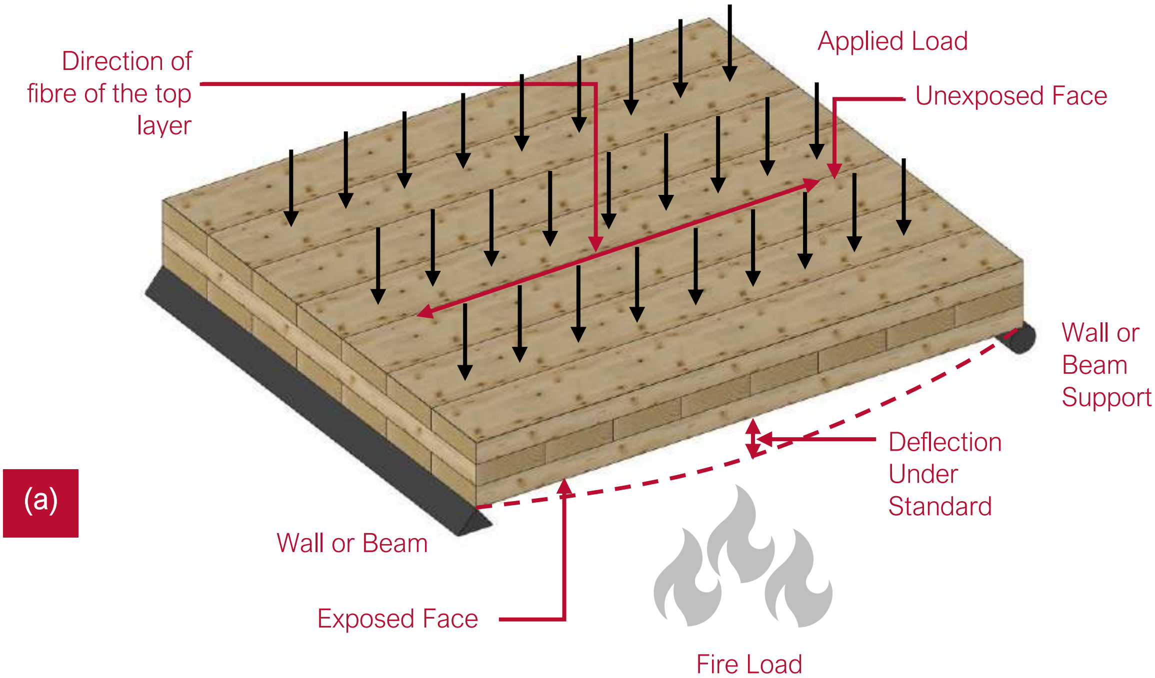
- **30/30/30:** 30 minute Structural Resistance; 30 minutes Integrity; 30 minute Insulation rating.
- **60/60/60:** 60 minute Structural Resistance; 60 minutes Integrity; 60 minute Insulation rating.
- **-/30/60:** Structural Resistance rating not applicable; 30 minutes Integrity; 60 minute Insulation rating.
- **120/-/-:** 120 minute Structural Resistance; Integrity rating not applicable; Insulation rating not applicable.

The FRR numbers refer to the time in minutes for which each of the criteria are satisfied when the element is exposed to temperature, pressure and applied load specified in the test procedure. A dash indicates the reference test or performance is not applicable.

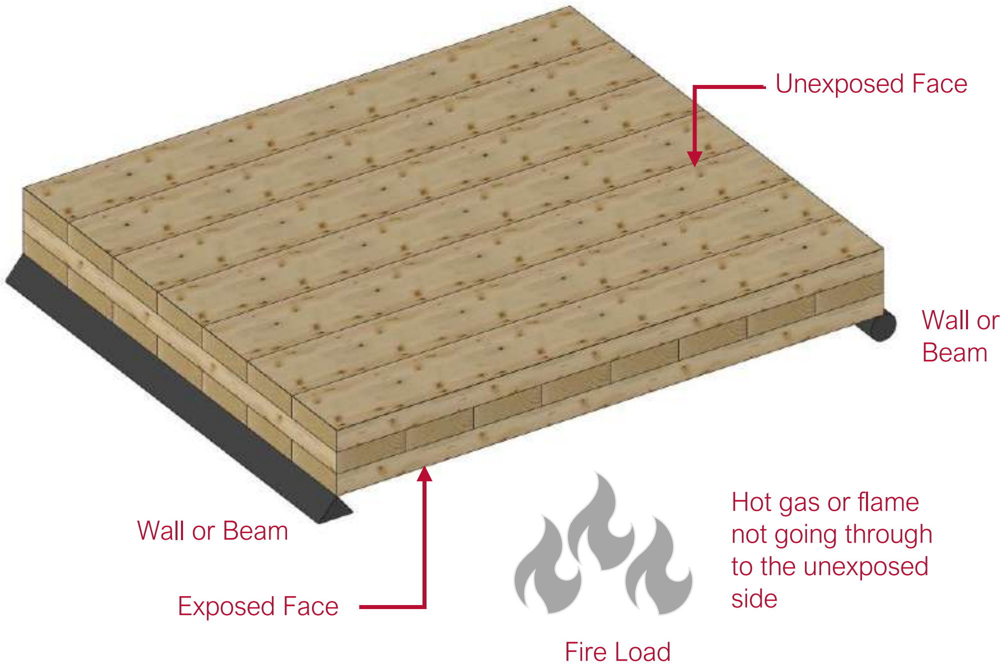
Figure 59a describes the structural adequacy of CLT. This is the ability to support a specified applied load and only applies to loadbearing elements in a structure. The assembly must support the applied load for the duration of the test (relates to the loadbearing function).

Figure 59b describes the element's integrity. This is the ability of the CLT element to prevent hot gasses or flames from penetrating on either side of the element for the defined amount of time. After this time, the element would be at risk of developing cracks or openings, through which hot gases and smoke could pass.

Figure 59c describes the element's insulation. This is the ability to limit the temperature rise on the non-fire face (unexposed face) of the CLT element. The CLT element must prevent the rise in temperature being greater than 180°C at any location, or an average of 140°C measured at several locations, above the initial temperature (relates to the separating function).



(b)



(c)

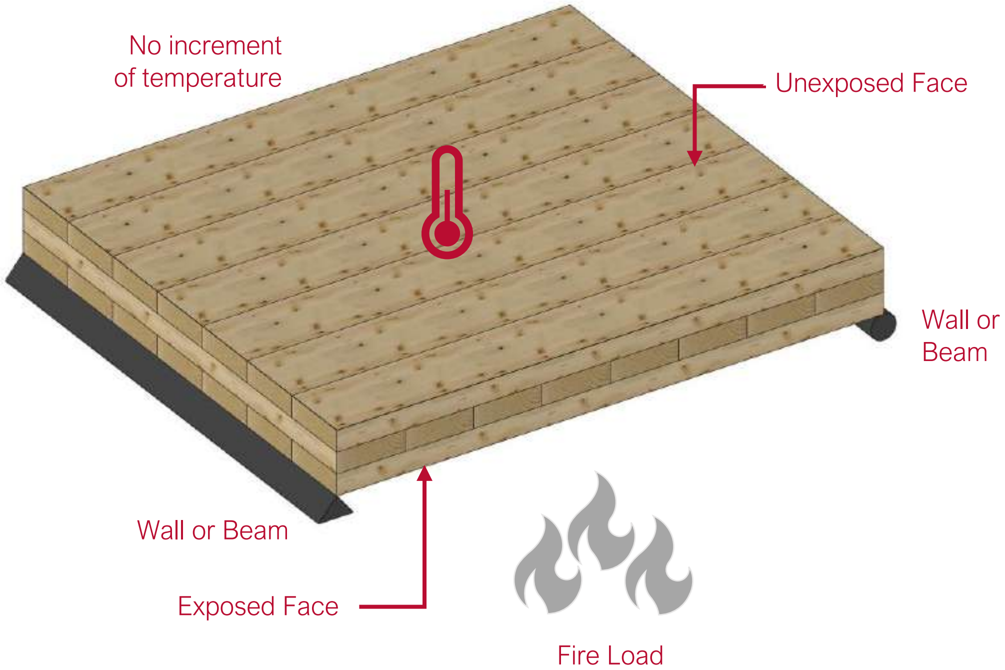


Figure 59: (a) Fire testing confirmed that a 103.5 mm thick Red Stag CLT panel satisfied the structural adequacy for 60 minutes during fire testing, (b) Fire testing confirmed that a 103.5 mm thick Red Stag CLT panel satisfied the integrity requirements for 60 minutes during fire testing, (c) Fire testing confirmed that a 103.5 mm thick Red Stag CLT panel satisfied the insulation requirements for 60 minutes during fire testing.

One of the major advantages of CLT is its natural fire resistance. CLT can be designed to accommodate substantial fire resistance and unlike steel, CLT remains structurally stable when subjected to high temperatures. CLT panels can be produced with fire resistances of 30, 60 and 90 minutes. As a general rule, well designed CLT buildings can provide similar levels of fire safety as steel or concrete buildings. CLT construction typically uses CLT panels for floor and loadbearing walls, which can provide fire-rated compartmentalisation to further reduce the risk of fire spread beyond its point of origin.

20. CLT Charring Behaviour

Red Stag CLT fire resistance is provided by charring created during a fire event. When the surface temperature at the face of Red Stag CLT ramps up 400 degrees Celsius or more, the timber starts to ignite and burn at a constant rate. As the timber burns, it loses its structural strength, and it creates a black layer of char. The char becomes an insulating layer preventing an excessive rise in temperature within the unburnt area(s), maintaining the structural performance of the insulated sections. This process supports in maintain the structural integrity while building occupants can exit the structure (refer to *Figure 60*).

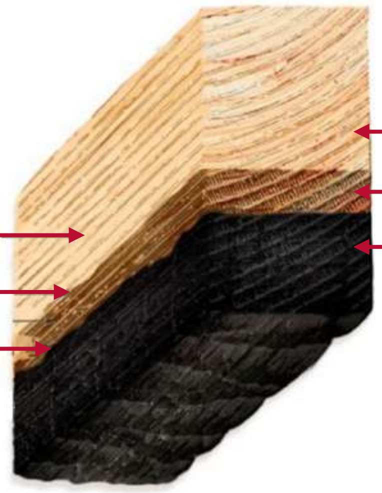


Figure 60: Different phases of degradation of timber in Red Stag CLT panel.

CLT performance in fire conditions has been very well studied, but the performance is not always well understood given the complexities related to char rate being dependent on layer or ply thickness, number of layers and the type of adhesive used. The delamination of multi-layered EWP like CLT depends on the heat resistance of the adhesive bond and the char rate of the timber during the fire event. Red Stag have completed a series of large and pilot scale fire testing on its CLT floor and wall systems to authenticate the structural stability, integrity, and insulation of the products.

The Fire Code is formulated to permit time for occupants to safely leave a burning building before structural collapse or succumbing to heat or smoke inhalation. The code stipulates a safe evacuation period of up to 60 minutes in New Zealand, for most building types and uses. Large-scale CLT fire testing was conducted by Red Stag to determine the overall fire resistance and fire performance of panels under structural loads (Refer to *Figure 61*).

The CLT floor and wall test specimens were respectively installed at the top and front of the furnaces to investigate parameters such as the structural performance, temperature profile, and deflection (*Figure 61a and Figure 61b*). The third-party fire test report confirmed no structural, integrity or instability failure after more than 60 minutes.

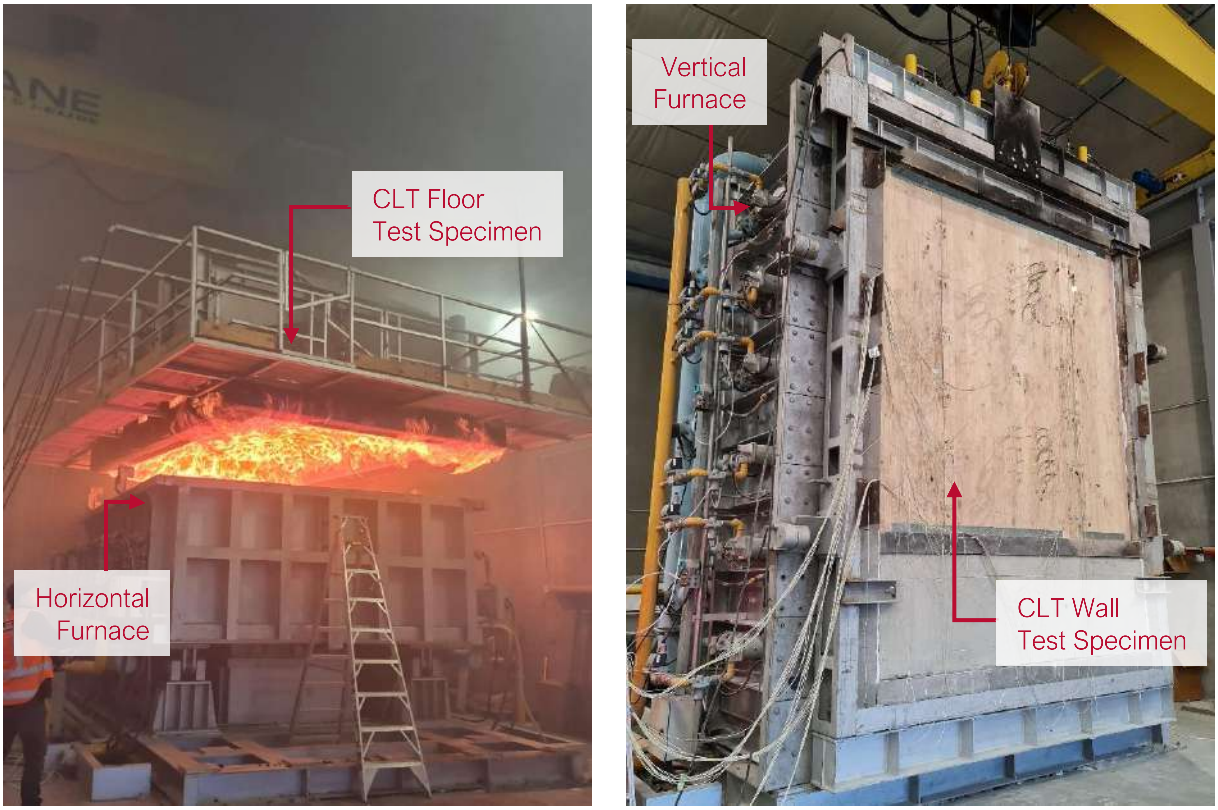
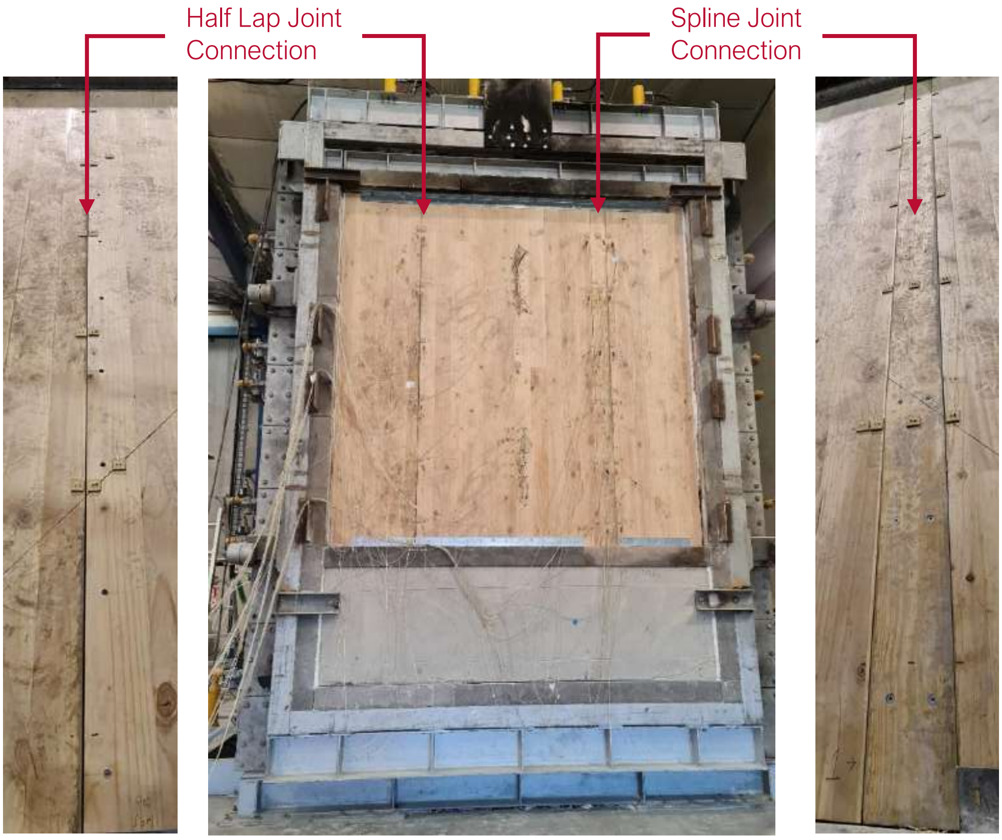


Figure 61: A general view of the large-scale fire test set-up and associated test specimen after the fire test on Red Stag CLT. a) Red Stag CLT floor test specimen after the fire test, b) Red Stag CLT wall test specimen before the fire test.

21. Fire Rated Red Stag CLT Connections

In New Zealand and Australia, there are no modern design rules for the structural fire design of connections in structural timber, including CLT. The only prescribed calculations are in AS/NZS 1720.4 (Timber structures - Part 4: Fire resistance of timber elements), which requires all steel fasteners to be protected from fire by timber cladding, timber plugs, or similar, without any details suitable for modern structures. Consequently, the structural fire design of connections is often undertaken differently for every job, with only enough detail used to satisfy the relevant local authority (or peer reviewer). This is generally achieved using a mixture of calculations from first principles, information from manufacturers of CLT or fasteners, or design methods from Eurocode 5.

Red Stag has tested a number of connections in Red Stag CLT floors and walls to verify the structural stability, integrity, and insulation of the systems. *Figure 62* shows the structurally loaded CLT wall connection fire test (before and after testing). Passive fire connection details based on the engineering fire assessment of the Red Stag CLT are presented in *Figure 63* to *Figure 64*.



(a)

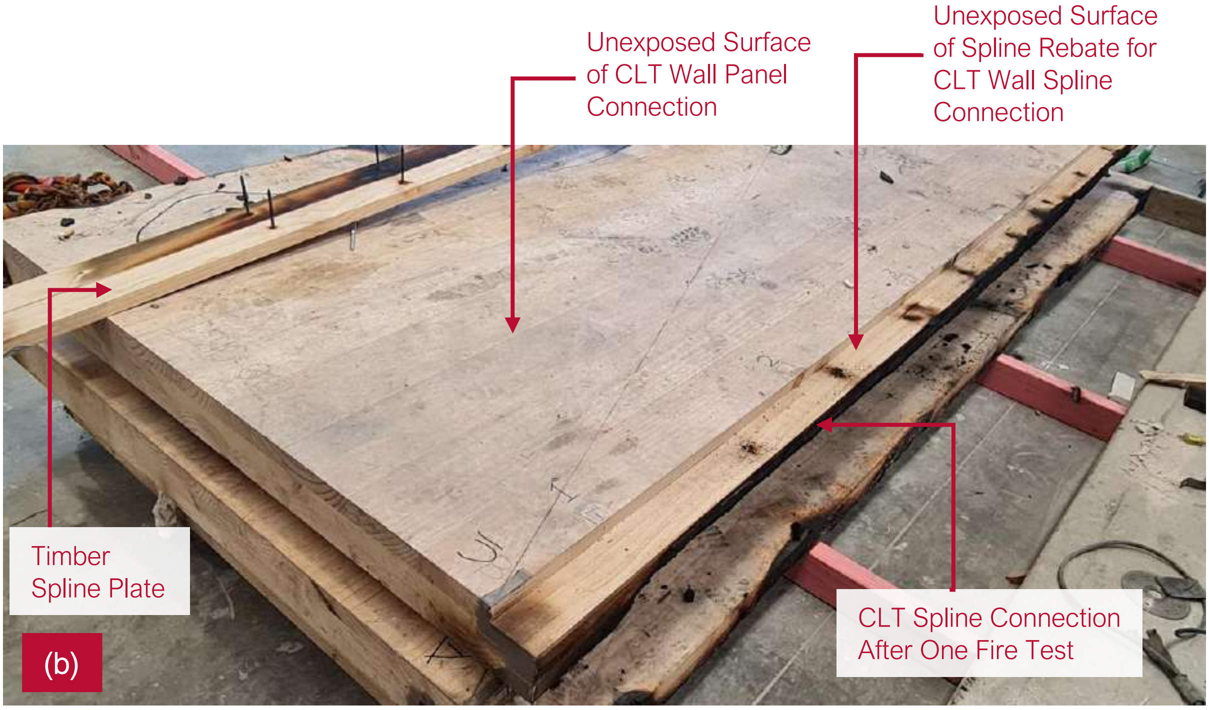
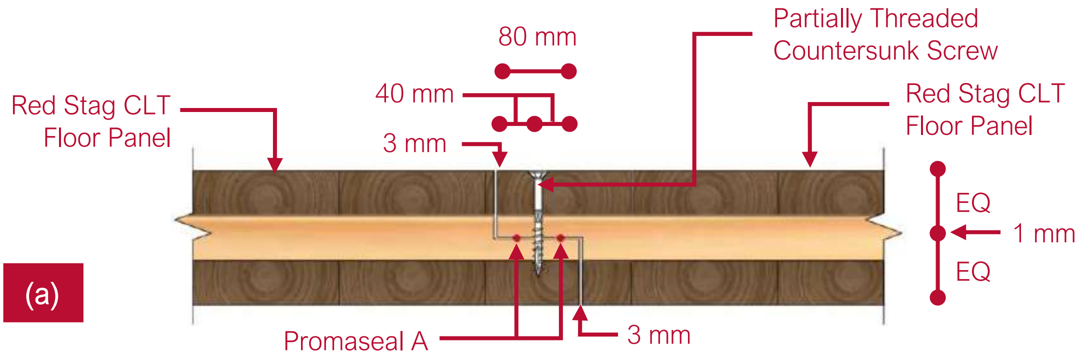


Figure 62: Large-scale Red Stag CLT wall fire test set-up after testing under structural loading to test CLT connection.



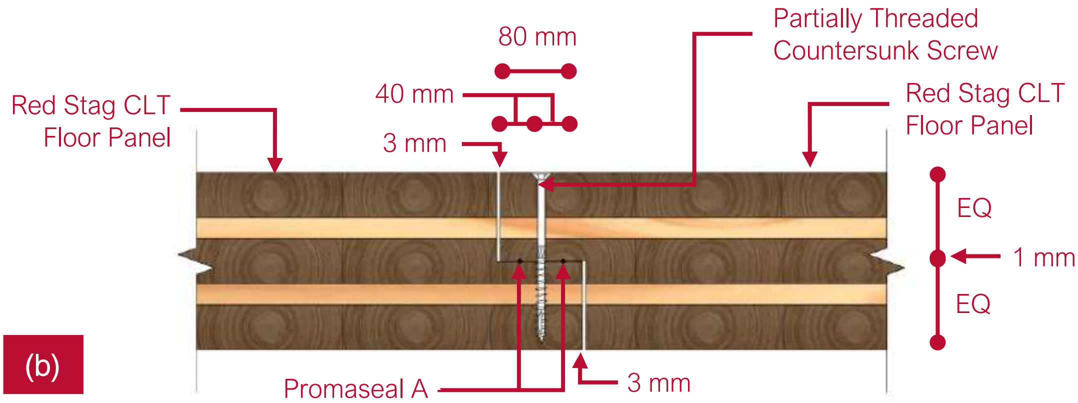


Figure 63: Red Stag CLT Panel to CLT Panel Half Lap Joint Connection [24], [25]. a) Three (3) Layer Red Stag CLT Panel, b) Five (5) Layer Red Stag CLT Panel.

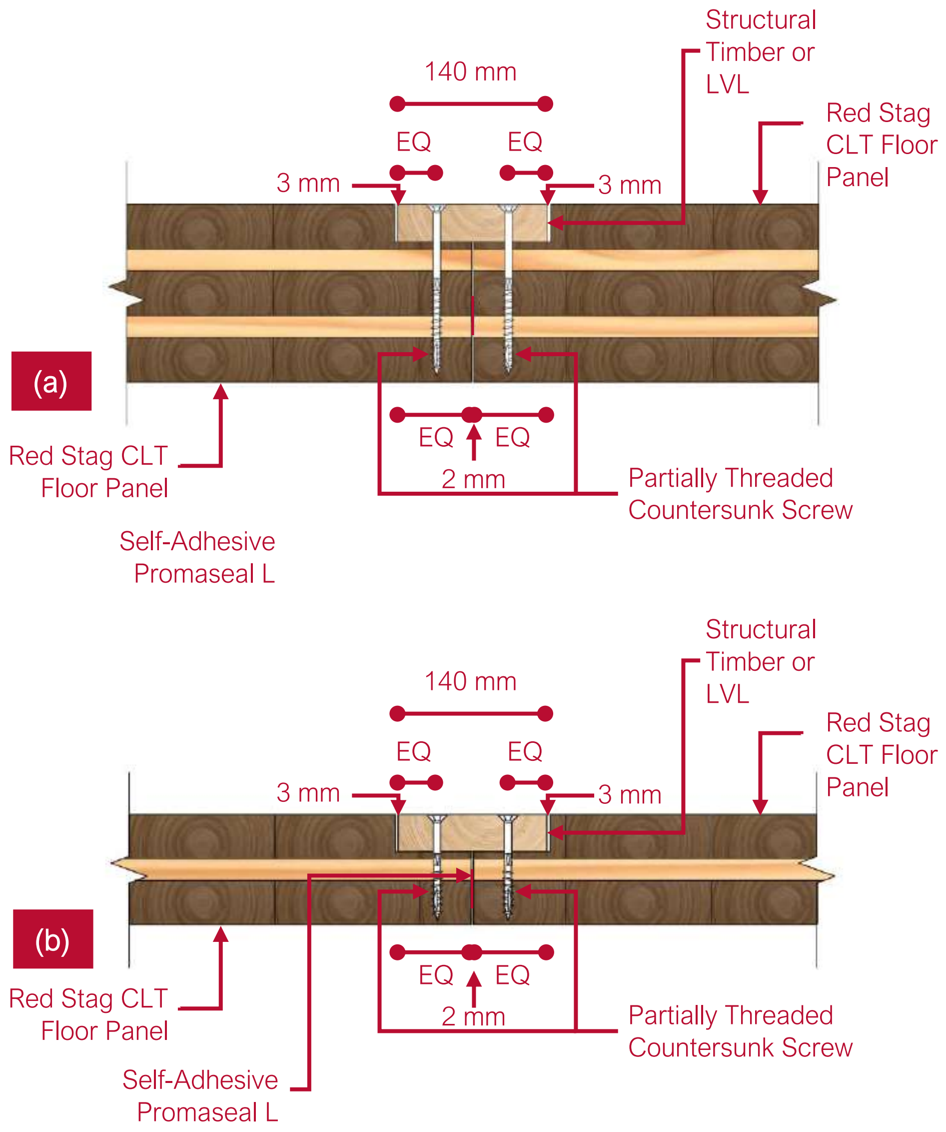


Figure 64: Red Stag CLT Panel to CLT Panel Spline Connection [24], [25]. a) Three (3) Layer Red Stag CLT Panel, b) Five (5) Layer Red Stag CLT Panel.

Any holes or penetrations for services must be constructed in a way that the fire performance of the CLT member is not compromised. Penetrations through the fire rated CLT floors or walls are required to have specific fire sealing or collar systems to maintain the integrity and installation. Although recent Canadian testing has shown that solutions for service penetrations in light timber frames are equally effective for protecting penetrations through solid wood panels, Red Stag have completed a wide range of large and full scale fire testing on penetrations through CLT wall and floor assemblies to ensure on the fire performance of Red Stag CLT. *Figure 65* and *Figure 66* illustrate fire penetration test configurations (pipes and cables) on Red Stag CLT floor and wall panels.

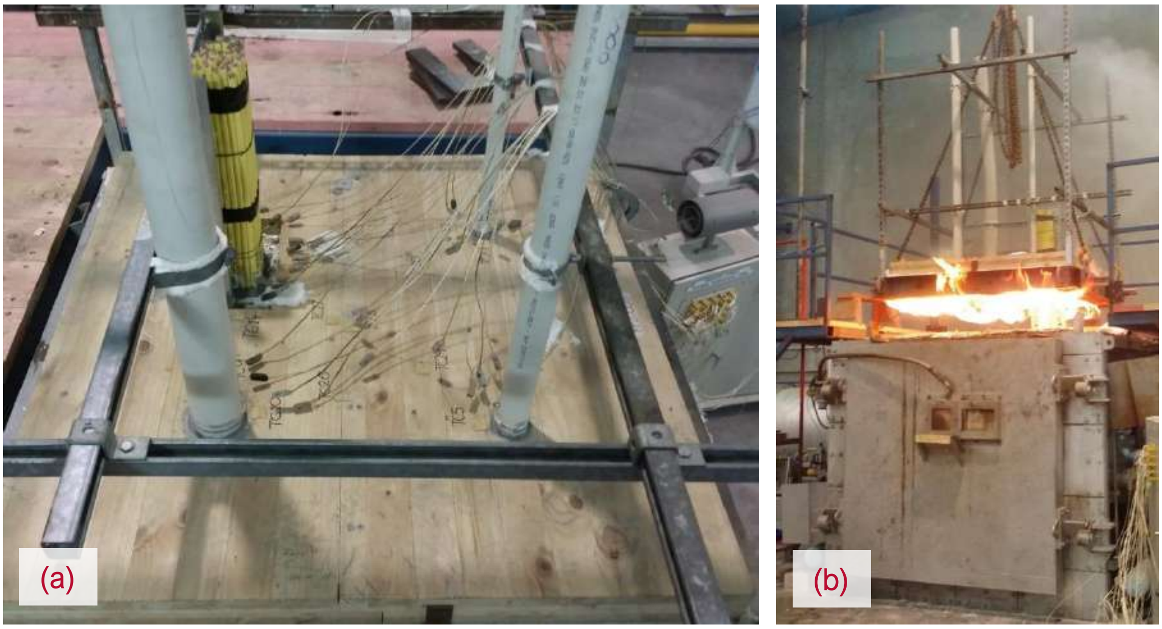
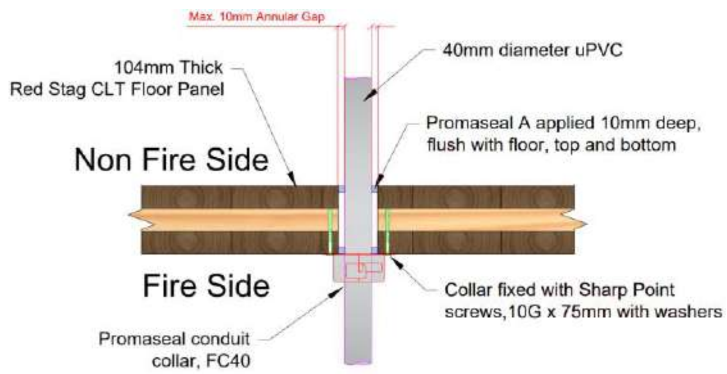


Figure 65: Various service (pipes and cables) fire tests on Red Stag CLT floor panels [26]. a) Specimen before the fire test, b) Specimen after the fire test.

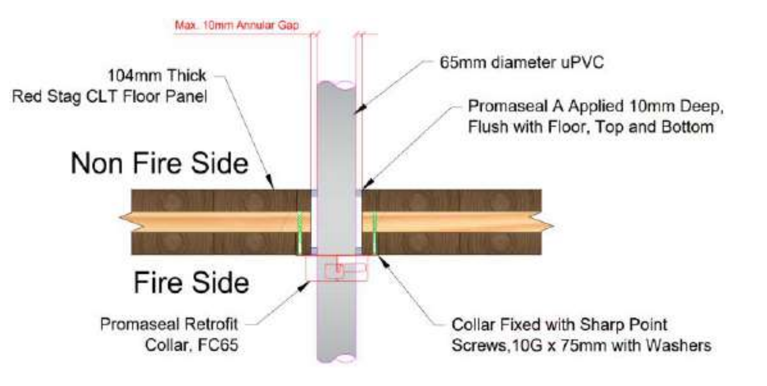
Figure 66: Various service (pipes and cables) fire tests on Red Stag CLT wall panels [26]. a) Specimen before the fire test, b) Specimen after the fire test.

The fire test results on Red Stag CLT are summarised in *Table 20*. Fire penetration testing was completed in accordance with AS 1530.4: 2014 (Methods for fire tests on building materials, components, and structures. Part 4: Fire-resistance test of elements of construction) and fire assessments.

<table>
<tr><th colspan="2">Table 20: Red Stag Panel Fire Rated Penetration Details [24],[26]</th></tr>
<tr><td colspan="2">Red Stag Fire Rated Penetration Detail for Ø40 mm uPVC Pipe</td></tr>
<tr><td>Type of service penetration</td><td rowspan="8">
</td></tr>
<tr><td>40 mm diameter uPVC</td></tr>
<tr><td>Fire stopping system</td></tr>
<tr><td>Promaseal A
Promaseal FC40 Collar</td></tr>
<tr><td>Type of CLT element</td></tr>
<tr><td>104 mm Red Stag CLT Floor</td></tr>
<tr><td>FRR (minutes)</td></tr>
<tr><td>-/60/60</td></tr>
</table>

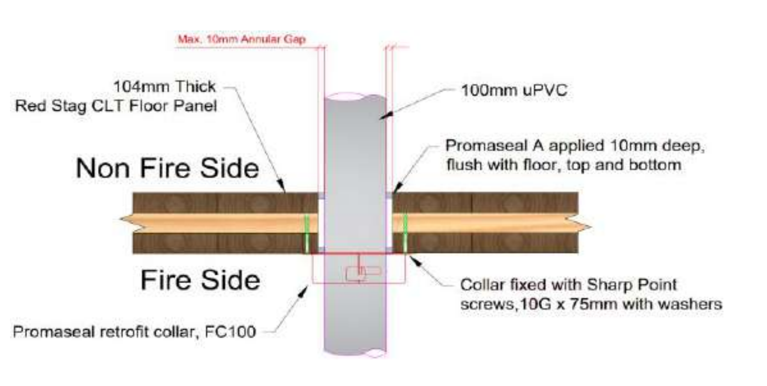
Red Stag Fire Rated Penetration Detail for Ø65 mm uPVC Pipe

Type of service penetration	65 mm diameter uPVC
Fire stopping system	Promaseal A Promaseal FC65 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



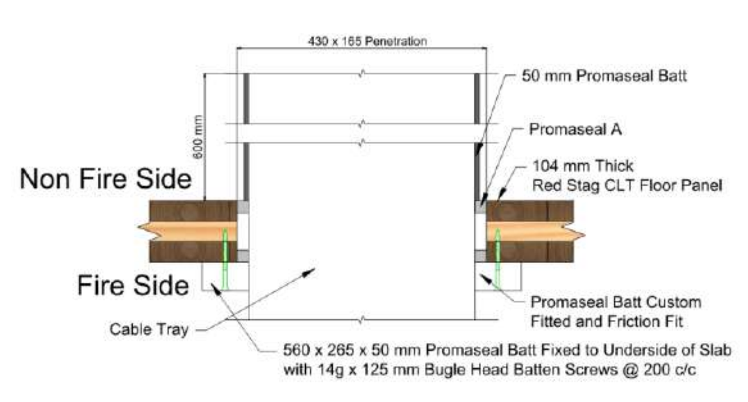
Red Stag Fire Rated Penetration Detail for Ø100 mm uPVC Pipe

Type of service penetration	100 mm diameter uPVC
Fire stopping system	Promaseal A Promaseal FC100 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



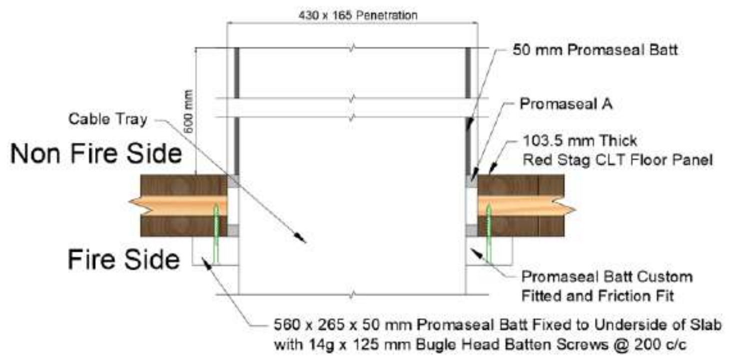
Fire Rated Penetration Detail for Comms Cable – D1 Configuration

Type of service penetration	D1 Cable Configuration
Fire stopping system	Promaseal A Two layer of 50 mm Promaseal Batt
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/30



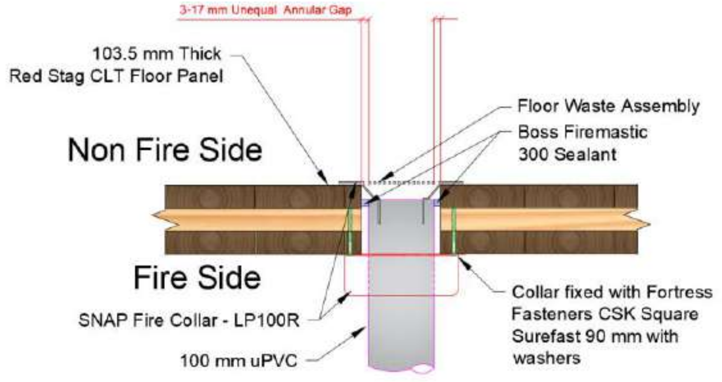
Fire Rated Penetration Detail for Comms Cable – D2 Configuration

Type of service penetration	D2 Configuration 60 Cable Bundle - Metal Cable Tray
Fire stopping system	Promaseal A Two layer of 50 mm Promaseal Batt
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/30



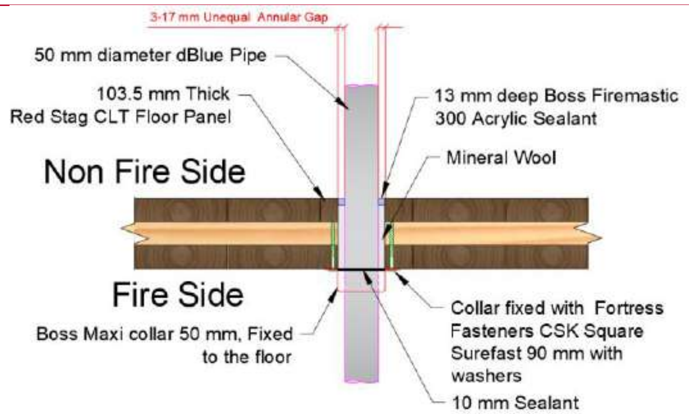
Red Stag Fire Rated Penetration Detail for Ø100 mm uPVC Pipe with Floor Waste Assembly

Type of service penetration	100 mm uPVC Pipe Floor Waste Assembly with Grate
Fire stopping system	Boss Firemastic 300 Sealant SNAP Fire Collar-LP100R
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



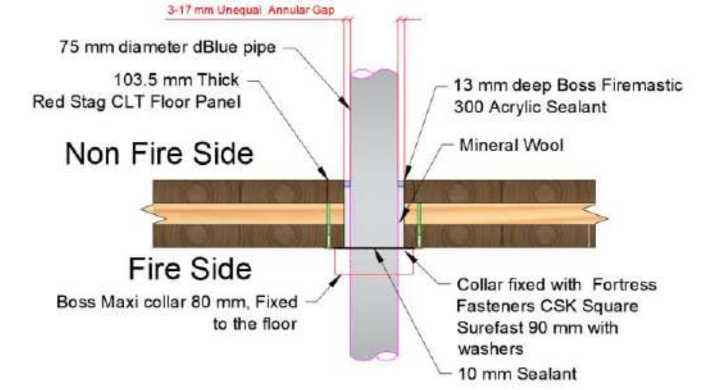
Red Stag Fire Rated Penetration Detail for Ø50 mm dBlue Pipe

Type of service penetration	50 mm Diameter dBlue Pipe
Fire stopping system	Boss Firemastic 300 Acrylic Sealant Boss Maxi FC50 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



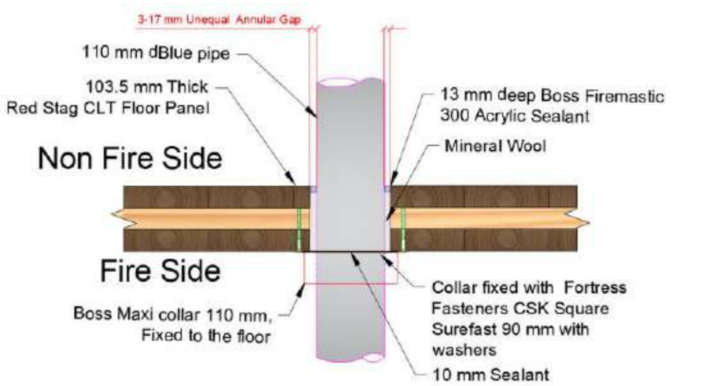
Red Stag Fire Rated Penetration Detail for Ø75 mm dBlue Pipe

Type of service penetration	75 mm Diameter dBlue Pipe
Fire stopping system	Boss Maxi Collar 80 mm Boss Firemastic 300 Sealant
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



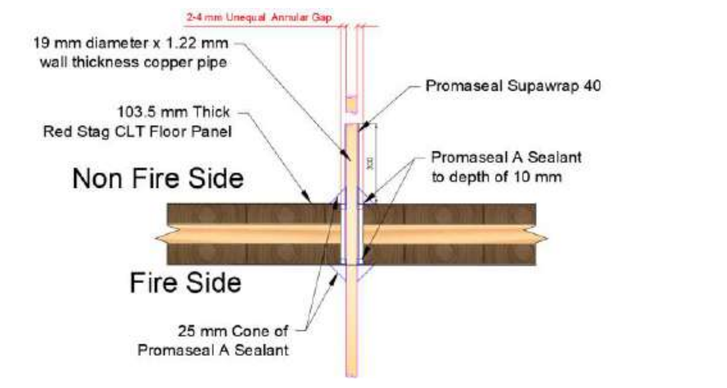
Red Stag Fire Rated Penetration Detail for Ø110 mm dBlue Pipe

Type of service penetration	110 mm Diameter dBlue Pipe
Fire stopping system	Boss Maxi Collar 80 mm Boss Firemastic 300 Sealant
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



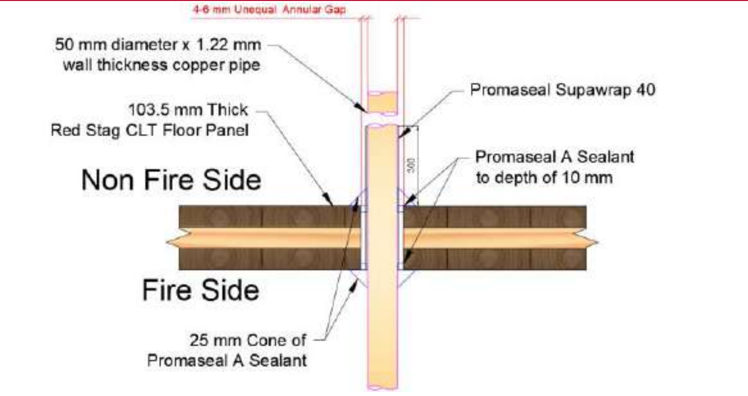
Red Stag Fire Rated Penetration Detail for Ø19 mm Copper Pipe

Type of service penetration	19 mm Diameter Copper Pipe
Fire stopping system	Promat Supawarp 40 Promaseal-A Sealant
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



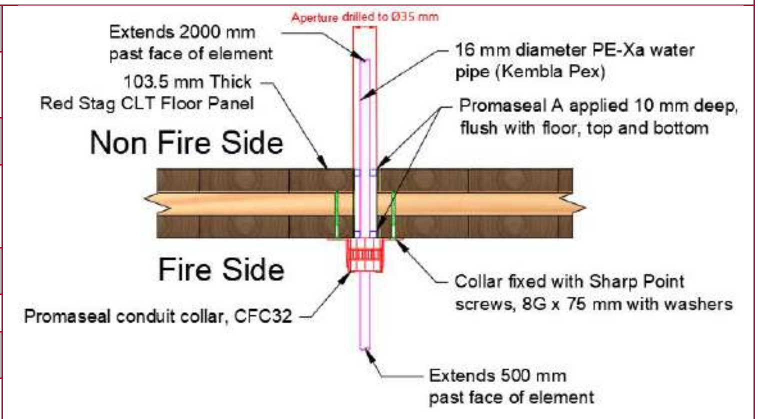
Red Stag Fire Rated Penetration Detail for Ø50 mm Copper Pipe

Type of service penetration	50 mm Diameter Copper Pipe
Fire stopping system	Promat Supawarp 40 Promaseal-A Sealant
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



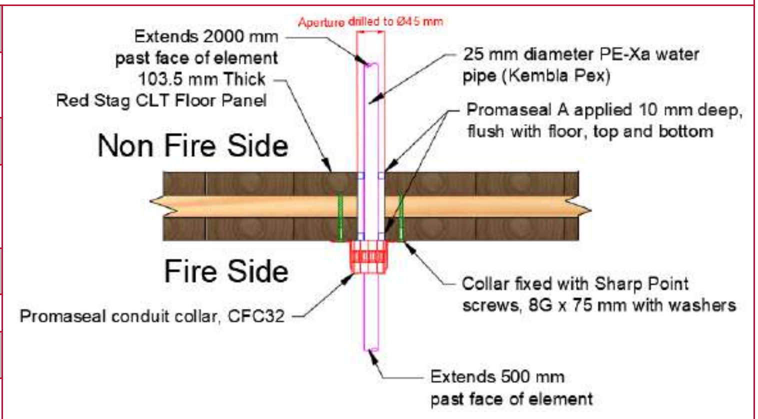
Red Stag Fire Rated Penetration Detail for Ø16 mm PE-Xa Water Pipe (Kembla Pex)

Type of service penetration	16 mm Diameter PE-Xa Water Pipe
Fire stopping system	Promaseal A Promaseal CFC32 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



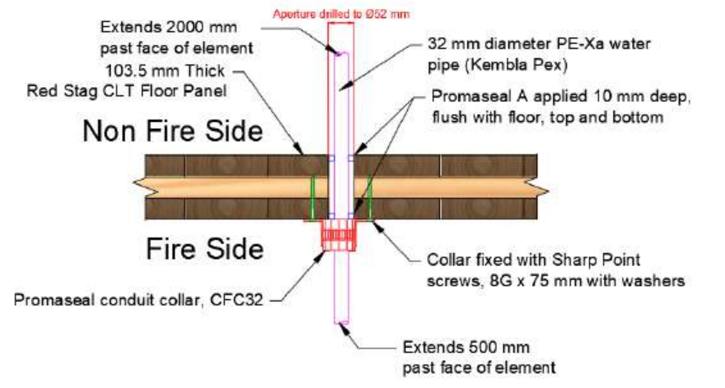
Red Stag Fire Rated Penetration Detail for Ø25 mm PE-Xa Water Pipe (Kembla Pex)

Type of service penetration	25 mm Diameter PE-Xa Water Pipe
Fire stopping system	Promaseal A Promaseal CFC32 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/30



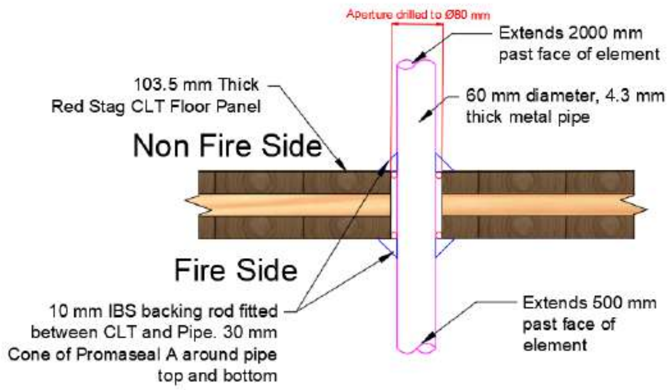
Red Stag Fire Rated Penetration Detail for Ø32 mm PE-Xa Water Pipe (Kembla Pex)

Type of service penetration	32 mm Diameter PE-Xa Water Pipe
Fire stopping system	Promaseal A Promaseal CFC32 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/30/30



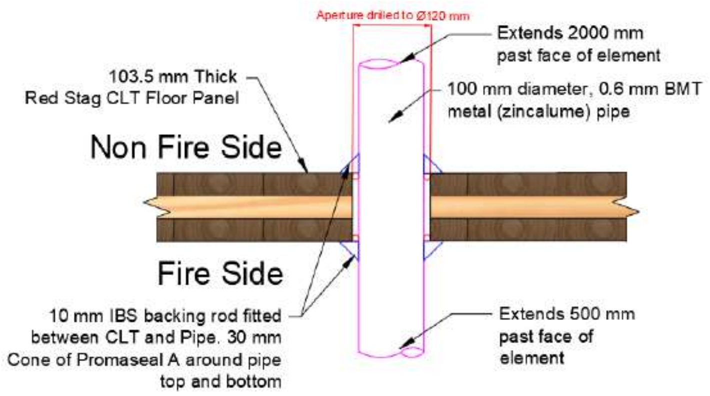
Red Stag Fire Rated Penetration Detail for Ø60 mm, 4.3 mm thick Metal Pipe

Type of service penetration	60 mm Diameter, 4.3 BMT Metal Pipe
Fire stopping system	Promaseal-A 10 mm IBS Backing Rod
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/30



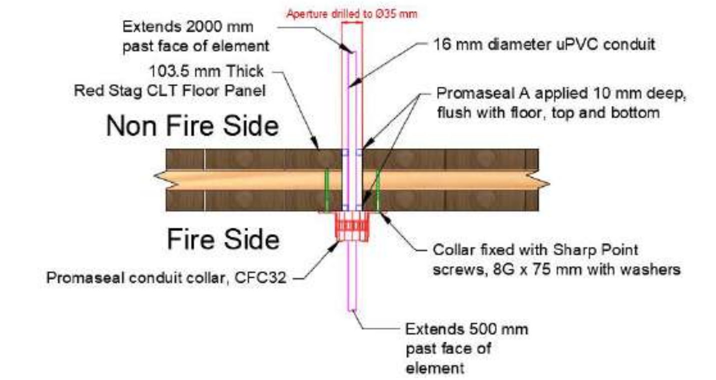
Red Stag Fire Rated Penetration Detail for Ø100 mm, 0.6 BMT Metal (Zincalume) Pipe

Type of service penetration	100 mm Diameter, 0.6 BMT Metal Pipe
Fire stopping system	Promaseal-A 10 mm IBS Backing Rod
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/-



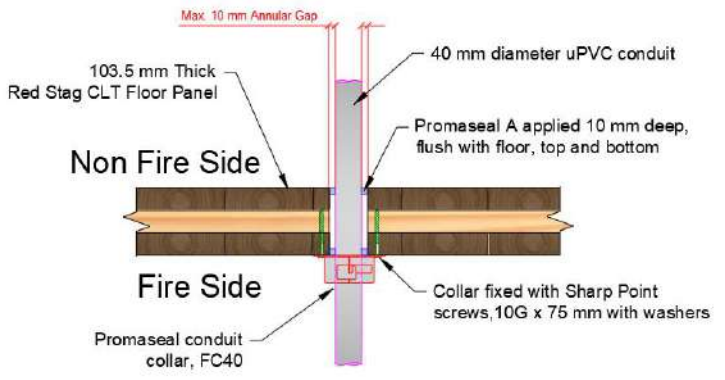
Red Stag Fire Rated Penetration Detail for Ø16 mm uPVC Conduit filled with 3-core TPS Cables

Type of service penetration	16 mm Diameter uPVC Conduit
Fire stopping system	Promaseal A Promaseal CFC32 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



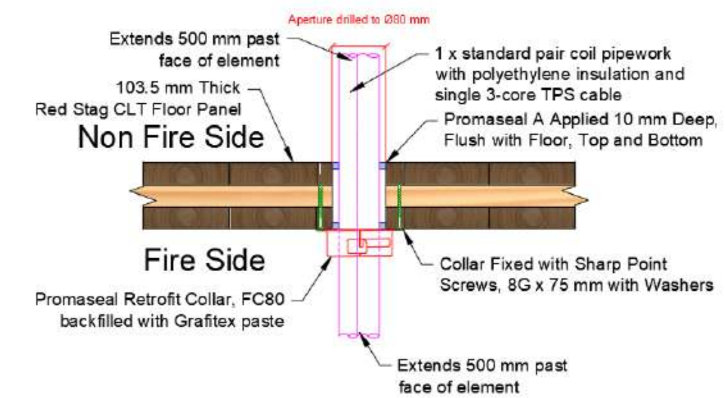
Red Stag Fire Rated Penetration Detail for Ø40 mm uPVC Conduit filled with 3-core TPS Cables

Type of service penetration	40 mm Diameter uPVC Conduit
Fire stopping system	Promaseal A Promaseal FC40 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



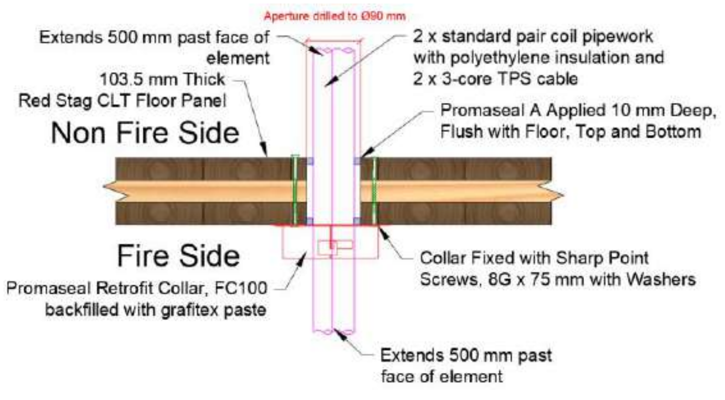
Red Stag Fire Rated Penetration Detail for Single STD Pair Coil & 2.5 mm 3C TPS

Type of service penetration	Single STD Pair Coil & 2.5 mm 3C TPS
Fire stopping system	Promaseal A Promaseal FC80 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/30/30



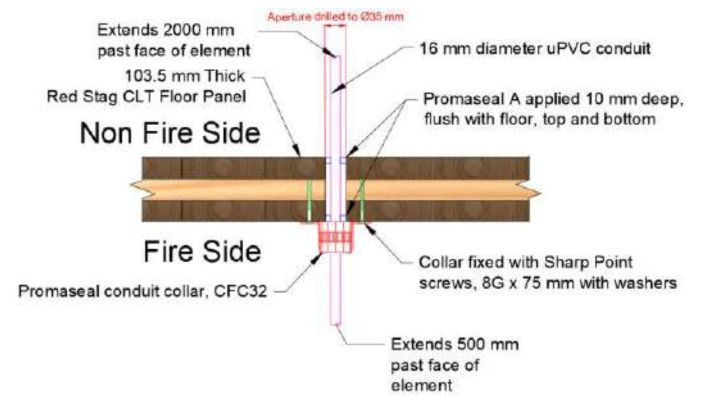
Red Stag Fire Rated Penetration Detail for Double STD Pair Coil & 2.5 mm 3C TPS

Type of service penetration	
Double STD Pair Coil & 2.5 mm 3C TPS	
Fire stopping system	
Promaseal A Promaseal FC100 Collar	
Type of CLT element	
104 mm Red Stag CLT Floor	
FRR (minutes)	
-/30/30	



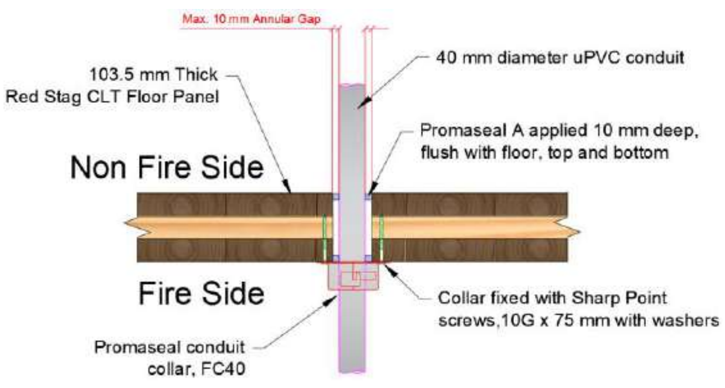
Red Stag Fire Rated Penetration Detail for Ø16 mm uPVC Conduit

Type of service penetration	
16 mm uPVC Conduit	
Fire stopping system	
Promaseal A Promaseal CFC32 Collar	
Type of CLT element	
104 mm Red Stag CLT Floor	
FRR (minutes)	
-/60/60	



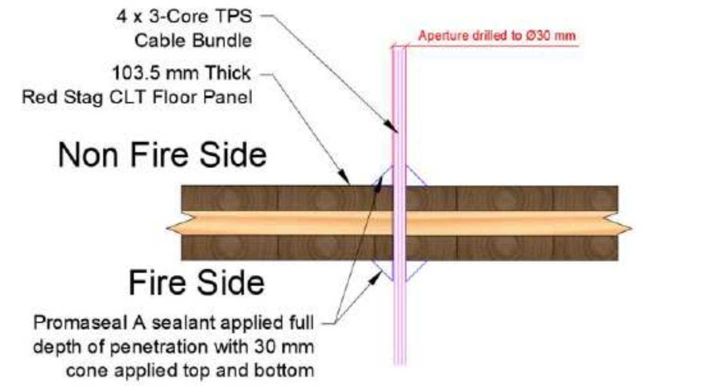
Red Stag Fire Rated Penetration Detail for Ø40 uPVC Conduit

Type of service penetration	
40 mm uPVC Conduit	
Fire stopping system	
Promaseal A Promaseal FC40 Collar	
Type of CLT element	
104 mm Red Stag CLT Floor	
FRR (minutes)	
-/60/60	



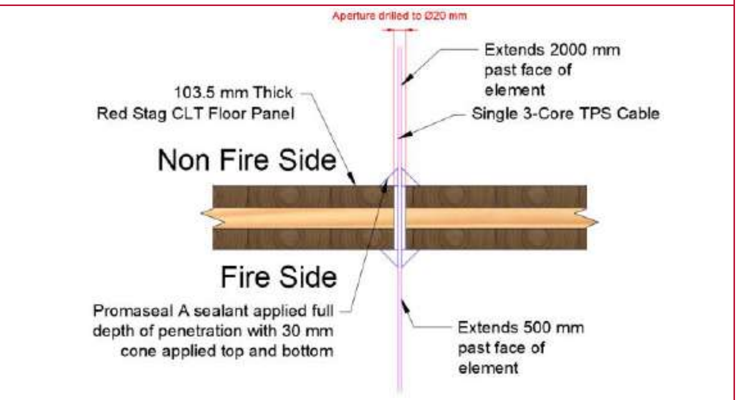
Red Stag Fire Rated Penetration Detail for 4 x 3-core TPS Cable Bundle

Type of service penetration	4 x 3-core TPS Cable Bundle
Fire stopping system	Promaseal A
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



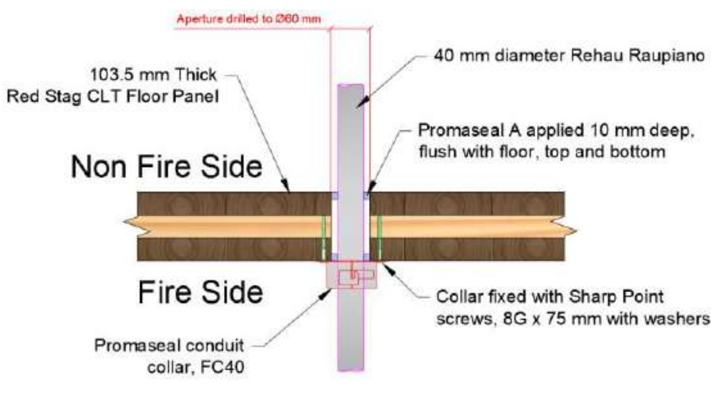
Red Stag Fire Rated Penetration Detail for Single 3-core TPS Cable

Type of service penetration	Single 3-core TPS Cable
Fire stopping system	Promaseal A
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



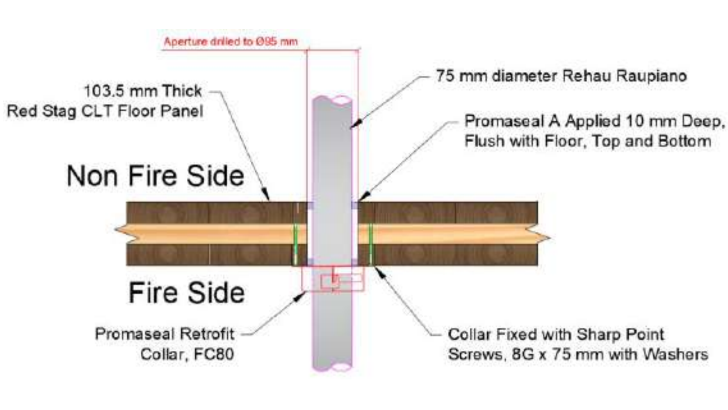
Red Stag Fire Rated Penetration Detail for Ø40 mm Rehau Raupiano Pipe

Type of service penetration	40 mm Diameter Rehau Raupiano Pipe
Fire stopping system	Promaseal A Promaseal FC40 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



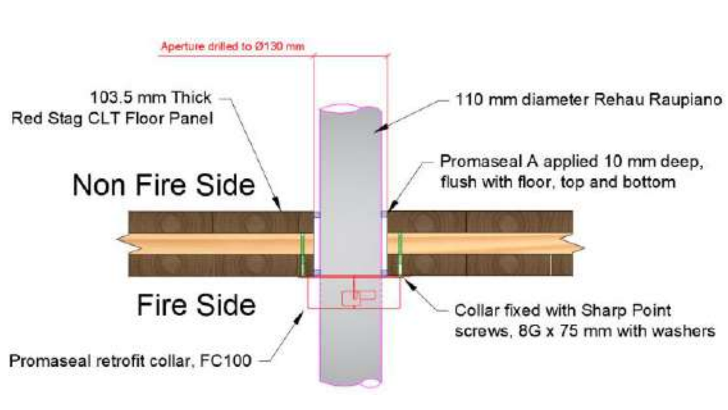
Red Stag Fire Rated Penetration Detail for Ø75 mm Rehau Raupiano Pipe

Type of service penetration	75 mm Diameter Rehau Raupiano Pipe
Fire stopping system	Promaseal A Promaseal FC80 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)-	-/60/60



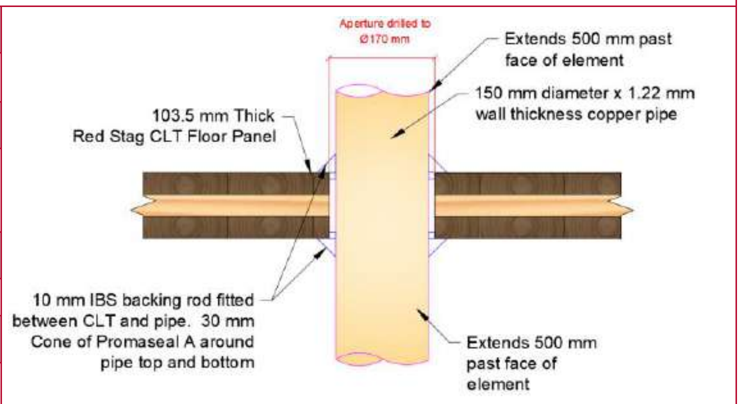
Red Stag Fire Rated Penetration Detail for Ø110 mm Rehau Raupiano Pipe

Type of service penetration	110 mm Diameter Rehau Raupiano Pipe
Fire stopping system	Promaseal A Promaseal FC100 Collar
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



Red Stag Fire Rated Penetration Detail for Ø150 mm Copper Pipe

Type of service penetration	150 mm Diameter Copper Pipe
Fire stopping system	Promaseal-A 10 mm IBS Backing
Type of CLT element	104 mm Red Stag CLT Floor
FRR (minutes)	-/60/60



23. Red Stag CLT Fire Spans

The fire report assessment based on the large scale structurally loaded experimental test has confirmed a 60 minute fire resistance for three-layer and five-layer load bearing Red Stag CLT floors (*Table 21* and *Table 22*). The large-scale CLT panel fire testing on Red Stag products based on AS 1530.4:2014 has been conducted by third-party testing facilities to determine the overall fire resistance and fire performance of the panels under structural loads. The third-party fire testing confirmed no structural, integrity or instability failure after more than 60 minutes at 900 degrees Celsius.

Table 21: Assessment outcome for loadbearing three (3) layer Red Stag CLT floors [a, b, 27]

Panel Title	Thickness	Layer 1	Layer 2	Layer 3	FRL
CLT3/103.5 [c]	103.5 mm	8 GPa, 34.5 mm	6 GPa, 34.5 mm	8 GPa, 34.5 mm	60/60/60
CLT3/126	126 mm	8 GPa, 42 mm	6 GPa, 42 mm	8 GPa, 42 mm	60/60/60
CLT3/135	135 mm	8 GPa, 45 mm	6 GPa, 45 mm	8 GPa, 45 mm	60/60/60

a. Three (3) layer Red Stag CLT floor systems may consist of either spline or lap joints.
b. Both surfaces of the three (3) layer Red Stag CLT floor systems were unprotected during the fire event.
c. Experimentally tested [27].

Table 22: Assessment outcome for loadbearing five (5) layer Red Stag CLT floors [a, b, 27]

Panel Title	Thickness	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	FRL
CLT5/130 [c]	130 mm	8 GPa, 35 mm	6 GPa, 20 mm	6 GPa, 20 mm	6 GPa, 20 mm	8 GPa, 35 mm	60/60/60
CLT5/166	166 mm	8 GPa, 42 mm	6 GPa, 20 mm	6 GPa, 42 mm	6 GPa, 20 mm	8 GPa, 42 mm	60/60/60
CLT5/210	210 mm	8 GPa, 42 mm	6 GPa, 42 mm	6 GPa, 42 mm	6 GPa, 42 mm	8 GPa, 42 mm	60/60/60

a. Five-layer Red Stag CLT floor systems may consist of either spline joint or lap joint.
b. Both surfaces of the five-layer Red Stag CLT floor systems were unprotected during fire event.
c. Experimentally tested [27].

to summarise the expected structural fire capacity of the Red Stag CLT floors considering different laminations, loading conditions and FRR. The tables are developed based on the third-party assessment with specific super imposed dead and live load for 30 minute or 60 minute FRR. The calculations for three (3) layer and five (5) layer CLT panels have been developed based on the full size experimental fire test results of three and five layer Red Stag CLT panels.

Table 23: Maximum span for three (3) layer simply supported single span Red Stag CLT floor panel for 30 minutes FRR [a] [28]

Panel Title	Applied Load (kPa)								
	Super Imposed Dead Load 0.5 kPa			Super Imposed Dead Load 1 kPa			Super Imposed Dead Load 2 kPa		
	Live Load (Imposed Load)			Live Load (Imposed Load)			Live Load (Imposed Load)		
	2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa
CLT 3/104	3.30 m	3.00 m	2.40 m	3.00 m	2.80 m	2.30 m	2.60 m	2.50 m	2.10 m
CLT 3/126	3.80 m	3.60 m	2.80 m	3.50 m	3.30 m	2.70 m	3.10 m	2.90 m	2.50 m

a. Three-layer Red Stag CLT floor design assumes an unprotected surface during fire event.

Table 24: Maximum span for three (3) layer simply supported single span Red Stag CLT floor panel for 60 minutes FRR [a] [28]

Panel Title	Applied Load (kPa)								
	Super Imposed Dead Load 0.5 kPa			Super Imposed Dead Load 1 kPa			Super Imposed Dead Load 2 kPa		
	Live Load (Imposed Load)			Live Load (Imposed Load)			Live Load (Imposed Load)		
	2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa
CLT 3/104	3.00 m	3.00 m	2.40 m	3.00 m	2.80 m	2.30 m	2.60 m	2.50 m	2.10 m
CLT 3/126	3.60 m	3.20 m	2.40 m	3.20 m	3.00 m	2.30 m	2.70 m	2.50 m	2.10 m

a. Three-layer Red Stag CLT floor design assumes an unprotected surface during fire event.

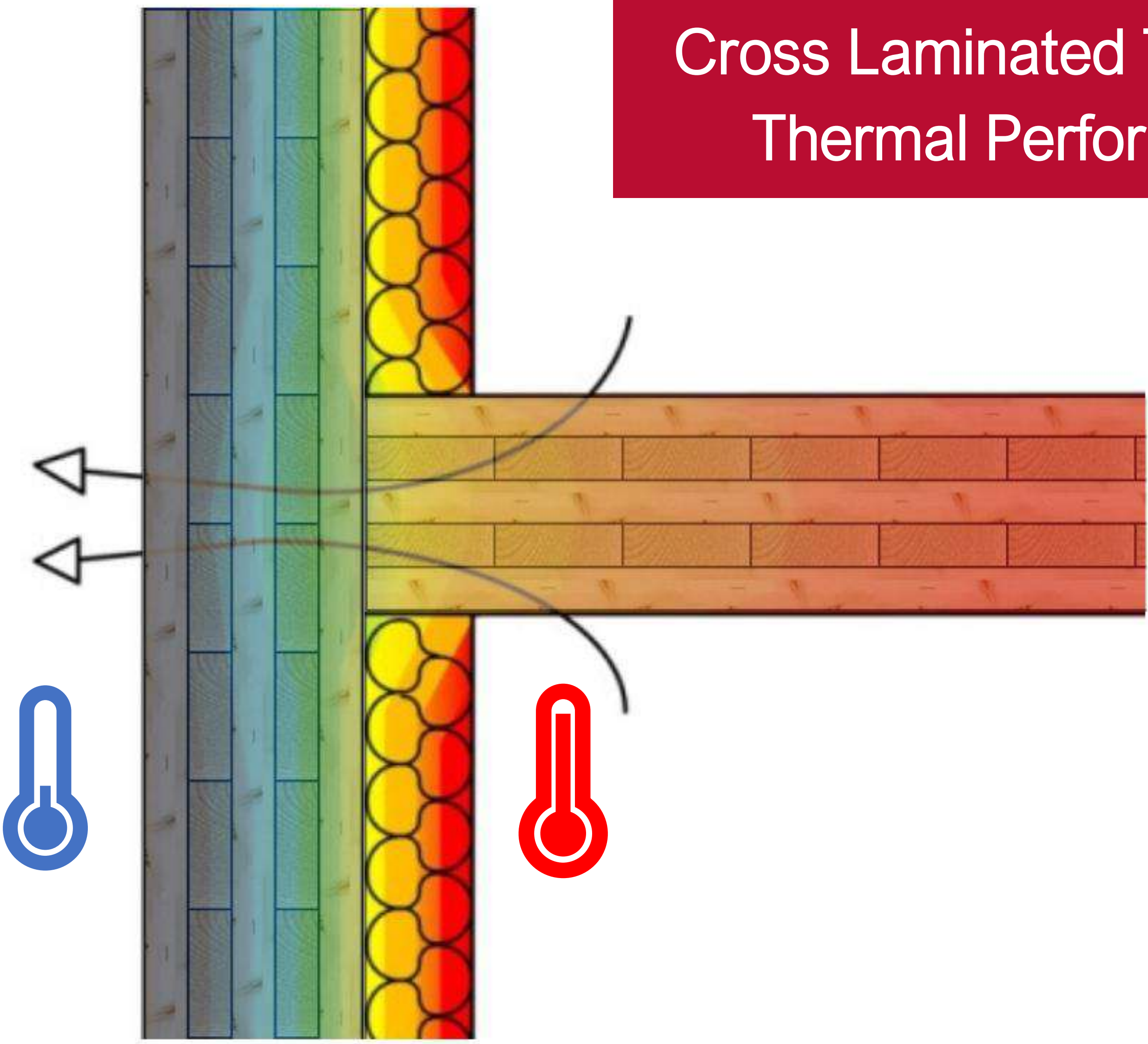
Table 25: Maximum span for five (5) layer simply supported single span Red Stag CLT floor panel for 30 or 60 minutes FRR [a] [29]

Panel Title	Applied Load (kPa)								
	Super Imposed Dead Load 0.5 kPa			Super Imposed Dead Load 1 kPa			Super Imposed Dead Load 2 kPa		
	Live Load (Imposed Load)			Live Load (Imposed Load)			Live Load (Imposed Load)		
	2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa	2 kPa	3 kPa	5 kPa
CLT 5/166	4.90 m	4.60 m	3.70m	4.50 m	4.30 m	3.60 m	4.00 m	3.80 m	3.30 m
CLT 5 /210	5.60 m	5.30 m	4.40 m	5.30 m	5.00 m	4.20 m	4.70 m	4.50 m	3.90 m

a. Five-layer Red Stag CLT floor design assumes an unprotected surface during fire event.

Section 5

Cross Laminated Timber Thermal Performance



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24. CLT Thermal Performance & Energy Efficiency

A significant benefit of CLT is its thermal performance. CLT is a solid monolithic timber system, with a relatively airtight configuration generated by glued layers of perpendicular lamella (boards) [30]. The natural insulative properties of timber, combined with the airtightness and mass of CLT creates a high performing thermal system compared to most other structural construction materials (Refer to *Figure 67* and *Figure 5* to *Figure 7* in Section 1).

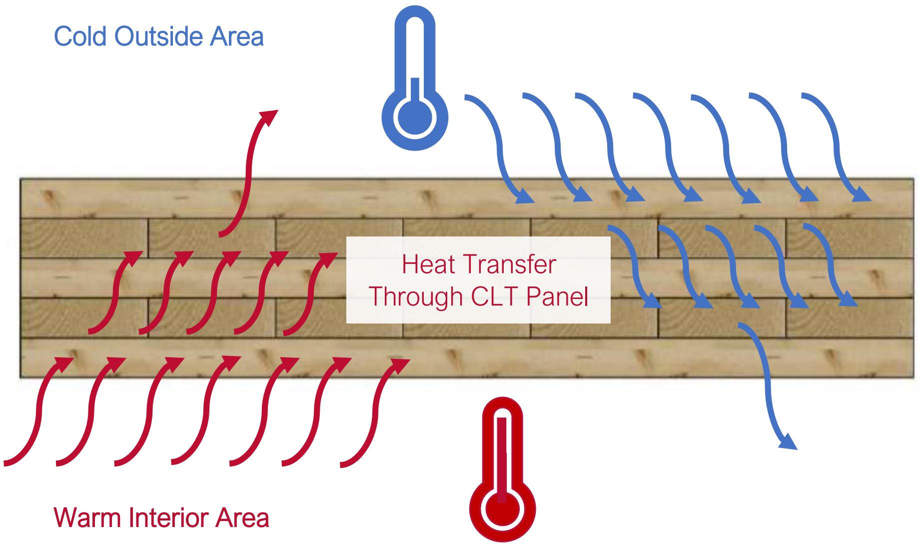

Figure 67: Thermal performance of the CLT building

The Red Stag CLT production process utilises face gluing with side hydraulic pressure to minimise the gap in boards in each layer to optimise the air tightness as much as practically possible [31] (Refer to *Figure 68* and *Figure 69*).

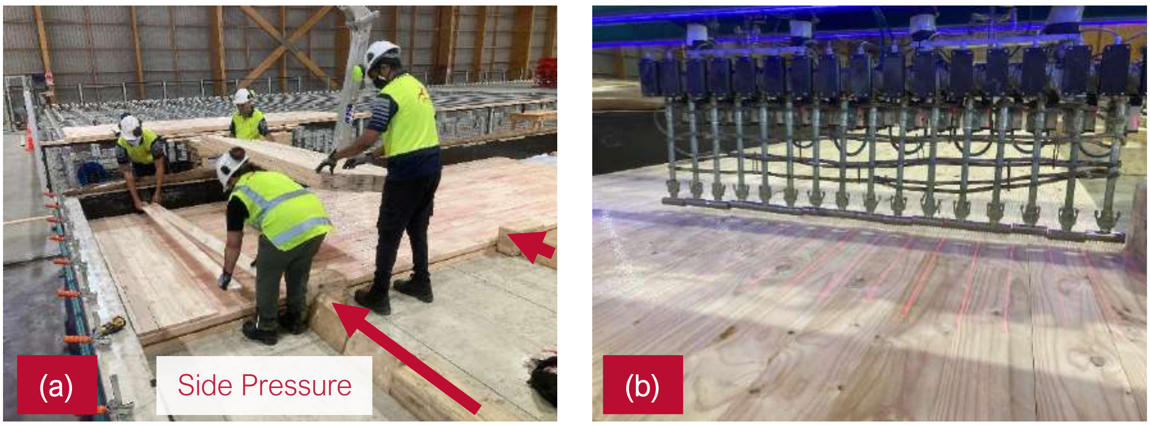

Figure 68: Red Stag Manufacturing line; (a) Layer arrangement with side pressure, (b) Adhesive distribution, (c) Hydraulic side pressure and Vacuum Membrane, (d) Final Red Stag CLT Product.

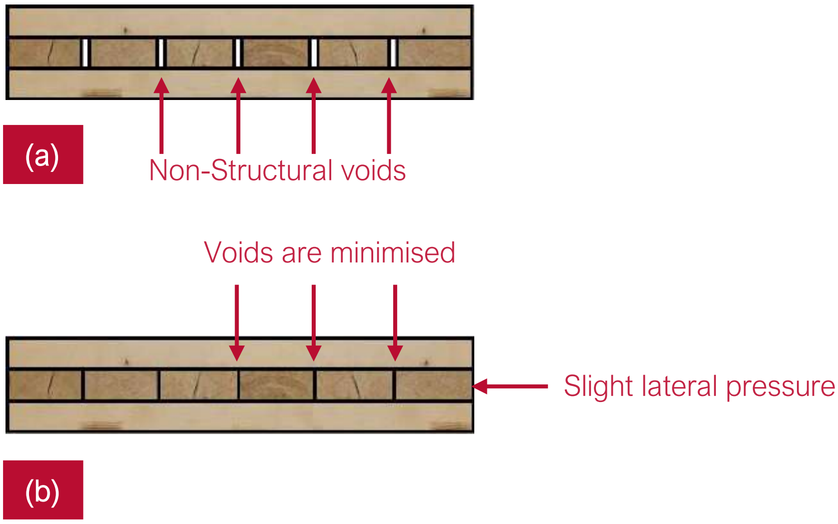

Figure 69: CLT panel manufacturing with and without lateral pressure.
a) CLT panel with non-structural voids, b) CLT panel with lateral pressure to minimise voids.

The advanced planing facilities at Red Stag generate edge tolerances of +/- 0.1 mm to further support the airtightness between lamellas.

CLT billets are then machined into panels using specialty large scale CNC equipment (*Figure 70*). Red Stag's CNC equipment can machine to precise tolerances, for panel joints and penetrations. The tight CNC tolerances allow for all jointing and penetrations to minimise airflow, supporting in generating an extremely tight building envelope.

Figure 70: CNC equipment with precise cutting capability.

CLT buildings trap in heat and regulate the internal environment and airflow up to 90 percent more efficiently than traditional structures. The increased thermal performance is primarily achieved by the high thermal mass of CLT systems. This results in the building temperature being stable throughout the day, keeping the structure warm in winter and cool in the summer, greatly reduce heating and cooling costs. The insulation performance of CLT structures can reduce the need for additional insulation and associated secondary costs.

24.1. Thermal Performance of Red Stag CLT

Thermal conductivity is a measure of the heat flow via conduction through a cross section of a material when a temperature gradient exists. The thermal conductivity of structural wood is much less than the conductivity of metals. The conductivity of structural softwood at 12 percent moisture content is in the range of 0.12 to 1.196 W/mK compared with 230 for aluminium, 50 for steel, 1.6 for concrete, 1.05 for glass, 1 for plaster, and 0.0.22 for Gypsum plasterboard [33], [41].

Red Stag CLT is a solid wood product, providing thermal mass. The key measure of CLT's thermal performance is the R-Value (insulating ability), which is related to the CLT panel thickness. The thicker the CLT, the greater the R-value or thermal performance.

The commonly used R-value for wood is 0.120 W/mK per 18 mm of thickness. On that basis, a 210 mm thick Red Stag CLT panel would have an R-Value of 1.75 m^2·°C/W. Softwood in general has approximately one-third the thermal insulating performance of a comparable thickness of fiberglass batt insulation, but approximately 10 times that of concrete and masonry, and 400 times that of solid steel [32],[34].

Table 26 to *Table 28* detail the thermal resistance (R-value) of CLT for various thicknesses of Red Stag CLT [35].

Table 26: Approximate R-Value of Three (3) Layer Red Stag CLT Panels		
Recipe Priority [a]	1	2
Panel Recipe	CLT 3/126	CLT 3/104
Layer 1, Radiata Pine	42 mm	42 mm
Layer 2, Radiata Pine	42 mm	20 mm
Layer 3, Radiata Pine	42 mm	42 mm
Panel Thickness	126 mm	104 mm
Thermal Resistance (R-Value) [b, 42]	1.05 m^2·°C/W	0.86 m^2·°C/W
Conductivity [b, 42]	0.84 W/mK	0.69 W/mK

a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.
b. Based on the NZS4214, Table E, softwoods (e.g. pine) at 12% moisture content, density of 450 kg/m^3, thickness of 18 mm, conductivity of 0.120 W/mK. The unit of measure is m^2·°C/W and assumes a single solid wood plank (Not CLT).

IMPORTANT: If a project is less than 200 m^3, Red Stag can only provide recipe priority 1 options unless agreed prior with the client. Recipe priority 2 or alternates are only available based on available feedstock and production capacity. If a project requires an alternate recipe to priority 1 options, please coordinate with Red Stag in advance.

Table 27: Approximate R-Value of Five (5) Layer Red Stag CLT Panels		
Recipe Priority [a]	1	2
Panel Recipe	CLT 5/210	CLT 5/166
Layer 1, Radiata Pine	42 mm	42 mm
Layer 2, Radiata Pine	42 mm	20 mm
Layer 3, Radiata Pine	42 mm	42 mm
Layer 4, Radiata Pine	42 mm	20 mm
Layer 5, Radiata Pine	42 mm	42 mm
Panel Thickness	210 mm	166 mm
Thermal Resistance (R-Value) [b, 42]	1.75 $m^2 \cdot °C/W$	1.38 $m^2 \cdot °C/W$
Conductivity [b, 42]	1.40 W/mK	1.10 W/mK

a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.
b. Based on the NZS4214, Table E, softwoods (e.g. pine) at 12% moisture content, density of 450 kg/m^3, thickness of 18 mm, conductivity of 0.120 W/mK. The unit of measure is $m^2 \cdot °C/W$ and assumes a single solid wood plank (Not CLT).

Table 28: Approximate R-Value of Seven (7) Layer Red Stag CLT Panels		
Recipe Priority [a]	1	2
Panel Recipe	CLT 7/294	CLT 7/228
Layer 1, Radiata Pine	42 mm	42 mm
Layer 2, Radiata Pine	42 mm	20 mm
Layer 3, Radiata Pine	42 mm	42 mm
Layer 4, Radiata Pine	42 mm	20 mm
Layer 5, Radiata Pine	42 mm	42 mm
Layer 6, Radiata Pine	42 mm	20 mm
Layer 7, Radiata Pine	42 mm	42 mm
Panel Thickness	294 mm	228 mm
Thermal Resistance (R-Value) [b, 42]	2.45 $m^2 \cdot °C/W$	1.90 $m^2 \cdot °C/W$
Conductivity [42]	1.96 W/mk	1.52 W/mk

a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.
b. Based on the NZS4214, Table E, softwoods (e.g. pine) at 12% moisture content, density of 450 kg/m^3, thickness of 18 mm, conductivity of 0.120 W/mK. The unit of measure is $m^2 \cdot °C/W$ and assumes a single solid wood plank (Not CLT).

Section 6

Cross Laminated Timber Penetrations & Chasing

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25. Penetrations and Chasing Through CLT

CLT floor systems support in simplifying the installation of utilities and services, to reduce time and cost on-site. This can include, but not be limited to mechanical and HVAC ducting, plumbing services, electrical, etc (Refer to *Figure 71*).

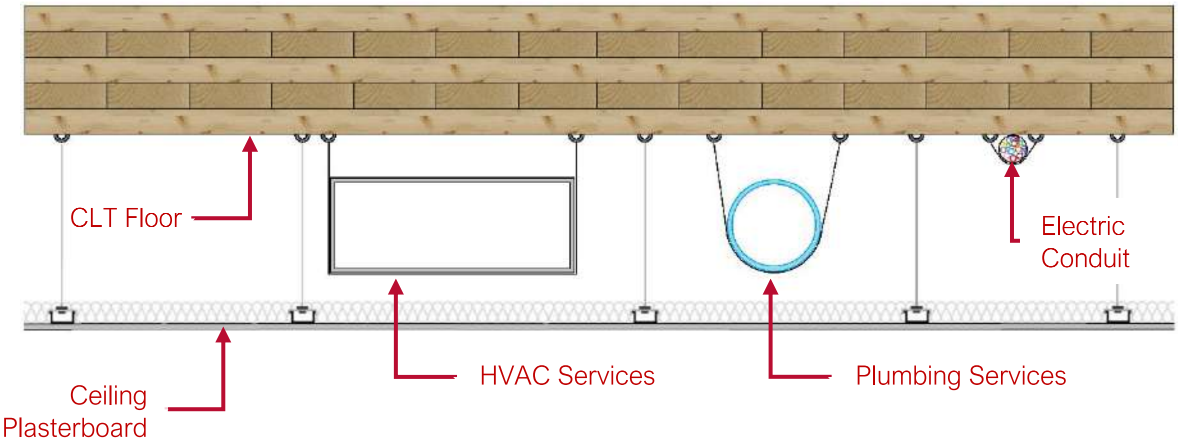
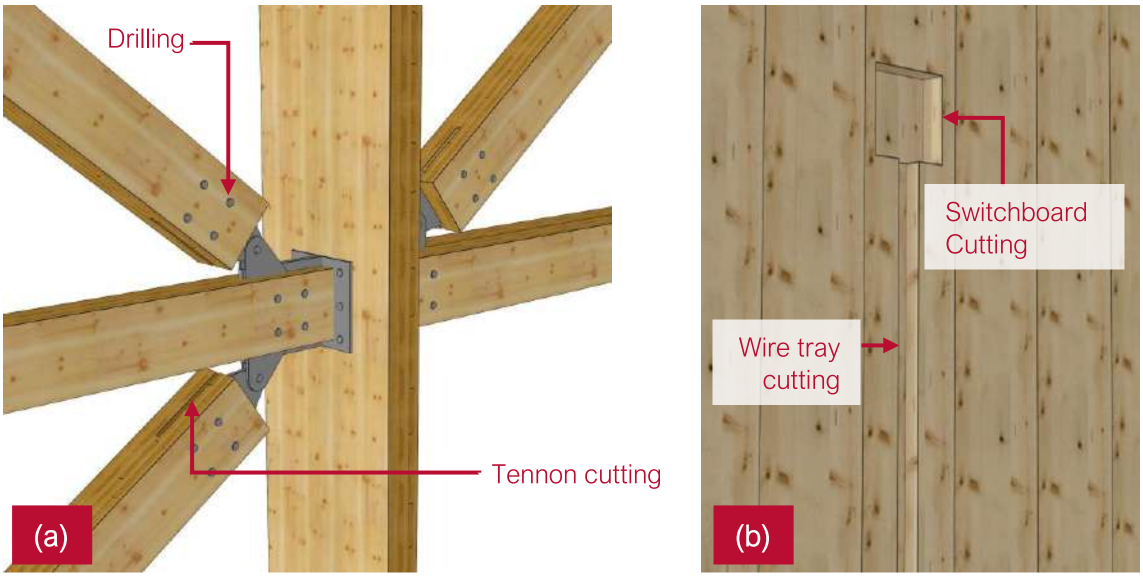


Figure 71: Cross-section view of suspended or direct fix utilities under CLT floor systems.

Depending on the design, the underside of CLT floors can be left exposed. Suspended ceiling or bulkheads could be used where services are to be concealed (e.g., bathroom and wet areas).

Depending on the connection details, or system design, more complex jointing or machining may be required in factory via advance CNC processing. Examples of more detailed machining options are illustrated in *Figure 72*.



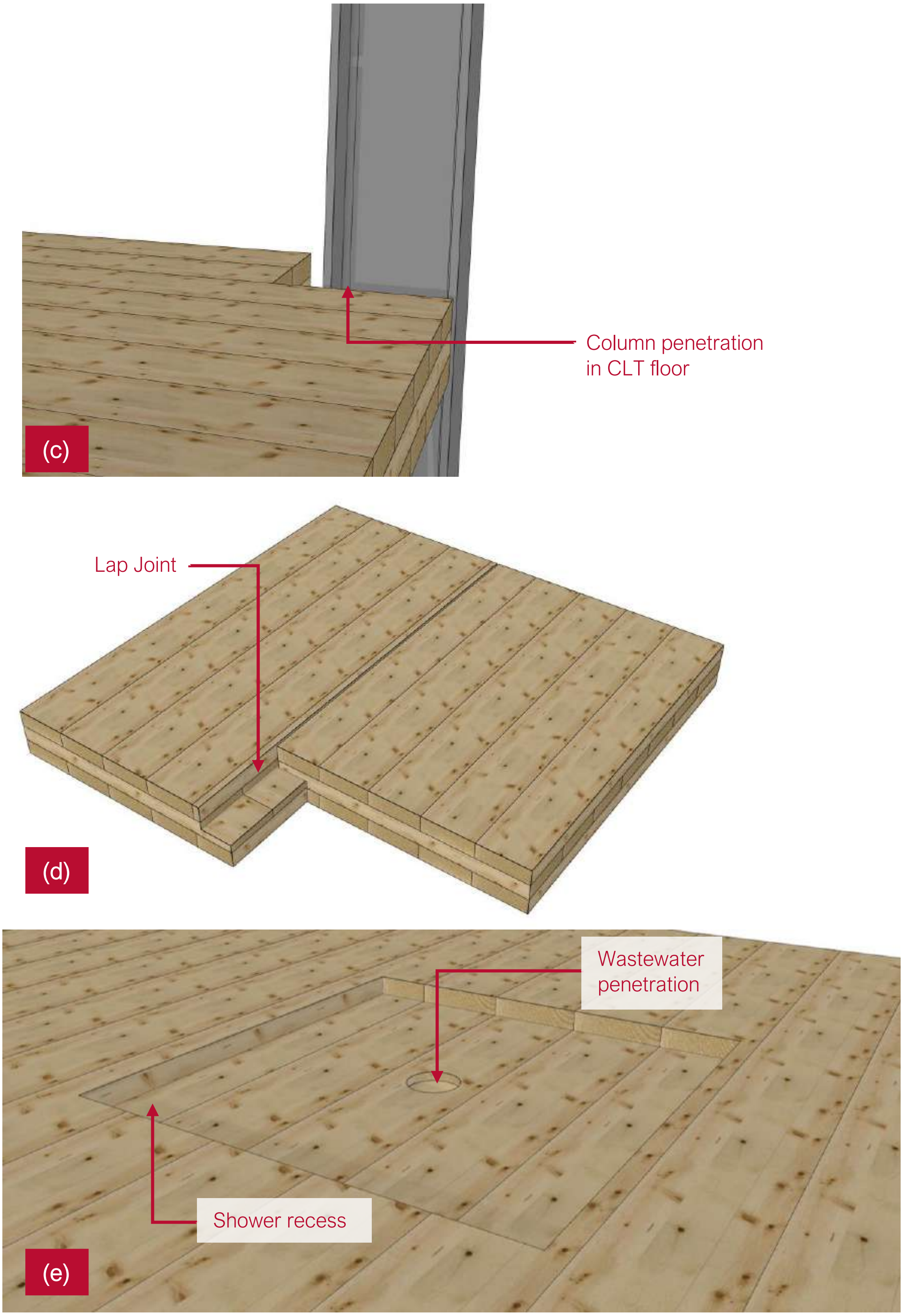


Figure 72: Penetrations and chasing through the Red Stag CLT panels. a) Slots and drilling for CLT members (beam, column and bracings, b) Electrical penetrations for walls, c) Column penetrations in floors, d) Lap joint, e) Shower tray.

Section 7

Cross Laminated Timber Quality Assurance

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26. Red Stag Routine EWP Quality Assurance

Red Stag has a comprehensive Quality Assurance (QA) programme for its manufacturing processes. The QA system is supported by Red Stag Standard Operating Procedures (SOP) and qualified by the programmes routine testing.

26.1 Finger Joint Quality Assurance

Each production batch should have no less than three FJ tests completed. The specimens should be drawn as evenly as practically possible over the production batch. If a production batch extends across multiple shifts, no less than three specimens should be drawn from each production shift.

Red Stag has invested in high quality testing equipment to confirm the quality of FJ. The testing equipment includes a high-capacity hydraulic press with speed-controlled ram for standard testing, calibrated load cell and associated digital display to show the applied load in kN to two decimal places (refer to *Figure 73).*

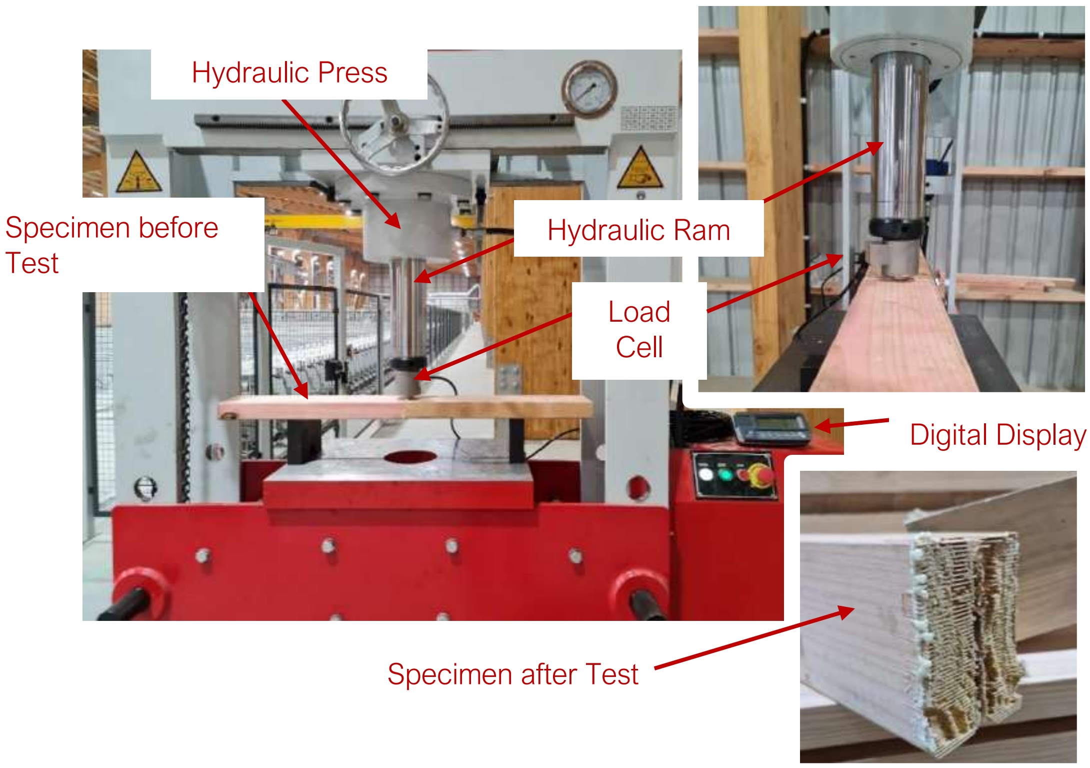


Figure 73: FJ test set-up.

26.1.1 Red Stag Finger Joint Test Report

Red Stag will maintain a documented QA programme to ensure conformance with the AS/NZS 1491:1996 standard. An example of the Red Stag test report for FJ testing is shown in *Figure 74*.

RED STAG WOOD SOLUTIONS	Finger Joint Test Report	
	Project No:	
	Billet No:	
Date of Test		Test No.:
Dimension of specimen	Width	Thickness
Species of Timber	Radiata Pine	
Timber Treatment	H1.2	
Moisture Content		
Type of adhesive	Henkel Purbond HB	
Test method	AS/NZS 1491.1996	
Test Result (kN)		MOR
Failure Mode Criteria		
Relevant Test Observation Notes:		
Tester Name:		
Tester Signature:		
Red Stag Wood Solutions Ltd.	10/06/2022 10:07	

Figure 74: Example of the Red Stag FJ test report.

26.2 Delamination Test

To confirm the lamination bond quality of EWP, Red Stag has a comprehensive testing procedure for sampling, testing, and documenting.

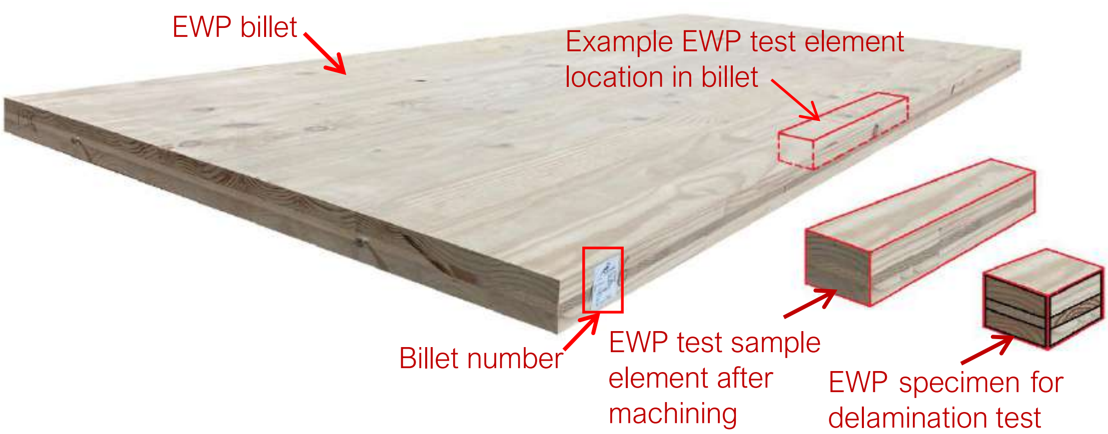


Figure 75: EWP delamination test specimen preparation.

Red Stag has invested in highly advanced automated delamination testing technology. The testing equipment comprises of a pressure vessel and drying chamber. The vessel has a pressure rating in excess of 600 kPa positive pressure and 85 kPa under vacuum. The system has a pressure pump and venturi for applying positive and negative pressure respectively up to the rating of the vessel. The drying chamber circulates heated air at a velocity range of 2 - 3 m/s, with a temperature range of 65 - 75 °C and a relative humidity range from 8 - 10 % (Refer to the *Figure 76*).

Figure 76: Delamination testing equipment.

26.2.1. Red Stag Delamination Test Report

Red Stag maintain a documented QA programme to ensure conformance with the Annex A of BS EN 16351:2021 or AS/NZS 1328.1 standards. The following items are reported:

a) Reference to the European Standard.
b) Date of the test.
c) Identification of test pieces and EWP billet/member from which the sample was taken.
d) Preservative treatment (if relevant).
e) Species of timber.
f) Type of adhesive and trade name.
g) Effective proportion of resin and hardener/reactive agent (if relevant).

h) Sizes of the test piece.

i) Linear measurement of all glue lines.

j) The total delamination length and the maximum delamination length.

k) Any relevant observation linked to the testing.

l) Name and signature of the person responsible for the testing.

27. Red Stag Third Part EWP Quality Testing

27.1 Overview

In addition to internal routine EWP quality assurance testing, Red Stag has a third party testing programme for its manufactured EWP. Red Stag has a routine monthly and annual testing plan to confirm the quality of the bonding in structural FJ, and EWP elements. In parallel, Red Stag conducts large scale testing of its EWP by certified third parties such as SCION[8] an annual basis[ii] to ensure the mechanical and structural performance of Red Stag EWP (refer to *Figure 77* and *Figure 78*).

Figure 77: SCION Research Centre. SCION is a New Zealand Crown Research Institute (CRI) that specialises in research, science and technology development for the forestry, wood product, wood-derived materials, and other biomaterial sectors.

Figure 78: BRANZ Research Campus. BRANZ is an independent research organisation that uses an impartial evidence-based approach to improving the performance of the New Zealand building systems.

[ii] Testing is targeted to be completed annually in the first quarter of each year with SCION or an equivalent third party subject to their other testing commitments.

28.1 EWP Mechanical Performance Testing

Red Stag manufactured EWP elements and associated feedstock have been tested by professional, certified third parties to ensure the durability, mechanical strength, and fire resistance. As shown in *Figure 79* to *Figure 81,* a series of large-scale experimental tests have been conducted on Red Stag CLT products to verify the quality and performance. Destructive large-scale four-point bending tests conducted by SCION confirm that Red Stag CLT panels exceed the stiffness and strength requirements to carry applied structural loads (refer to *Figure 79*). Testing on short, intermediate, and long-span CLT panels show exceptional structural performance under shear force, bending moment, and combination of the two.

Figure 79: Large scale mechanical testing conducted by SCION; (a) Long span testing; (b) Medium span testing; (c) Short span testing.

28.2 EWP Glue Bond Performance Testing

Red Stag EWP glue bond quality and durability has been assessed by delamination testing with third-party specialists. Testing is being primarily conducted in the Red Stag laboratory, with supplementary parallel spot testing completed by third parties at no less than one sample per week (refer to *Figure 80*). Third-party testing confirms an average delamination percentage under the standard allowable limit, confirming the glue line bonds are sufficiently durable. In addition to the delamination testing, repeated large-scale bending tests conducted by SCION verify that there are no adverse issues associated with glue line performance. No glue line failure or board separation was observed during all deflection testing.

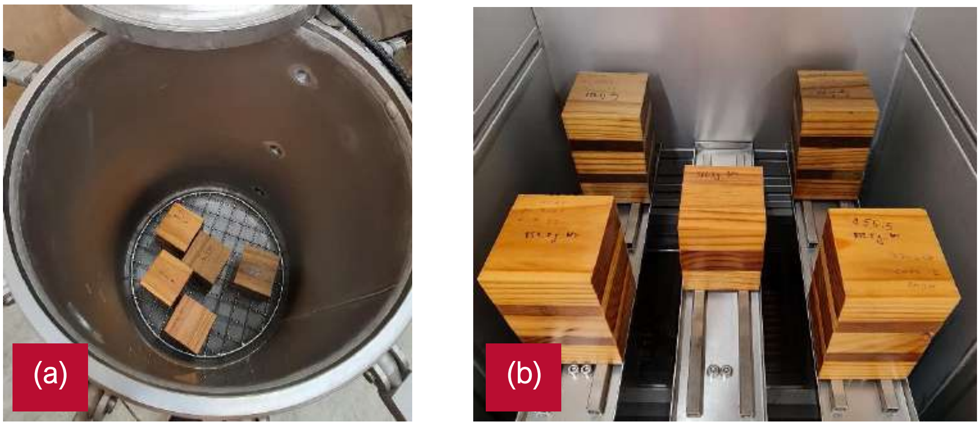


Figure 80: Delamination testing equipment; a) EWP specimens in pressure vessel; b) EWP specimens in drying chamber.

28.3 EWP Fire Performance Testing

The Fire Code is formulated to permit time for occupants to safely leave a burning building before structural collapse or succumbing to heat or smoke inhalation. The code stipulates that the safe evacuation period of up to 60 minutes in New Zealand will cover the majority of building types and uses. Large-scale CLT panel fire testing has been conducted by Red Stag to determine the overall fire resistance and fire performance of panels under structural loads (Refer to *Figure 81*). CLT test specimens were installed in a furnace to investigate parameters such as the structural performance during a fire event, temperature profile and deflection. BRANZ fire testing confirmed no structural, integrity or instability failure after more than 60 minutes at 900 degrees Celsius.

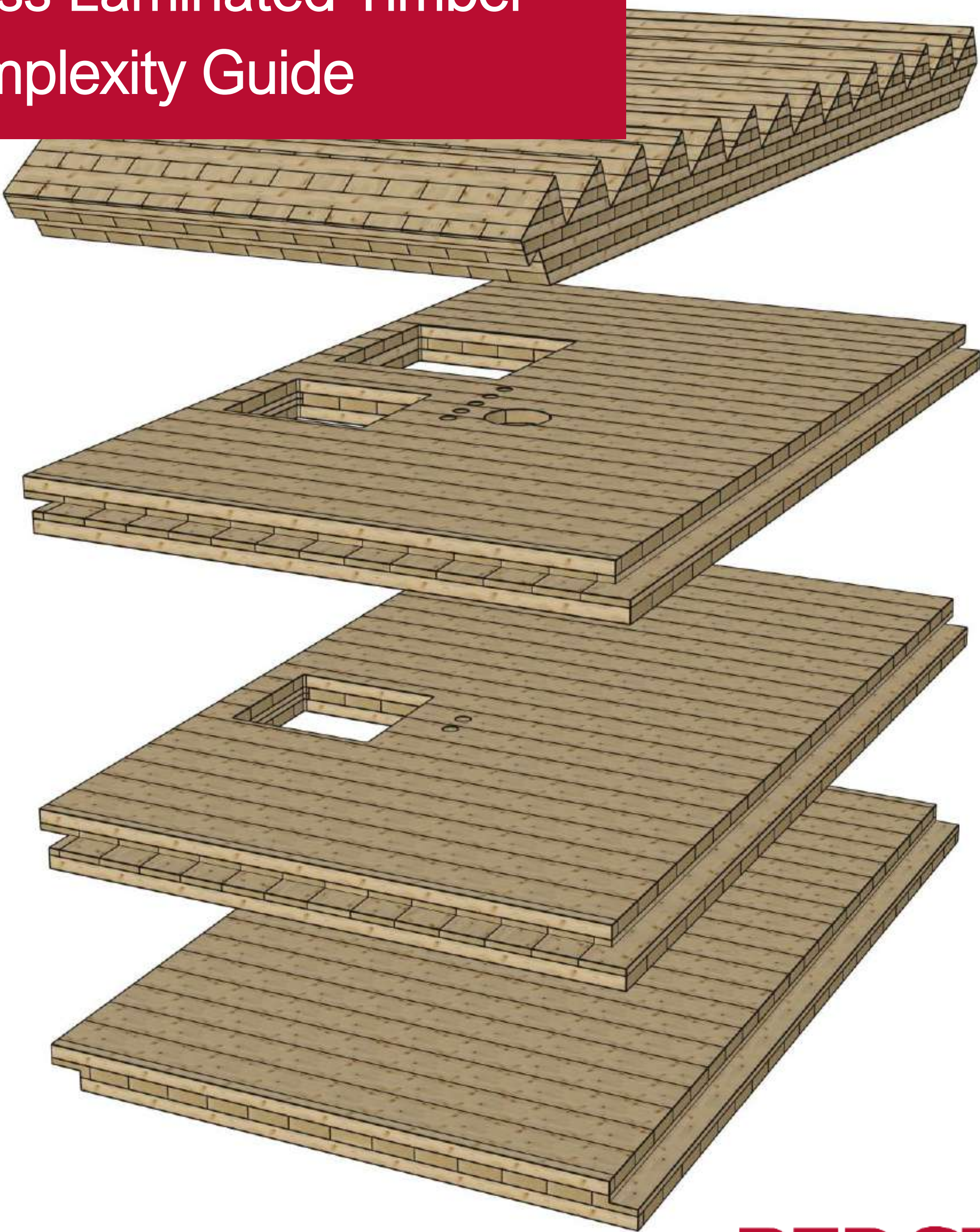
Figure 81: Large-scale fire testing on Red Stag EWP conducted by BRANZ; (a) Red Stag CLT floor test specimen after fire testing; (b) Red Stag CLT wall test specimen before fire testing.

29. Reports, Assessments and Guides

Red Stag has wide range of documents to support projects based the test reports and calculations. Supporting documents include but are not limited to: Red Stag Design Guide, Red Stag Project Guide, and Red Stag Regulatory Fire Information Report 1.1.

Section 8

Cross Laminated Timber Complexity Guide



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The CLT panel complexity is influenced by two characteristics:

- How difficult the project is to digitally model.
- How difficult each element is to manufacture (grading, recipe, machining, ancillary processing and finishing, etc).

The complexity of Red Stag EWP elements is defined in no less than six categories: basic, standard, moderate, difficult, very difficult, and extreme.

30.1 Complexity of Red Stag EWP Elements Based on Type

The definition of complexity generally varies based on the element type:

30.1.1. Floors
30.1.2. Walls/Roofs
30.1.3. Stairs
30.1.4. Beams

Basic processing is the same for all element types. Typically, floors require the least processing and stairs/beams (other than simple beams) typically require the most complex processing.

30.2 Basic Complexity Red Stag EWP Elements

Basic complexity only includes plumb trim cuts processed via the three axis saw around the billet perimeter. Basic complexity excludes shop drawings and all other forms of processing (no milling, jointing, penetrations, lifting fixing positions, etc) and excludes all other forms of jointing and penetrations (refer to *Figure 82*).

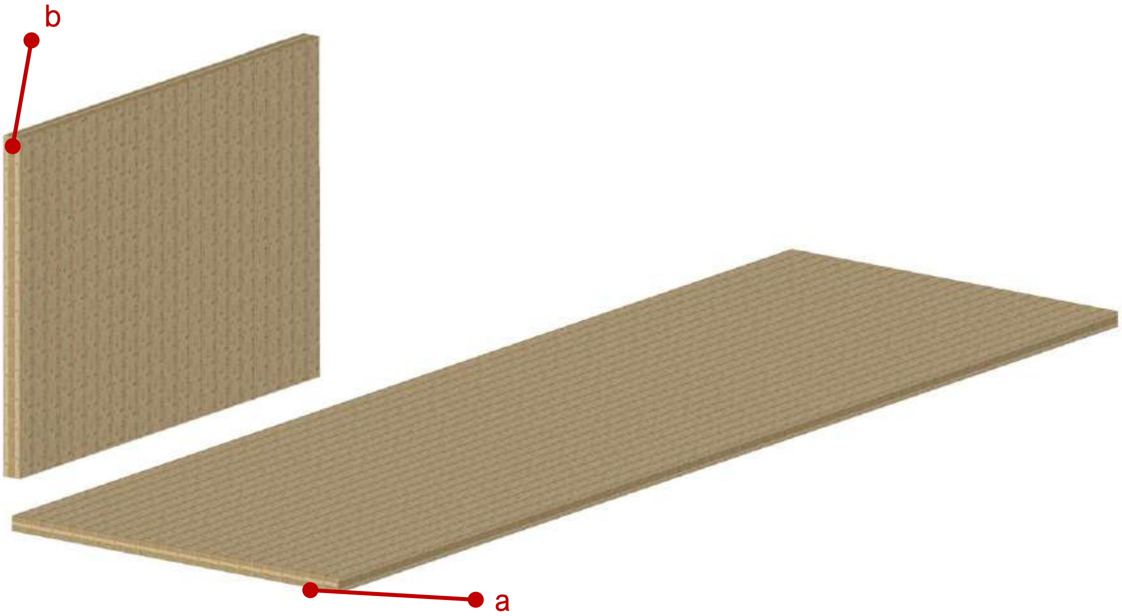


Figure 82: Example of basic complexity processing of Red Stag EWP elements; a) Corner of basic complexity Red Stag CLT floor panel; b) Corner of basic complexity Red Stag CLT wall panel.

30.3 Standard Complexity Red Stag EWP Elements

Standard complexity includes basic processing, plus lifting fixing positioning and two edge jointing without the need to flip elements. Jointing options include upper face spline board [iii] interfaces and up to 80 mm wide half lap joints accessible on the top face and underside lap joints accessible from the edge without the need to flip panels or remove adjacent elements prior to processing. No face processing is included other than the required lifting system positioning (refer to *Figure 83*).

[iii] Spline boards are not included in the Red Stag scope of supply unless specifically included in the ancillary pricing and project specific tags as being included as an option.

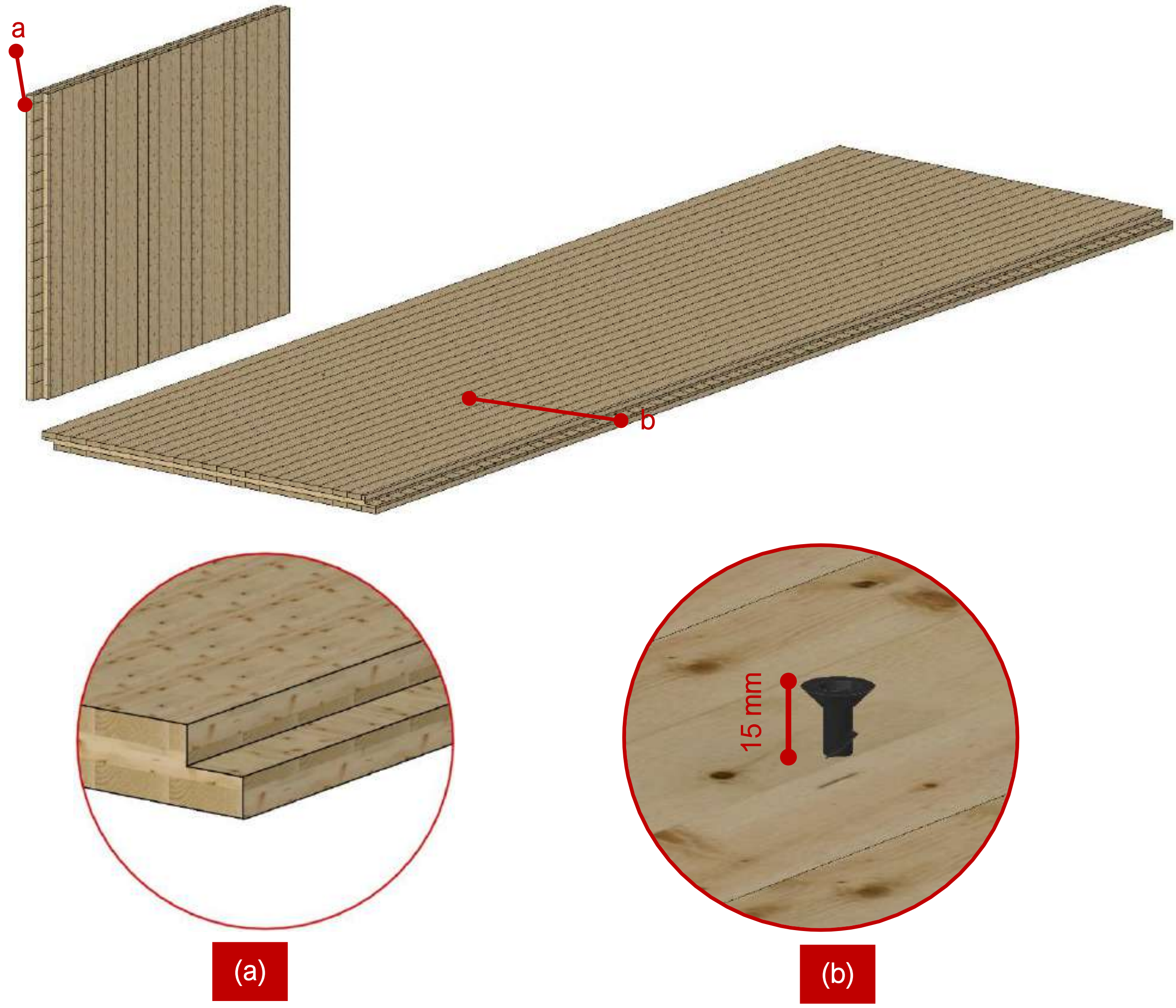


Figure 83: Example of standard complexity processing; a) Two edge lap/spline joint rebate (maximum 80 mm wide), requiring no panel flipping or adjacent panel movement; b) Predrilling/installation of lifting screws.

30.4 Moderate Complexity Red Stag EWP Elements

Moderate complexity includes four edge jointing without the need to flip elements. Jointing options include upper face spline board [i] interfaces and up to 80 mm wide half lap joints accessible on the top face and underside lap joints accessible from the edge without the need to flip panels or remove adjacent elements prior to processing. Minor face processing (single side without the need for element flipping) up to three basic radial penetrations and up to one curved radii opening is included in the complexity reference (refer to *Figure 84*).

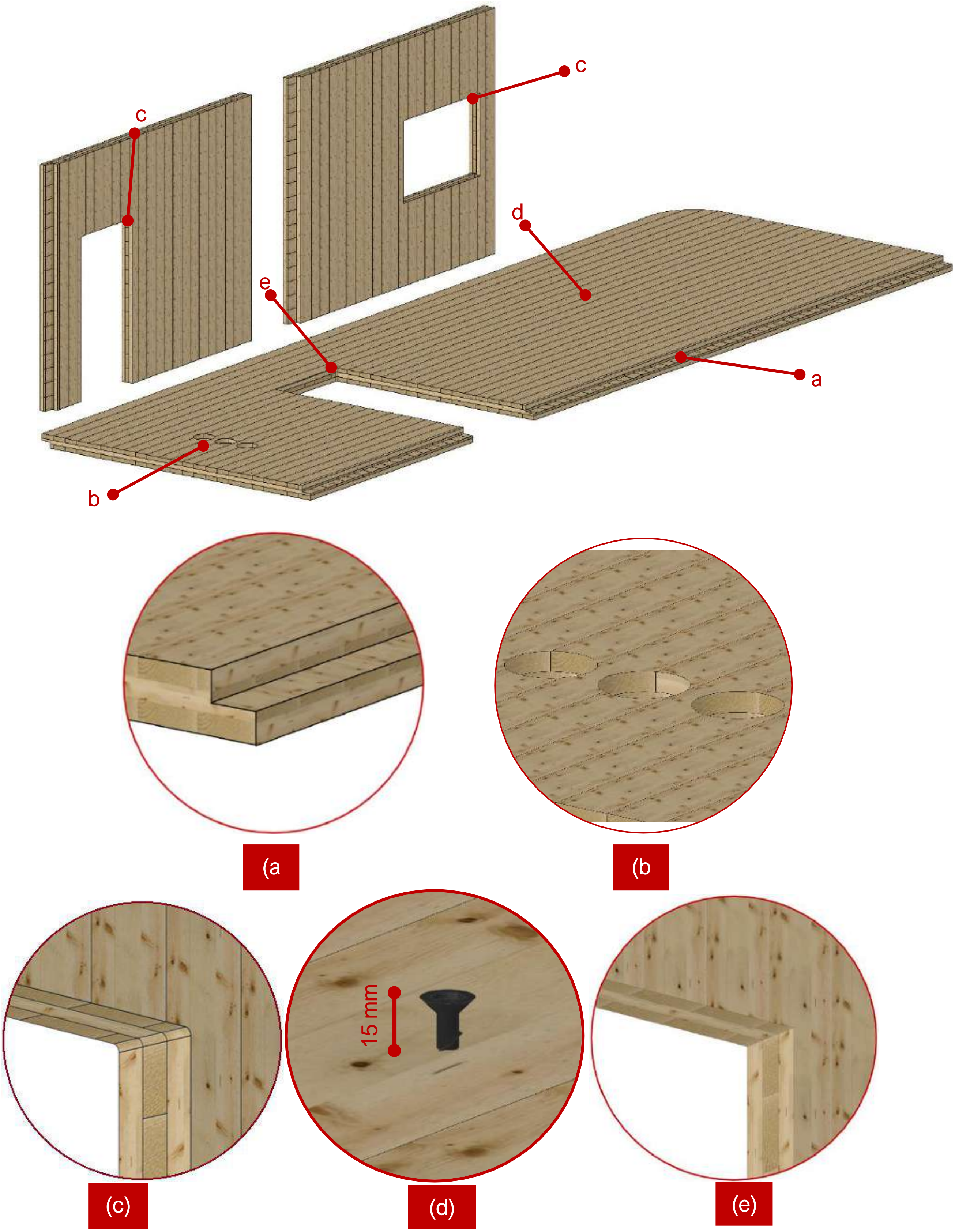
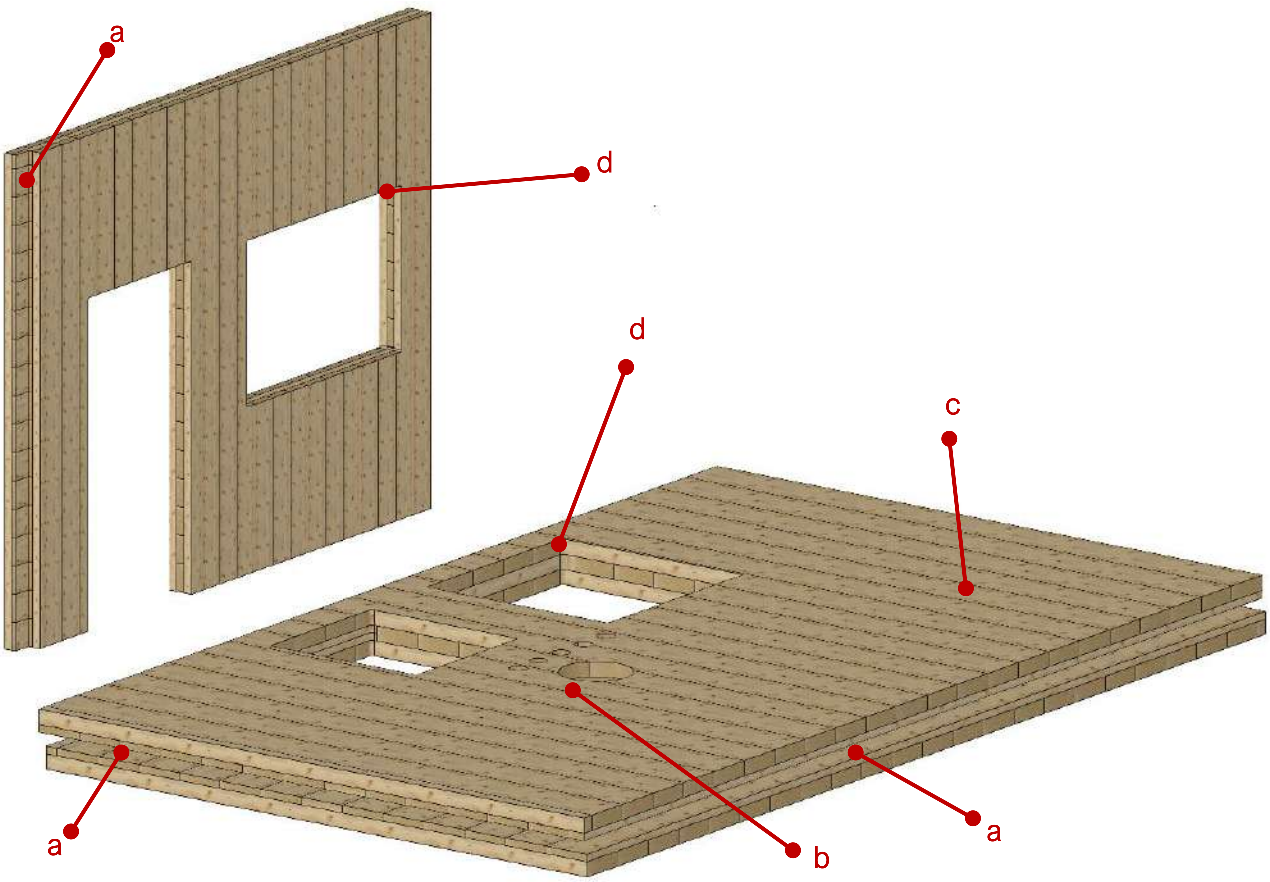


Figure 84: Example of moderate complexity processing of Red Stag EWP elements; a) Lap/spline joint rebate, b) Up to three standard circular penetrations; c) Up to one opening with corner radii transitions; d) Predrilling/installation of lifting screws.

30.5 Difficult Complexity Red Stag EWP Elements

Difficult complexity includes four edge jointing without the need to flip elements. Jointing options include upper face spline board [i] interfaces and up to 100 mm wide half lap joints accessible on the top face and underside lap joints accessible from the edge without the need to flip panels or remove adjacent elements prior to processing. Moderate face processing (single side without the need for element flipping) up to six basic radial penetrations and up to two curved radii openings or one square cornered opening is included in the complexity reference (subject to tooling limitations). No recessing or secondary rebating other than perimeter joints is included (refer to

Figure 85).



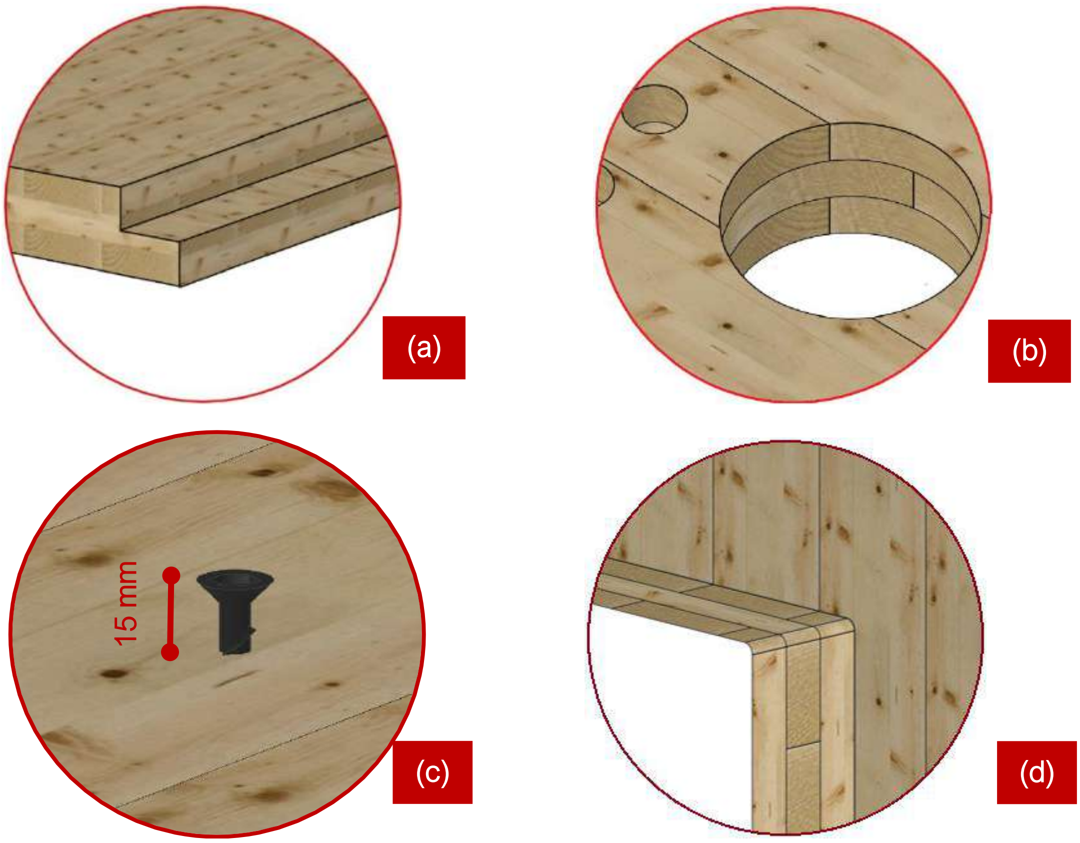


Figure 85: Example of difficult complexity processing of Red Stag EWP elements; a) Lap/spline joint rebate without flipping or panel removal up to 100 mm wide, b) Up to six simple radii penetrations over and above of basic fixing locators, c) Predrilling/installation of lifting screws/; d) Square penetration with radii corner.

30.6 Very Difficult Complexity Red Stag EWP Elements

Very difficult complexity includes four edge jointing without the need to flip elements. Jointing options include upper face spline board [i] interfaces and up to 120 mm wide half lap joints accessible on the top face and underside lap joints accessible from the edge without the need to flip panels or remove adjacent elements prior to processing. Reasonably extensive face processing (single side without the need for element flipping) up to eight basic radial penetrations and up to four curved radii openings or three square cornered openings (subject to tooling limitations) are included in the complexity reference. Up to two openings may be substituted for a moderate recess or trenched pathway (refer to *Figure 86*).

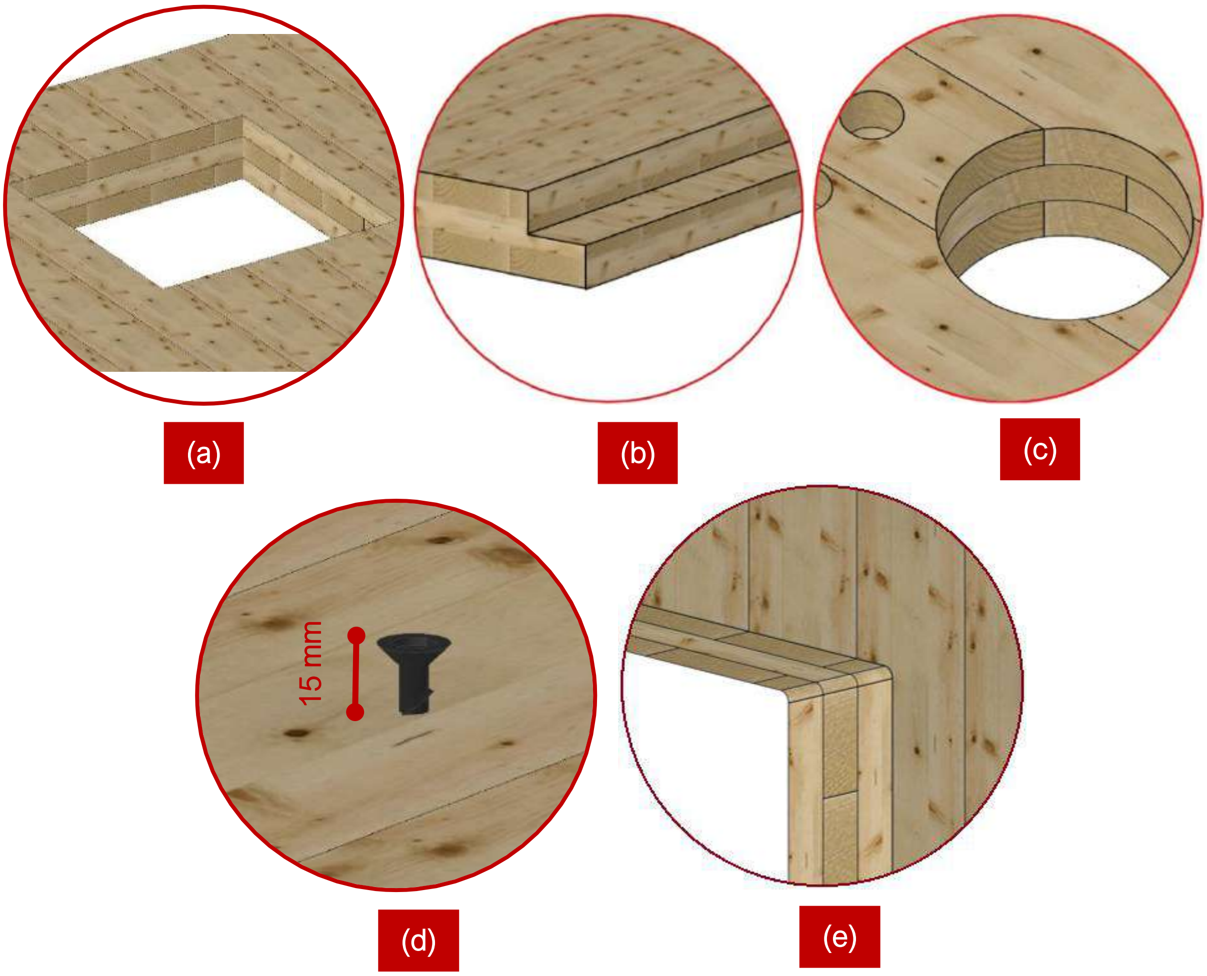


Figure 86: Example of very difficult complexity processing of Red Stag EWP elements; a) Up to three square cut outs (subject to minimum size for tooling); b) Lap/spline joint rebate without flipping or panel removal up to 120 mm wide; c) Up to six simple radii penetrations over and above of basic fixing locators; d) Predrilling/installation of lifting screws; e) Door or window corner on Red Stag CLT Wall Panel (either four radii openings or three-square openings).

30.7 Extreme Complexity Red Stag EWP Elements

In the largest majority of cases, Red Stag EWP element processing is managed from basic to very difficult; however, some elements require more processing time and will have an extreme classification. Extreme classifications are based on the estimated CNC time required to process the element, typically related to the volume of milling and drilling time (refer to *Figure 87*).

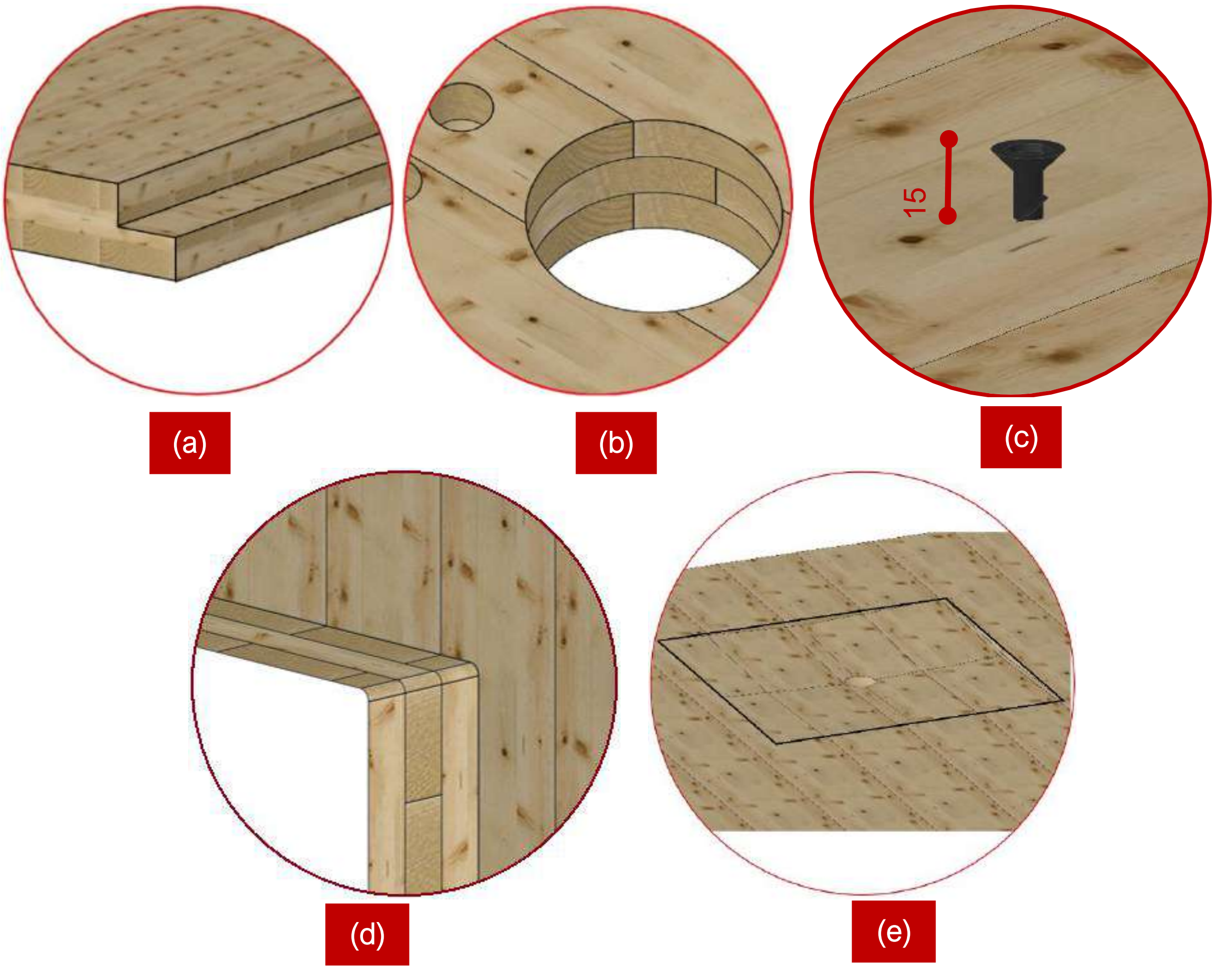


Figure 87: Example of extreme difficultly processing of Red Stag EWP elements; a) Lap/spline joint rebate without flipping or panel removal generally up to 150 mm wide; b) Generally up to eight simple radii penetrations over and above of basic fixing locators; c) Recess for lifting screws; d) Generally up to six openings or two recesses (e.g. doors, windows, trenching) with radii corners or four with square corners subject to tooling restrictions.

30.8 Dual Face Processing of Red Stag EWP Elements

Each of the six complexity levels described above are based on elements being processed from one face only.

If all six faces of an EWP elements require processing, elements need to be processed on one face and then flipped prior to processing the balance of the element. The flipping process is time consuming to remove, the element from the CNC, flip in a controlled manner and then returned to the CNC for re-indexing (0, 0, 0) before the balance of the machining can be completed. The highest face complexity will determine the complexity level for both faces (*Figure 88* and *Figure 89*).

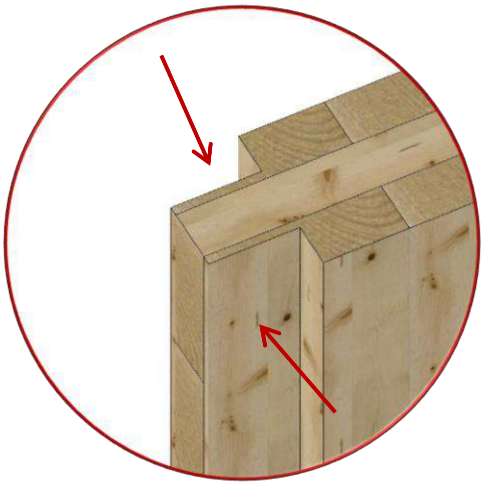


Figure 88: Double Spline Joint Plate Connection with two sides CNC process.

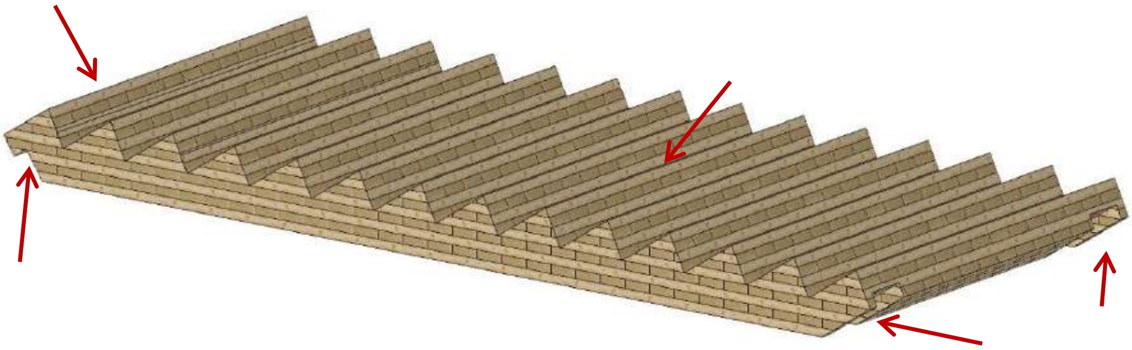


Figure 89: Red Stag CLT Stairs with dual face CNC processing (Very difficult classification).

All stair elements have a minimum classification of difficult. The angles and jointing requirements may require extensive milling (not just saw cuts) and can require two face processing. *Figure 90* and Figure 91is an example of a difficult two face CLT stair element. Pilot drilling and additional rebating would transition the element to a very difficult or extreme classification dependent on the degree of machining time.

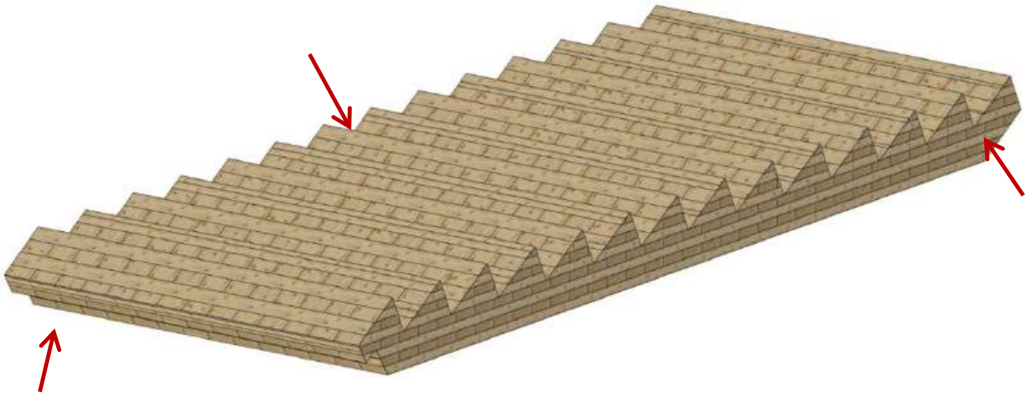


Figure 90: Common Red Stag CLT stairs requiring two face processing.

Figure 11 is a representation of a very difficult CLT stair element. The classification is due to the very time-consuming milling requirement for the top tread.

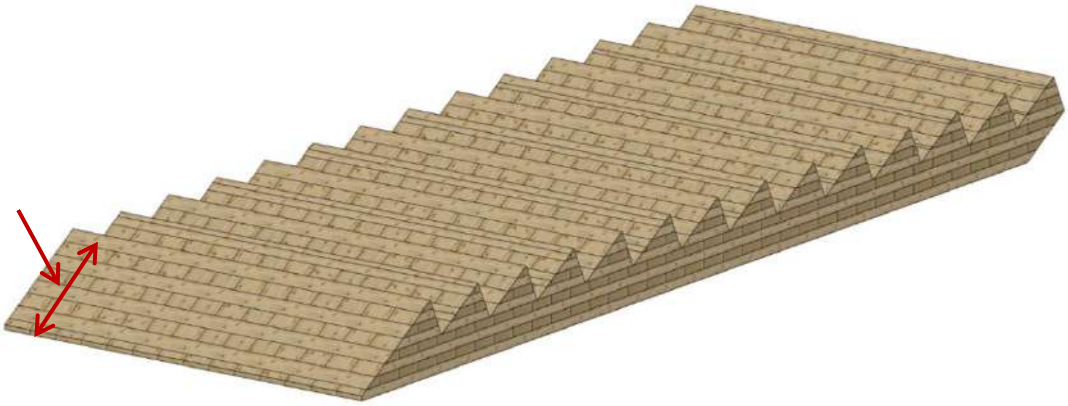
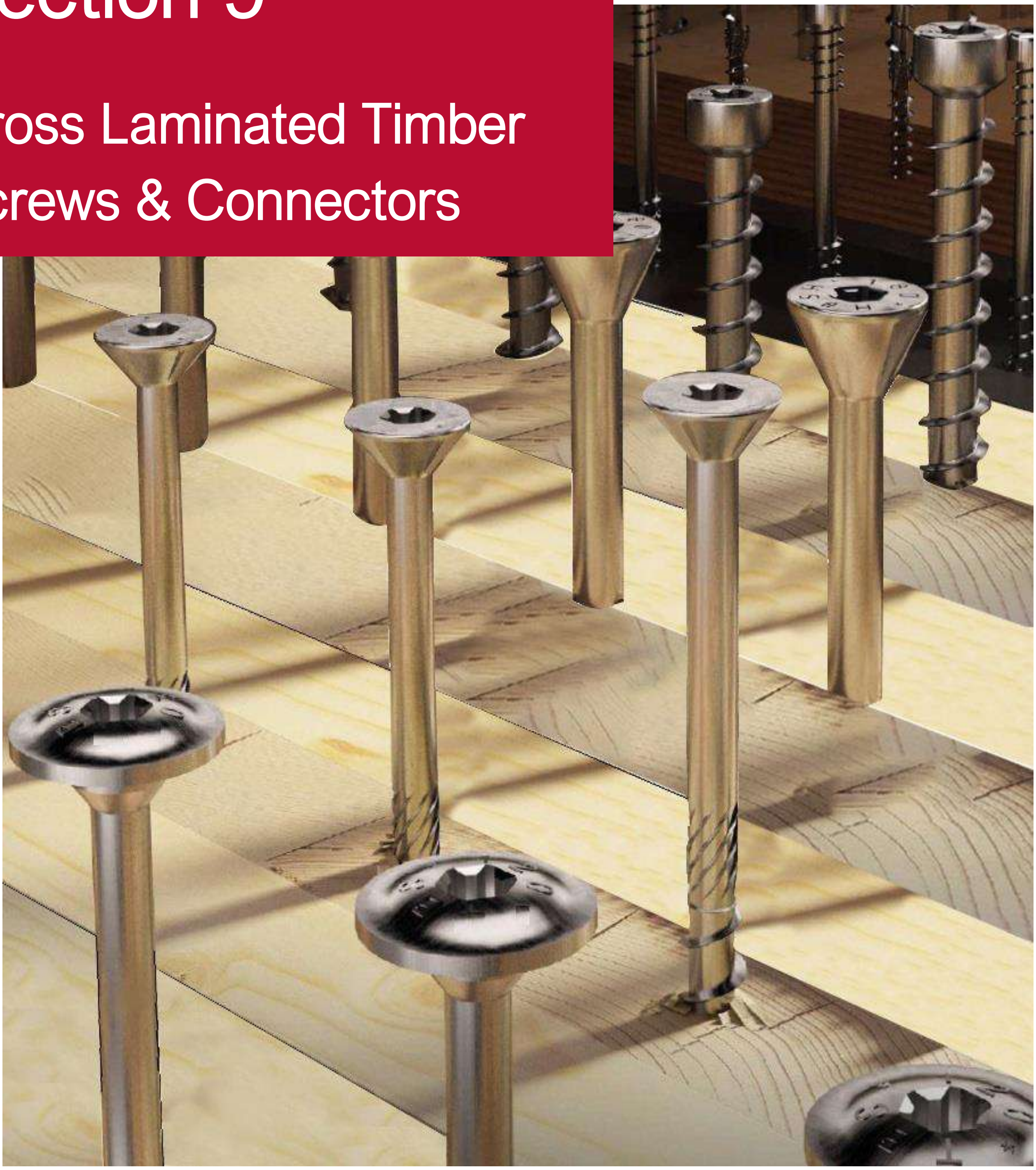


Figure 91: Example of a very difficult Red Stag CLT stair based the extensive mill time.

Section 9

Cross Laminated Timber Screws & Connectors



Make it better

Red Stag CLT Design Guide V1.3
September 2022

31. General Overview of EWP Connections

Screw connections play an essential role in the assembly of Mass Timber buildings. Screw connectors support in maintaining the integrity of EWP elements throughout mass timber buildings to provide the designed strength, stiffness, stability, and ductility.

Self-tapping screws are the most common fastener utilised in the assembly of EWP projects. *Section 3* of the *Red Stag CLT Design Guide* summarises other types of traditional and innovative fasteners and fastening systems utilised in EWP assemblies.

Red Stag stocks and can provide a wide range of high-quality fixings for various EWP structural applications and connections. Red Stag has primarily partnered with Rothoblaas for its fixings and mass timber solutions. Red Stag has a significant inventory of Rothoblaas fixings and installation aids to support in reducing lead times for projects. Further technical details are summarised in this section.

32. Quality Control and Production

Rothoblaas designs, tests, manufactures, and certifies its products. The manufacturing process is systematically monitored and controlled to ensure compliance and quality at each stage (refer to *Figure 92*).

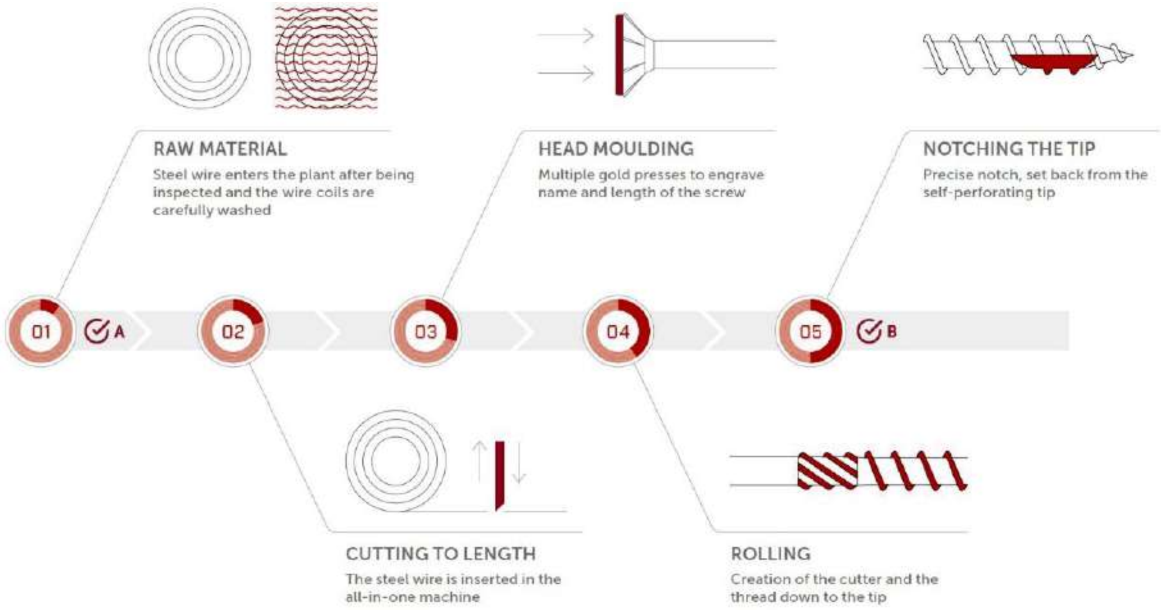


Figure 92: Rothoblaas Production Quality Controls [43].

32.1 Quality of the Steel

The steel annealing and tempering process provides Rothoblaas screws with a balance between resistance (f_{yk} = 1000 N/mm^2) and ductility.

During the production process, each screw is assigned an identifying batch number, providing the traceability of raw materials before the product enters the market (refer to *Figure 86*).

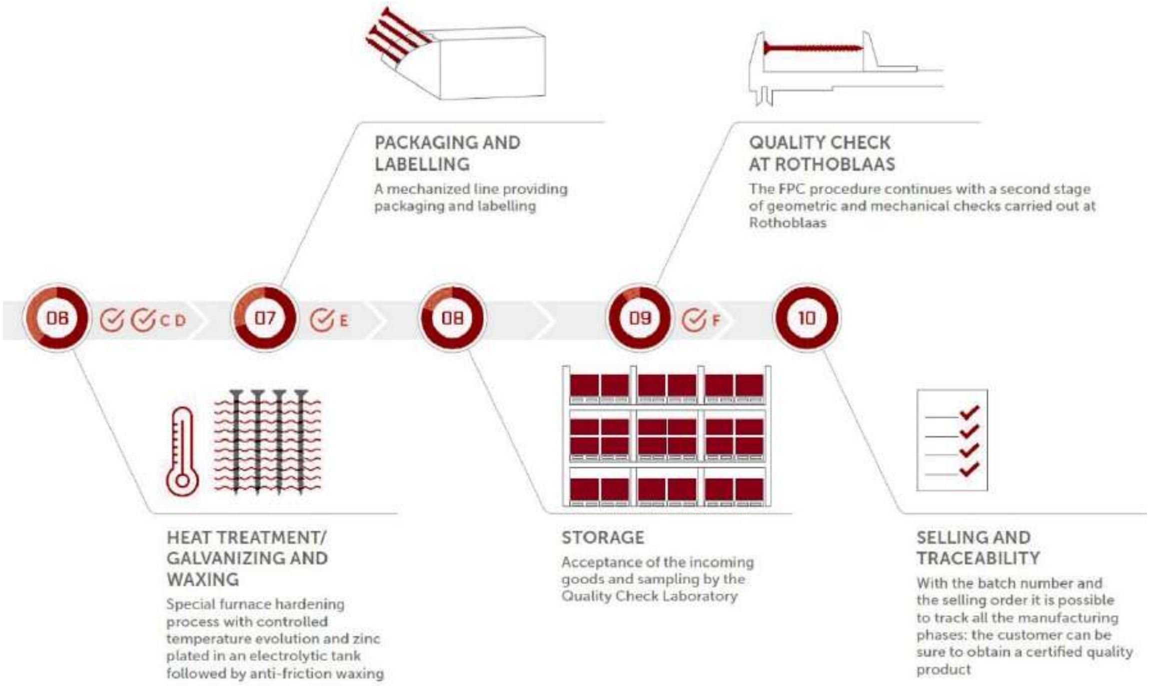


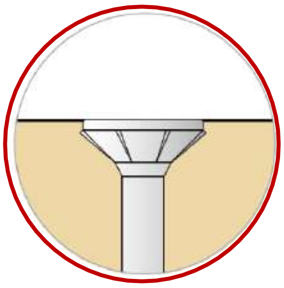
Figure 93: Screw Quality Controls [43].

32.1.1 Fixing Control Process

- Verification, check, and registration of the incoming raw materials.
- Geometric inspection according to regulated tolerances and calibration.
- Mechanical check: ultimate resistance to torsion, tension and bending angle.
- Confirm coating thickness and salt spray sample tests.
- Inspection of package and label.
- Application testing.

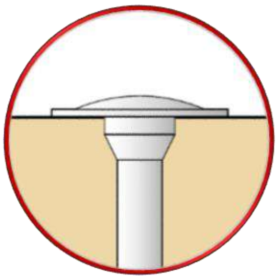
In addition to the dimensions and sizes, screws are technically defined in three main parts: head, thread, and tip [43].

33.1 Heads

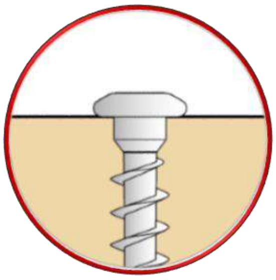


Head Type: Countersunk with ribs.

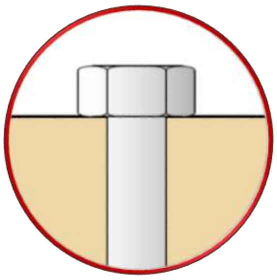
Screw Type:HBS, HBS COIL, HBS EVO, HBS S, HBS S BULK, VGS, SCI A2/A4, SBS, SPP.



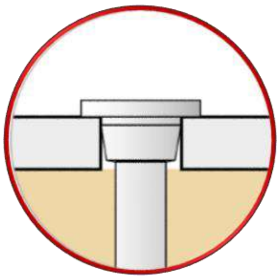
Head Type: Flange.
Screw Type: TBS, TBS MAX, TBS EVO.



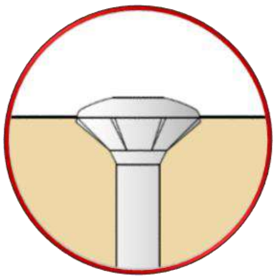
Head Type: Round.
Screw Type: LBS.



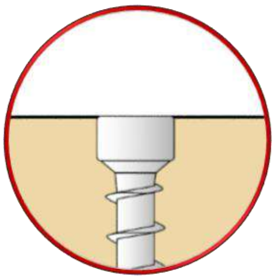
Head Type: Hexagonal.
Screw Type: KOP, SKR, VGS, MTS A2.



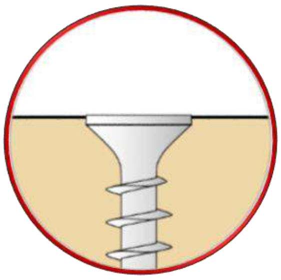
Head Type: Pan Head.
Screw Type: HBS P, HBS P EVO, KKF AISI410.



Head Type: Convex.
Screw Type: EWS A2, EWS AISI410, MCS A2.

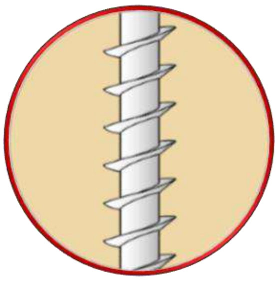


Head Type: Cylindrical.
Screw Type: VGZ, VGZ EVO, VGZ H, DGZ, CTC, MBS, SBD, KKZ A2, KWP A2, KKA AISI410, KKA Colour.

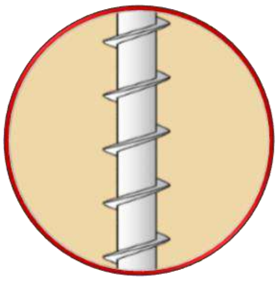


Head Type: Bugle.
Screw Type: DWS, DWS Coli.

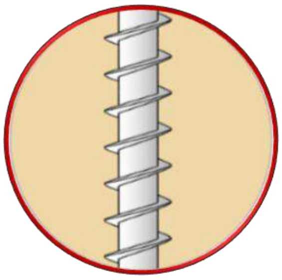
33.2 Thread



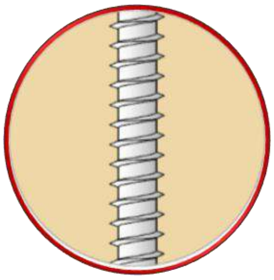
Thread Type: Asymmetric “Umbrella”.
Screw Type: HBS , HBS Coil, HBS S, HBS S Bulk, HBS EVO, HBS P, HBS P EVO, TBS, TBS EVO, SCI A2/A4.



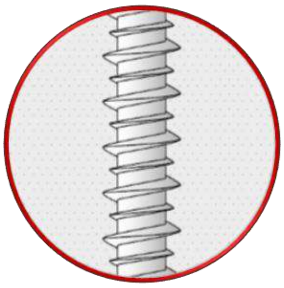
Thread Type: Symmetrical Coarse Thread.
Screw Type: VGZ, VGZ EVO, VGS, SCA A2.



Thread Type: Symmetrical Fine Thread.
Screw Type: HBS H, HTS, SHS, SHS AISI410, LBS, DWS, DWS Coil, KKF AISI410, MCS A2, VGZ H.

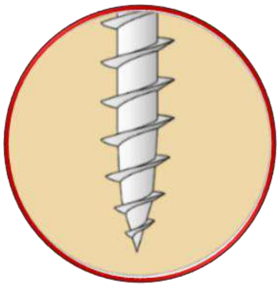


Thread Type: Fine (Metal).
Screw Type: KKA AISI 410, KKA Colour, SBS, SPP, SBS A2, SBN, SBN A2.

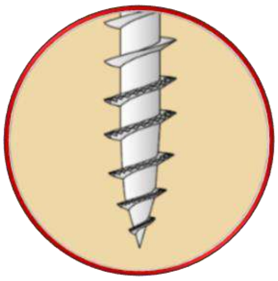


Thread Type: Hi-Low (Concrete).
Screw Type: MBS, SKR, SKS.

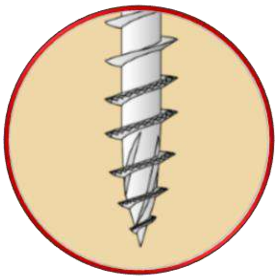
33.3 Tip



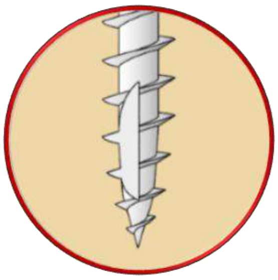
Tip Type: Sharp.
Screw Type: HBS (L ≤ 50 mm), HBS COIL (L ≤ 50 mm), HTS, LBS, DRS, DRT, DWS, DWS Coil, KWP A2, SCA A2, MCS A2.



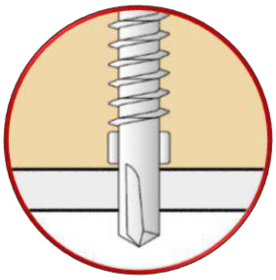
Tip Type: Sharp Saw.
Screw Type: HBS S, HBS S Bulk.



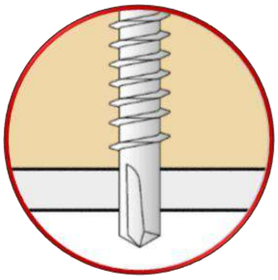
Tip Type: Sharp Saw Nibs.
Screw Type: VGS Ø13.



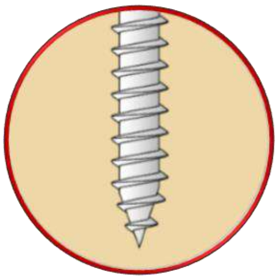
Tip Type: Sharp 1 Cut.
Screw Type: HBS (L > 50 mm), HBS Coil (L > 50 mm), HBS EVO, HBS P, HBS P EVO, TBS, TBS EVO, VGZ, VGZ EVO, VGS, DGZ, CTC, SHS, SHS AISI410,KKT A4 Colour , KKT A4, EWS A2, EWS AISI410, KKF AISI410, SCI A2/A4.



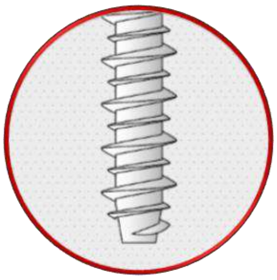
Tip Type: Metal (with Fins).
Screw Type: SBS, SBS A2, SPP.



Tip Type: Metal (without Fins).
Screw Type: SBD, SBN, SBN A2.



Tip Type: Standard (Wood).
Screw Type: MBS, KOP, MTS A2.



Tip Type: Concrete.
Screw Type: SKR, SKS.

33.4 Geometry

Every detail of the screw geometry is analysed and developed to increase strength and application performance. The details that make the differences in screws are listed below (refer to *Figure 94*).

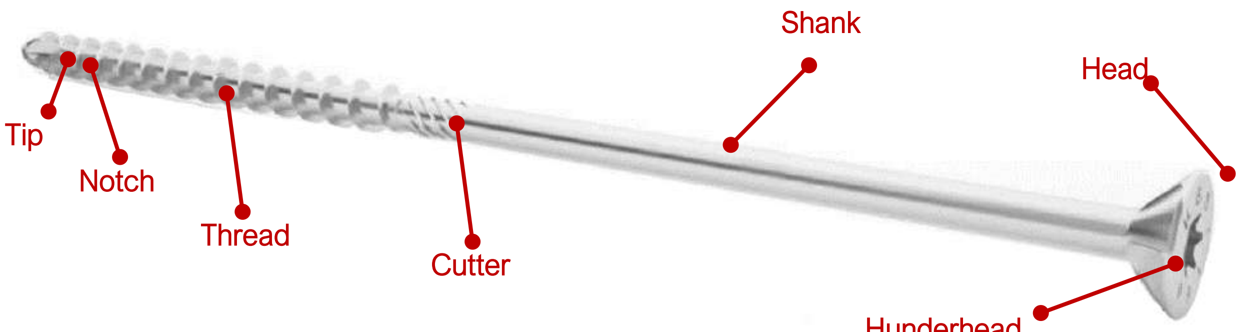
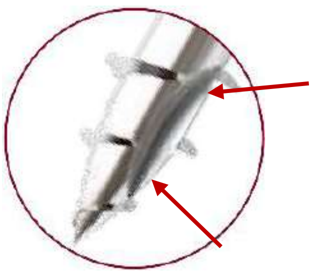


Figure 94: Screws detail and geometry [43].

33.4.1 Self-Perforating Tip

The self-perforating tip, enhanced with exclusive geometries for particular types of wood (LVL, hardwood, etc), with corkscrew thread running all the way to the tip, guaranteeing a fast, high-performance initial grip.

33.4.2 Notch



The notch makes it possible to tear the fibres during insertion, thus preventing the risk of splitting or cracking the wood. The setback position of the notch is essential to guarantee excellent grip and perforation of the tip.

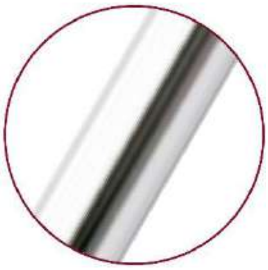
33.4.3 Thread

With carefully designed geometries, the thread allows fast, secure screwing, with the thread pitch related to screw diameter and length. Coarse-pitch threads are well suited to medium/long screws as they make screwing faster; on the other hand, fine-pitch threads are ideal for small screws which require great care and precision during screwing.

33.4.4 Cutter

The geometry of the cutter is carefully studied to widen the wood grain and move away the shavings created as the screw progresses into the timber. The cutter creates the space for the passage of the shank and limits screw overheating.

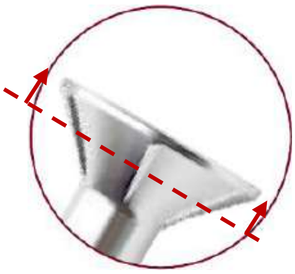
33.4.5 Shank



The shank is covered by special surface waxing, which considerably reduces friction and torsional stress during screwing.

33.4.6 Underhead

33.4.7 Head



Head geometry defines screw resistance to penetration.

33.5 Common Timber Screws for Red Stag EWP.

Although there are a wide range of screw options for various applications, the Red Stag EWP Design Guide introduces the most common options. *Table 29* to *Table 33* and

Figure 95 summarise the tested values that are certified and calculated for EWP by Rothoblaas.

33.5.1 HBS Countersunk Screws

- **Superior Strength**

  Steel with superb yield and failure strength (f_{yk} = 1000 N/mm^2). Very high torsional strength $f_{tor,k}$ for safer screwing.

- **Structural Applications**

  Approved for structural applications subject to stresses in any direction versus the grain (α = 0° - 90°). Asymmetric “umbrella” threading for better wood pull-through.

- **Ductility**

  The bending angle is 20° greater than standard, certified according to ETA-11/0030. Cyclical SEISMIC-REV tests according to EN 12512. Seismic performance tested according to EN 14592.

- **Chromium (VI) Free**

  Total absence of hexavalent chromium. Compliance with the strictest regulations governing chemical substances (SVHC).

- **Material**

  Galvanized carbon steel.

- **Fields of Use**

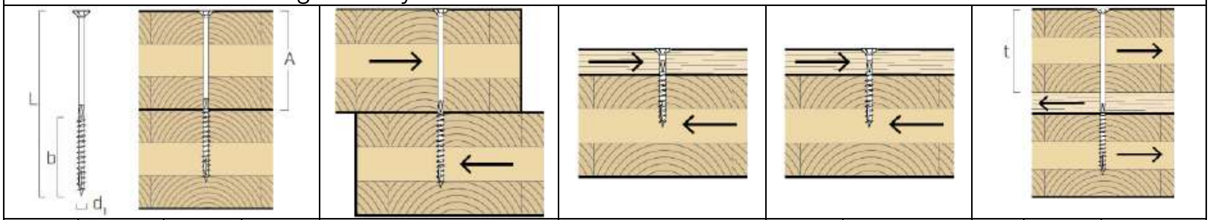
  CLT panels, GLT beams, solid timber, high density timber.

- **Dimensional Characteristics**

  Diameter from 3.5 mm to 12 mm.

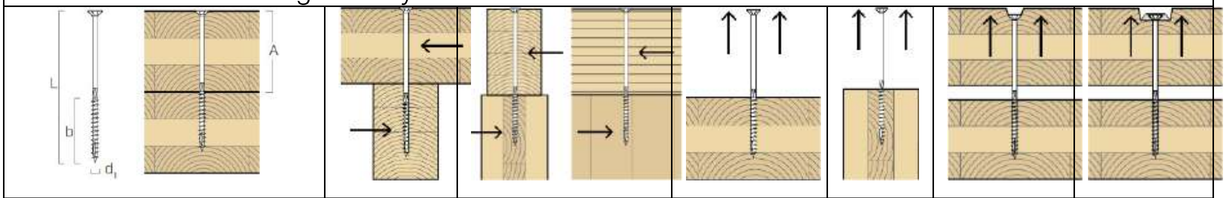
  Length from 30 mm to 600 mm.

Table 29: HBS Screw geometry and mechanical characteristics [43].



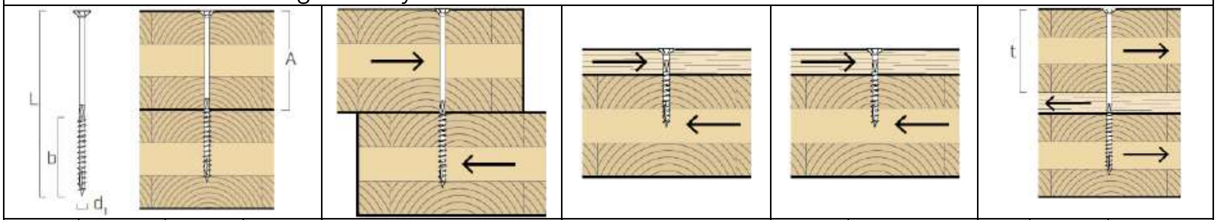
d_1 mm	L mm	b mm	A mm	R_{vk} kN	R_{vk} kN		R_{vk} kN		t mm	R_{vk} kN
8	80	52	28	2.42	1.84	Span = 18 mm	2.30	Span = 18 mm	-	-
	100	52	48	3.04	2.13		2.30		40	2.92
	120	60	60	3.11	2.26		2.30		50	2.92
	140	60	80	3.11	2.26		2.30		60	2.92
	160	80	80	3.11	2.58		2.30		70	2.92
	180	80	100	3.11	2.58		2.30		80	2.92
	200	80	120	3.11	2.58		2.30		90	2.92
	220	80	140	3.11	2.58		2.30		100	2.92
	240	80	160	3.11	2.58		2.30		110	2.92
	260	80	180	3.11	2.58		2.30		120	2.92
	280	80	200	3.11	2.58		2.30		130	2.92
	300	100	200	3.11	2.58		2.30		140	2.92
	320	100	220	3.11	2.58		2.30		150	2.92
	340	100	240	3.11	2.58		2.30		160	2.92
	360	100	260	3.11	2.58		2.30		170	2.92
	380	100	280	3.11	2.58		2.30		180	2.92
	400	100	300	3.11	2.58		2.30		190	2.92
	440	100	340	3.11	2.58		2.30		210	2.92
	480	100	380	3.11	2.58		2.30		230	2.92
	520	100	420	3.11	2.58		2.30		250	2.92

Table 30: HBS Screw geometry and mechanical characteristics [43].



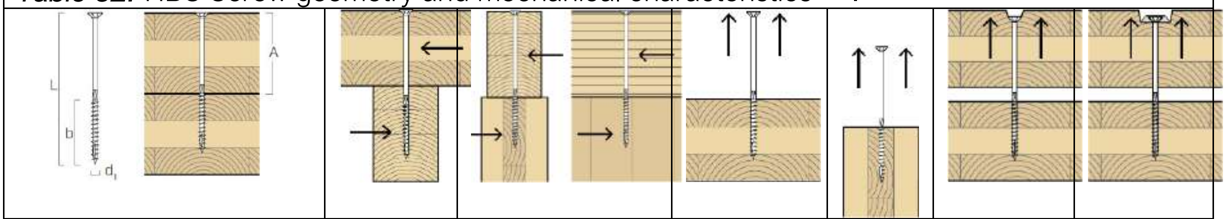
d_1 mm	L mm	b mm	A mm	$R_{v,k}$ kN	$R_{v,k}$ kN	$R_{ax,k}$ kN	$R_{ax,k}$ kN	$R_{head,k}$ kN	$R_{head,k}$ kN
8	80	52	28	2.51	2.19	4.87	3.70	2.21	6.56
	100	52	48	3.17	2.19	4.87	3.70	2.21	6.56
	120	60	60	3.17	2.32	5.62	4.21	2.21	6.56
	140	60	80	3.17	2.32	5.62	4.21	2.21	6.56
	160	80	80	3.17	2.66	7.49	5.45	2.21	6.56
	180	80	100	3.17	2.66	7.49	5.45	2.21	6.56
	200	80	120	3.17	2.66	7.49	5.45	2.21	6.56
	220	80	140	3.17	2.66	7.49	5.45	2.21	6.56
	240	80	160	3.17	2.66	7.49	5.45	2.21	6.56
	260	80	180	3.17	2.66	7.49	5.45	2.21	6.56
	280	80	200	3.17	2.66	7.49	5.45	2.21	6.56
	300	100	200	3.17	2.66	9.36	6.66	2.21	6.56
	320	100	220	3.17	2.66	9.36	6.66	2.21	6.56
	340	100	240	3.17	2.66	9.36	6.66	2.21	6.56
	360	100	260	3.17	2.66	9.36	6.66	2.21	6.56
	380	100	280	3.17	2.66	9.36	6.66	2.21	6.56
	400	100	300	3.17	2.66	9.36	6.66	2.21	6.56
	440	100	340	3.17	2.66	9.36	6.66	2.21	6.56
	480	100	380	3.17	2.66	9.36	6.66	2.21	6.56
	520	100	420	3.17	2.66	9.36	6.66	2.21	6.56

Table 31: HBS Screw geometry and mechanical characteristics [43].



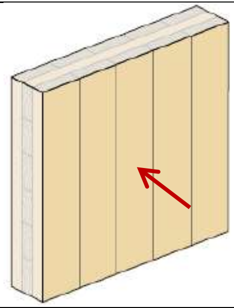
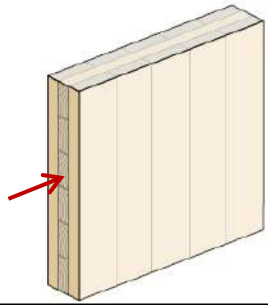
d1 mm	L mm	b mm	A mm	Rvk kN	Rvk kN		Rvk kN		t mm	Rvk kN
10	80	52	28	3.40	2.34	Span = 22 mm	3.31	Span = 22 mm	-	-
	100	52	48	3.86	2.91		3.31		-	-
	120	60	60	4.45	3.03		3.31		50	3.89
	140	60	80	4.49	3.03		3.31		60	3.89
	160	80	80	4.56	3.37		3.31		70	3.89
	180	80	100	4.56	3.37		3.31		80	3.89
	200	80	120	4.56	3.37		3.31		90	3.89
	220	80	140	4.56	3.37		3.31		100	3.89
	240	80	160	4.56	3.37		3.31		110	3.89
	260	80	180	4.56	3.37		3.31		120	3.89
	280	80	200	4.56	3.37		3.31		130	3.89
	300	100	200	4.56	3.76		3.31		140	3.89
	320	100	220	4.56	3.76		3.31		150	3.89
	340	100	240	4.56	3.76		3.31		160	3.89
	360	100	260	4.56	3.76		3.31		170	3.89
	380	100	280	4.56	3.76		3.31		180	3.89
	400	100	300	4.56	3.76		3.31		190	3.89

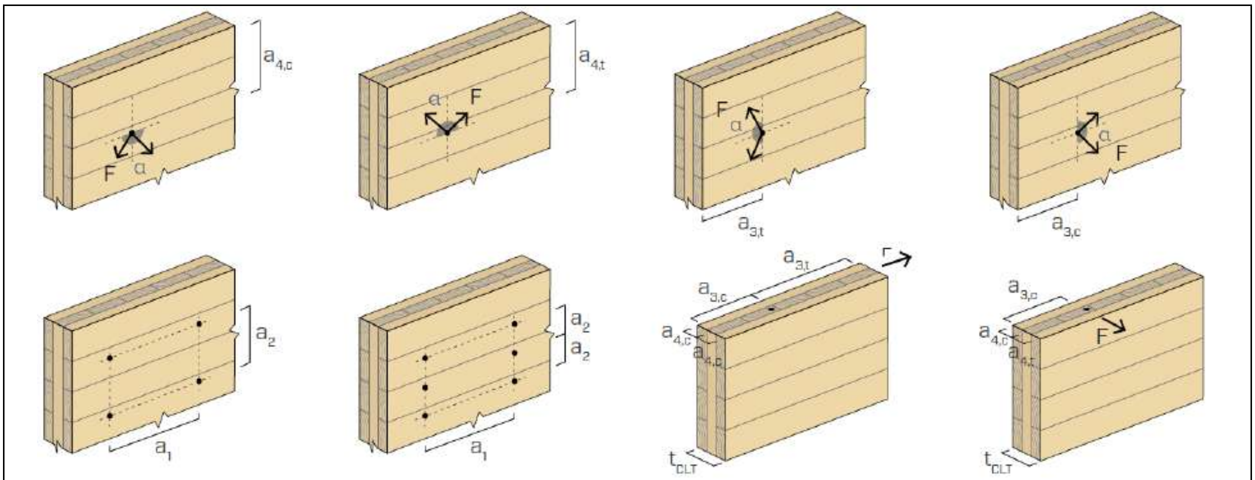
Table 32: HBS Screw geometry and mechanical characteristics [43].



d1 mm	L mm	b mm	A mm	Rv,k kN	Rv,k kN	Rax,k kN	Rax,k kN	Rhead,k kN	Rhead,k kN
10	80	52	28	3.01	6.08	4.87	4.42	3.50	9.45
	100	52	48	3.01	6.08	4.87	4.42	3.50	9.45
	120	60	60	3.12	7.02	5.62	5.03	3.50	9.45
	140	60	80	3.12	7.02	5.62	5.03	3.50	9.45
	160	80	80	3.46	9.36	7.49	6.51	3.50	9.45
	180	80	100	3.46	9.36	7.49	6.51	3.50	9.45
	200	80	120	3.46	9.36	7.49	6.51	3.50	9.45
	220	80	140	3.46	9.36	7.49	6.51	3.50	9.45
	240	80	160	3.46	9.36	7.49	6.51	3.50	9.45
	260	80	180	3.46	9.36	7.49	6.51	3.50	9.45
	280	80	200	3.46	9.36	7.49	6.51	3.50	9.45
	300	100	200	3.86	11.70	9.36	7.96	3.50	9.45
	320	100	220	3.86	11.70	9.36	7.96	3.50	9.45
	340	100	240	3.86	11.70	9.36	7.96	3.50	9.45
	360	100	260	3.86	11.70	9.36	7.96	3.50	9.45
	380	100	280	3.86	11.70	9.36	7.96	3.50	9.45
	400	100	300	3.86	11.70	9.36	7.96	3.50	9.45

Table 33: Minimum distance and spacing placement of HBS screws for shear and axial loads in EWP [43].

										
	Screw Inserted Without Pre-Drilling Lateral Face					Screw Inserted Without Pre-Drilling Narrow Face				
d_1 [mm]			8	10	12			8	10	12
a_1 [mm]	4 x d		32	40	48	10 x d		80	100	120
a_2 [mm]	2.5 x d		20	25	30	4 x d		32	40	48
$a_{3,t}$ [mm]	6 x d		48	60	72	12 x d		96	120	144
$a_{3,c}$ [mm]	6 x d		48	60	72	7 x d		56	70	84
$a_{4,t}$ [mm]	6 x d		48	60	72	6 x d		48	60	72
$a_{4,c}$ [mm]	2.5 x d		20	25	30	3 x d		24	30	36
d = Nominal screw diameter										



Notes:
The minimum distances are compliant with ETA-11/0030 and are to be considered valid unless otherwise specified in Rothoblaas technical documents for CLT panels.
Minimum CLT thickness t_{min} =10 x d
Minimum CLT thickness t_{min} =10 x d and minimum screw pull-through depth t_{pen} = 10 x d

Figure 95: Minimum distance and spacing of HBS screws for shear and axial loads in EWP [43].

33.5.2 VGS Fully Threaded Screws with Countersunk or Hexagonal Head

- **Tension**

  Deep thread and high resistance steel (f_{yk} = 1000 N/mm^2) for excellent tensile performance. Approved for structural applications subject to stresses in any direction versus. the grain (α = 0° - 90°).

- **Countersunk or Hexagonal Head**

  Countersunk head up to L = 600 mm, ideal for use on plates or for concealed reinforcement. Hexagonal head L > 600 mm to facilitate the driving hold on the head.

  Countersunk Head

  Diameter Options: 9 mm, 11 mm, 13 mm.

  Length Option: maximum 600 mm.

  HEXAGONAL Head

  Diameter Options: 11 mm, 13 mm.

  Length Option: maximum 600 mm.

- **Chromium (VI) Free**

  Total absence of hexavalent chromium. Compliance with the strictest regulations governing chemical substances (SVHC).

- **Material**

  Galvanized carbon steel.

- **Fields of Use**

  CLT panels, GLT beams, solid timber, high density timber.

- **Dimensional Characteristics**

  Diameter: 9 mm, 11 mm and 13 mm.

  Length from 100 mm to 1200 mm.

The provided geometry, mechanical characteristics, and technical information of VGS screws by Rothoblaas are summarised in *Figure 96* and *Table 34*.

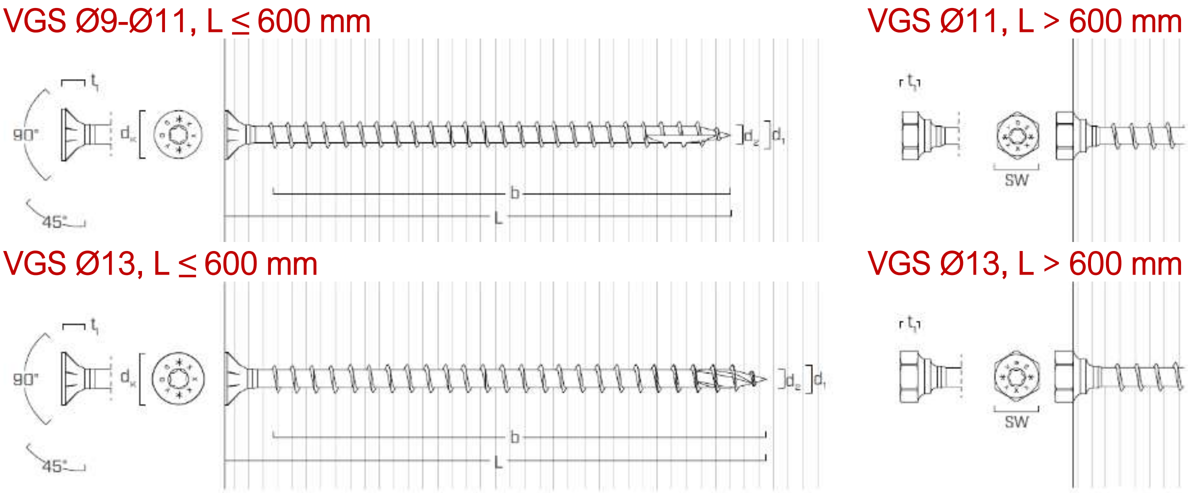


Figure 96: VGS Screw detail and geometry [43].

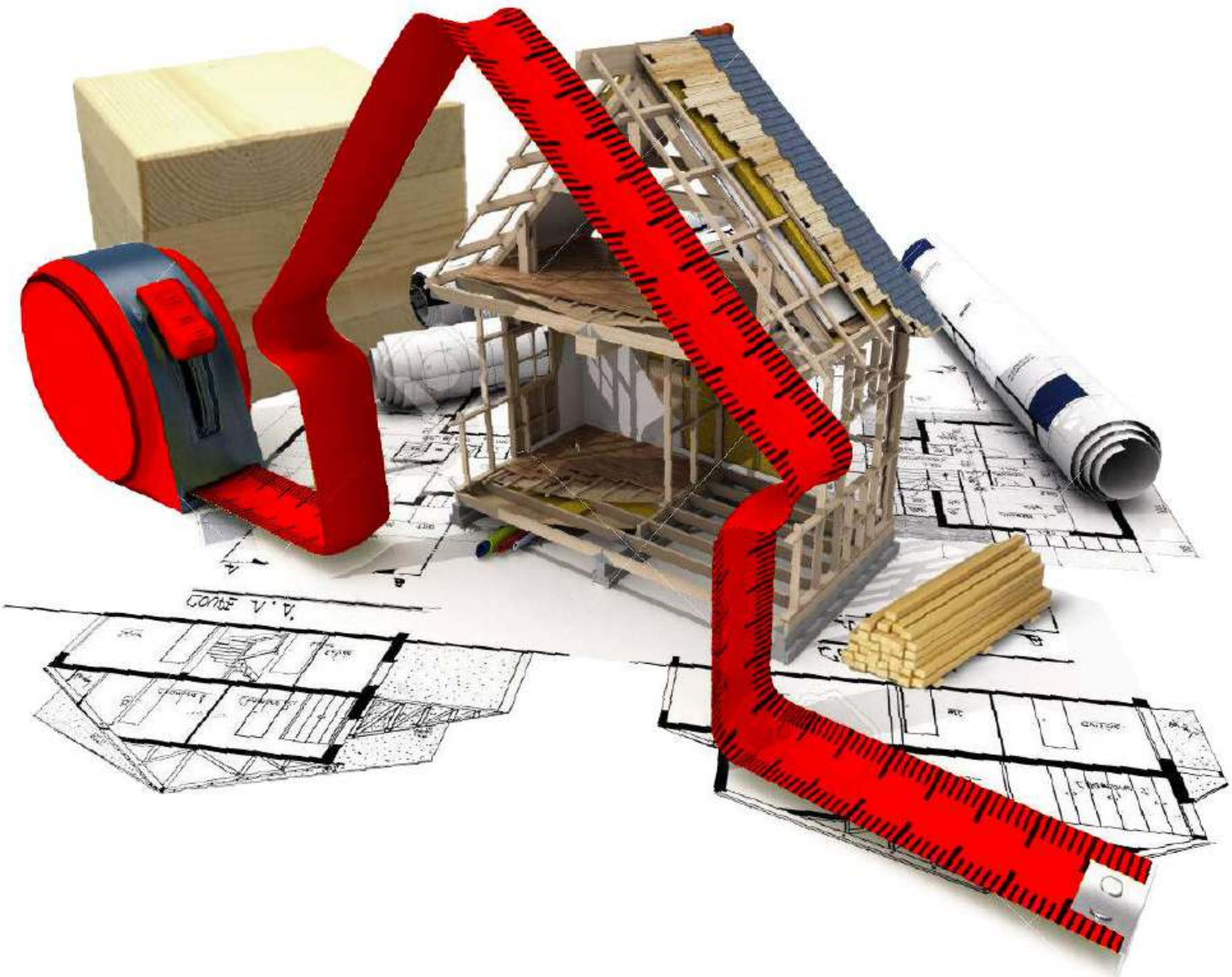
Table 34: VGS Screw geometry and mechanical characteristics [43].

Nominal Diameter	d_1 [mm]	9	11 [L ≤ 600 mm]	11 [L > 600 mm]	13 [L ≤ 600 mm]	13 [L > 600 mm]
Head diameter	d_k [mm]	16	19.30	-	22.00	-
Wrench size	SW	-	-	SW17	-	SW19
Head thickness	t_1 [mm]	6.50	8.20	6.40	9.40	7.50
Tip diameter	d_2 [mm]	5.90	6.60		8.00	
Pre-drilling hole diameter [a]	d_v [mm]	5.0	6.0		8.0	
Characteristic yield moment	$M_{y,k}$ [Nm]	27.2	45.9		70.9	
Characteristic withdrawal resistance parameter [b]	$f_{ax,k}$ [N/mm^2]	11.7	11.7		11.7	
Associated density	ρ_a [kg/m^3]		350		350.0	
Characteristic tensile strength	$f_{ten,k}$ [kN]		38.0		53.0	
Characteristic yield strength	$f_{y,k}$ [N/mm^2]		1000		1000	

[a] Pre-drilling valid for softwood.
[b] Valid for softwood – maximum density 440 kg/m^3.
For applications with different materials or with high density.
For VGS Ø13 screw a Ø8x80 predrilling is recommended.

Section 10

Cross Laminated Timber Design Calculation



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34. Overview

The Cross Laminated Timber (CLT) design examples in this section are provided to assist the market with the design and specification of Red Stag CLT. The technical examples provided have been developed based on the Canadian FPInnovation CLT Handbook, NZS 3603 Timber Structures Standard, NZS 1170 Structural Design Actions and the EN 1995-1-1 Eurocode 5 Design of Timber Structures (Refer to the *Table 35* below). This document is intended as a guide only (not a specification basis) to support in calculating and designing CLT members. Please refer to the relevant standards for further information to ensure that the project engineer, designer or specifier confirm the basis for each design to ensure it is fit for purpose and does not simply rely on the examples in this section.

Table 35: Referenced standards and documents utilised in the CLT floor design example.
The Red Stag CLT Floor Design Calculation Example has been developed in Conjunction with the Following Standards:
CLT Design Guide: FPInnovations CLT Handbook 2011, Chapter 3, Structural Design of CLT Elements. FPInnovations CLT Handbook 2011, Chapter 7, Vibration Performance of CLT Floors. Canadian CLT Handbook has been used as the primary design basis for Red Stag CLT to confirm the bending strength.
NZS 3603:1993: NZS 3603:1993 Timber Structures Standard is currently under review with an anticipated 2022 revision. Timber characteristics information from the New Zealand Timber Standard is used in Red Stag CLT floor design calculations.
AS/NZS 1170.1: AS/NZS 1170.1:2002 Structural design actions - Part 1: Permanent, imposed, and other actions. Permanent loads, imposed loads and load combinations from the New Zealand structural design action standard are used in Red Stag CLT design calculations.
EN 1995-1-1: EC 5: EN 1995-1-1:2004+A1:2008 - Eurocode 5: Design of timber structures. Vibration of the Red Stag CLT floor design example is calculated based on the recommended method in EN 1995-1-1:2004+A1:2008 - Eurocode 5, Section 7.5.

35.1 CLT Floor Panel Design – Longitudinal Direction

Calculation of the longitudinal members is based on the FPInnovation CLT design guide Mechanical jointed and simplified methods.

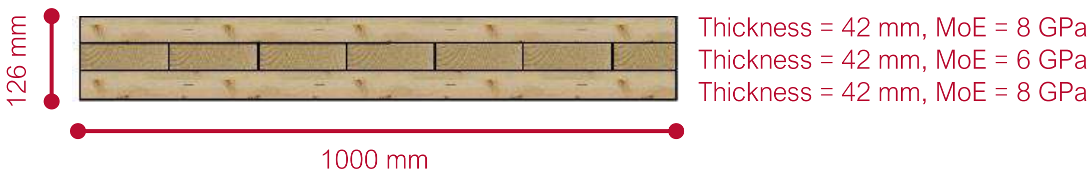

Figure 97: Red Stag CLT Panel Cross-Section

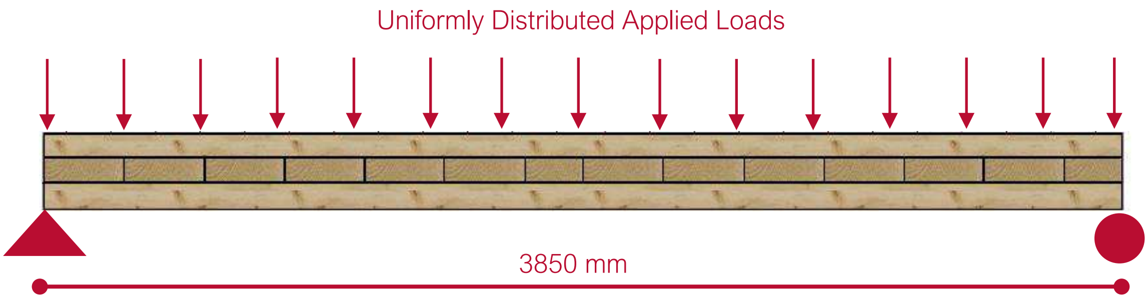

Figure 98: Red Stag CLT Panel Elevation

35.2 Assumption and Applied Loads:

Strength Reduction Factor (Ø) = 0.9 [36]

Bending Strength (F_b) = 14 MPa [36]

CLT Weight = 0.63 kPa - Calculated based on a Red Stag CLT density of 500 kg/m^3

Additional Dead Load = 0.5 kPa

Live Load = 2.0 kPa - Refer to AS/NZS 1170.1 [37]

35.3 Calculation of the Effective Bending Stiffness using the Mechanical Jointed Beam Theory (Gamma Method)

L = Span of panels = 3850 mm = 3.85 m

b = Width of the CLT panel = 1 m [37]

h_i = Thickness of board layers in direction of action [38]

h_1 = 42 mm

h_2 = 42 mm

$\overline{h_i}$ = Thickness of board layers in direction perpendicular to actions [38]

$\overline{h_1}$ = 42 mm

$A_i = b_i \times h_i$ [38]

A_1 = (42×1000) = 42000 mm^2

A_2 = (42×1000) = 42000 mm^2

$I_1 = \frac{b_i \times {h_i}^3}{12}$ [38]

$I_1 = \frac{b \times {h_1}^3}{12} = \frac{1000 \times 42^3}{12}$ = 6174000 mm^4

$I_2 = \frac{b \times {h_3}^3}{12} = \frac{1000 \times 42^3}{12}$ = 6174000 mm^4

E_1 = 8000 MPa [36]

E_2 = 8000 MPa [36]

$\gamma_1 = \frac{1}{1+\Pi^2 \times \frac{E_1 \times A_1}{L^2} \times \frac{h_1}{G_R \times b}}$ [38]

$\gamma_2 = \frac{1}{1+\Pi^2 \times \frac{E_3 \times A_3}{L^2} \times \frac{h_2}{G_R \times b}}$ [38]

where $\frac{h_i}{G_R \times b}$ = slip modulus due to shear deformation between layers and G_R = shear modulus perpendicular to the grain or rolling shear modulus [38].

E_0= MoE for longitudinal layers = 8000 MPa [36]

E_{90} = 266.67 MPa

G_0 = 500 MPa

G_R = 50 GPa [38]

E_0= MoE for transvers layers = 6000 MPa [36]

E_{90} = 200 MPa

G_0 = 375 MPa

G_R = 37.5 GPa [38]

L = span in mm (simple span; in direction of action //) [38]

$\gamma_1 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{3850^2} \times \frac{42}{37.5 \times 1000}} = 0.89$

$\gamma_2 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{3850^2} \times \frac{42}{37.5 \times 1000}} = 0.89$

$\overline{a_1} = \frac{h_1}{2} + \frac{\overline{h_1}}{2}$ [38]

$\overline{a_2} = \frac{h_2}{2} + \frac{\overline{h_1}}{2}$ [38]

$\overline{a_1} = \frac{42}{2} + \frac{42}{2} = 42$ mm

$\overline{a_2} = \frac{42}{2} + \frac{42}{2} = 42$ mm

$EI_{eff\,//} = \sum_{i=1}^{2} (E_i I_i + \gamma_i E_i A_i a_i^2)$ [38]

$EI_{eff\,//} = (E_1 I_1 + \gamma_1 E_1 A_1 a_1^2) + (E_2 I_2 + \gamma_2 E_2 A_2 a_2^2)$ [38]

$EI_{eff} = (8000 \times 6174000 + 0.889 \times 8000 \times 42000 \times 42^2) + (8000 \times 6174000 + 0.889 \times 8000 \times 42000 \times 42^2)$

$= 6 \times 10^{11} + 6 \times 10^{11} = 1.152 \times 10^{12}$ N.mm^2

$I_{eff} = \frac{1.152 \times 10^{12}}{8000} = 1.44 \times 10^8$ mm^4

35.4 Calculation of Bending Strength using the Mechanically Jointed Beams Theory (Gamma Method)

$M_r = \varnothing \times F_b \times \frac{I_{eff}}{(\delta_1 a_1 + 0.5 h_1)}$ ($E_1 = E_2$) [38]

$F_b = 14$ MPa [36]

$\varnothing = 0.9$ [36], [38]

$M_r = 0.9 \times 14 \times \frac{1.44 \times 10^8}{(0.89 \times 42 + 0.5 \times 42)} \times 10^{-6} = 31.12$ kN.m

35.5 Calculation of Bending Strength using the Simplified Method

$M_r = Ø \times F_b \times \frac{I_{eff}}{0.5h_1}$ [38]

$F_b = 14$ [36]

$Ø = 0.9$ [36], [38]

$M_r = 0.9 \times 14 \times \frac{1.44 \times 10^8}{0.5 \times 126} \times 10^{-6} = 28.81$ kN.m

35.6 Calculation of Applied Bending Moment

$M^* = \frac{(1.2 \times \text{Dead Load} + 1.5 \times \text{Live Load}) \times Span^2}{8}$ [38], [39]

$M^* = \frac{(1.35 \times \text{Dead Load}) \times Span^2}{8}$ [38], [39]

Dead Load = CLT Weight + Additional Dead Load

CLT Weight = CLT Thickness × Timber Weight = 126 × (5/1000) = 0.63 kPa

Additional Dead Load = 0.5 kPa.

Live Load = 2 kPa on Floor

$M^* = \frac{(1.2 \times (0.63 + 0.5) + 1.5 \times 2) \times 3.85^2}{8} = 8.07$ kN.m

$M^* = \frac{(1.35 \times (0.63 + 0.5)) \times 3.85^2}{8} = 3.14$ kN.m

35.7 Bending Capacity Check

$M_{r\ \text{Mechanical jointed method}}$ = 31.12 kN.m ≥ M^*= 8.07 kN.m √ ok

$M_{r\ \text{Mechanical jointed method}}$ = 31.12 kN.m ≥ M^*= 3.14 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 28.81 kN.m ≥ M^*= 8.07 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 28.81 kN.m ≥ M^*= 3.14 kN.m √ ok

35.8 Deflection Check

$\Delta_{\text{CLT Deflection}} = \frac{5\times(\text{Uniformly Distributed Applied Load})\times Span^4}{(384\times(EI_{eff}\,)}$ [38], [39]

$\Delta_{\text{CLT Deflection}} = \frac{5\times((\text{CLT Weight} + \text{Additional Dead Load}\,)+0.4\times\text{Live Load}\,)\times 3850^4}{(384\times(EI_{eff}\,))}$

$\Delta_{\text{CLT Deflection}} = \frac{5\times((0.63+0.5)+0.4\times 2)\times 3850^4}{(384\times(1.152\times 10^{12}\,)}$ = 4.79 mm

Creep Factor (K_2) = 2

Long term deflection = 4.79 × 2 = 9.58 mm → long term deflection

Long term deflection = 9.58 ≤ $\Delta^* = \frac{3850}{400}$ = 9.625 mm √ ok

35.9 Vibration Check

$f = \frac{3.142}{2L^2}\sqrt{\frac{(EI)^{1m}_{eff}}{\rho\ A}}$ [40]

ρ × A = m = is the mass per unit area in kg/m^2.

L = is the floor span in m.

m = linear mass of the CLT for a 1-m wide panel (kg/m).

EI_{eff} = effective bending stiffness.

$f = \frac{3.142}{2\times 3.85^2}\sqrt{\frac{1.152\times 10^{12}}{500\ \times(1\times\frac{126}{1000})}}$ = 14.33 ≥ 8Hz √ ok

36.1 CLT Floor Panel Design – Longitudinal Direction

Calculation of the longitudinal members is based on the FPInnovation CLT design guide Mechanical jointed and simplified methods.

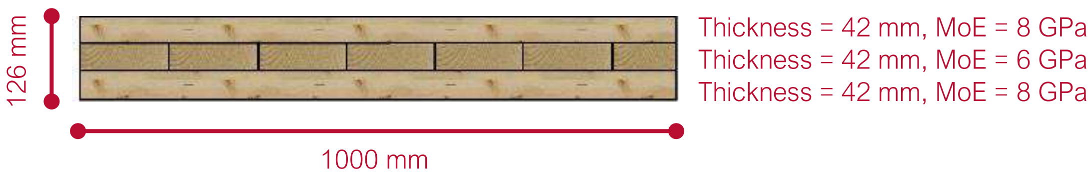

Figure 99: Red Stag CLT Panel Cross-Section

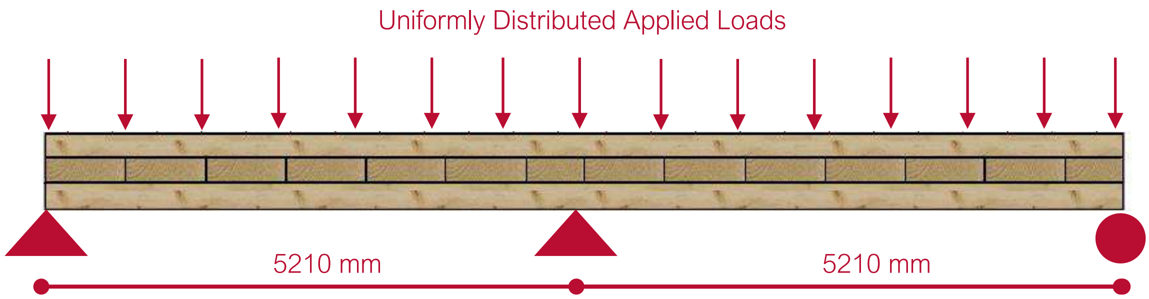

Figure 100: Red Stag CLT Panel Elevation

36.2 Assumption and Applied Loads:

Strength Reduction Factor (Ø) = 0.9 [36]

Bending Strength (F_b) = 14 MPa [36]

CLT Weight = 0.63 kPa - Calculated based on a Red Stag CLT density of 500 kg/m^3

Additional Dead Load = 0.5 kPa

Live Load = 2.0 kPa - Refer to AS/NZS 1170.1 [37]

36.3 Calculation of the Effective Bending Stiffness using the Mechanical Jointed Beam Theory (Gamma Method)

L = Span of panels = 5210 mm = 5.21 m

b = Width of the CLT panel = 1 m [38]

h_i = Thickness of board layers in direction of action [38]

h_1 = 42 mm

h_2 = 42 mm

$\overline{h_i}$ = Thickness of board layers in direction perpendicular to actions [38]

$\overline{h_1}$ = 42 mm

$A_i = b_i \times h_i$ [38]

$A_1 = (42 \times 1000) = 42000 \text{ mm}^2$

$A_2 = (42 \times 1000) = 42000 \text{ mm}^2$

$I_1 = \frac{b_i \times {h_i}^3}{12}$ [38]

$I_1 = \frac{b \times {h_1}^3}{12} = \frac{1000 \times 42^3}{12} = 6174000 \text{ mm}^2$

$I_2 = \frac{b \times {h_3}^3}{12} = \frac{1000 \times 42^3}{12} = 6174000 \text{ mm}^2$

E_1 = 8000 MPa [36]

E_2 = 8000 MPa [36]

$\gamma_1 = \frac{1}{1+\Pi^2 \times \frac{E_1 \times A_1}{L^2} \times \frac{h_1}{G_R \times b}}$ [38]

$\gamma_2 = \frac{1}{1+\Pi^2 \times \frac{E_3 \times A_3}{L^2} \times \frac{h_2}{G_R \times b}}$ [38]

where $\frac{h_i}{G_R \times b}$ = slip modulus due to shear deformation between layers and G_R = shear modulus perpendicular to the grain or rolling shear modulus [38].

E_0= MoE for longitudinal layers = 8000 MPa [36]

E_{90} = 266.67 MPa

G_0 = 500 MPa

G_R = 50 GPa [38]

E_0= MoE for transvers layers = 6000 MPa [36]

E_{90} = 200 MPa

G_0 = 375 MPa

G_R = 37.5 GPa [38]

L = span in mm (simple span; in direction of action //) [38]

$$\gamma_1 = \frac{1}{1+\frac{3.14^2\times 8000\times 42000}{5210^2}\times\frac{42}{37.5\times 1000}} = 0.936$$

$$\gamma_2 = \frac{1}{1+\frac{3.14^2\times 8000\times 42000}{5210^2}\times\frac{42}{37.5\times 1000}} = 0.936$$

$$a_1 = \frac{h_1}{2}+\frac{\overline{h_1}}{2}$$ [38]

$$a_2 = \frac{h_2}{2}+\frac{\overline{h_1}}{2}$$ [38]

$$a_1 = \frac{42}{2}+\frac{42}{2} = 42 \text{ mm}$$

$$a_2 = \frac{42}{2}+\frac{42}{2} = 42 \text{ mm}$$

$$EI_{eff\,//} = \sum_{i=1}^{2}(E_i I_i + \gamma_i E_i A_i {a_i}^2)$$ [38]

$$EI_{eff\,//} = (E_1 I_1 + \gamma_1 E_1 A_1 {a_1}^2) + (E_2 I_2 + \gamma_2 E_2 A_2 {a_2}^2)$$ [38]

$$EI_{eff} = (8000\times 6174000+0.936\times 8000\times 42000\times 42^2) + (8000\times 6174000+0.936\times 8000\times 42000\times 42^2)$$

$$= 6\times 10^{11}+6\times 10^{11}$$

$$= 1.208\times 10^{12} \text{ N.mm}^2$$

$$I_{eff} = \frac{1.208\times 10^{12}}{8000} = 1.51\times 10^{8} \text{ mm}^4$$

36.4 Calculation of Bending Strength using the Mechanically Jointed Beams Theory (Gamma Method)

$$M_r = \varnothing\times F_b\times\frac{I_{eff}}{(\delta_1 a_1+0.5h_1)} \quad (E_1 = E_2)$$ [38]

F_b = 14 MPa [36]

Ø = 0.9 [36], [38]

$$M_r = 0.9\times 14\times\frac{1.51\times 10^8}{(0.936\times 42+0.5\times 42)}\times 10^{-6} = 31.55 \text{ kN.m}$$

36.5 Calculation of Bending Strength using the Simplified Method

$M_r = \varnothing \times F_b \times \frac{I_{eff}}{0.5h_1}$ [38]

$F_b = 14$ [36]

$\varnothing = 0.9$ [36], [38]

$M_r = 0.9 \times 14 \times \frac{1.51 \times 10^8}{0.5 \times 126} \times 10^{-6} = 30.21$ kN.m

36.6 Calculation of Applied Bending Moment

$M^* = \frac{(1.2 \times \text{Dead Load} + 1.5 \times \text{Live Load}) \times Span^2}{8}$ [38], [39]

$M^* = \frac{(1.35 \times \text{Dead Load}) \times Span^2}{8}$ [38], [39]

Dead Load = CLT Weight + Additional Dead Load

CLT Weight = CLT Thickness × Timber Weight = 126 × (5/1000) = 0.63 kPa.

Additional Dead Load = 0.5 kPa.

Live Load = 2 kPa on Floor

$M^* = \frac{(1.2 \times (0.63+0.5) + 1.5 \times 2) \times 5.21^2}{8} = 14.78$ kN.m

$M^* = \frac{(1.35 \times (0.63+0.5)) \times 5.21^2}{8} = 5.75$ kN.m

36.7 Bending Capacity Check

$M_{r\ \text{Mechanical jointed method}}$ = 31.55 kN.m ≥ M^*= 14.78 kN.m √ ok

$M_{r\ \text{Mechanical jointed method}}$ = 31.55 kN.m ≥ M^*= 5.75 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 30.21 kN.m ≥ M^*= 14.78 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 30.21 kN.m ≥ M^*= 5.75 kN.m √ ok

36.8 Deflection Check

$\Delta_{\text{CLT Deflection}} = \frac{5\times(\text{Uniformly Distributed Applied Load})\times Span^4}{(384\times(EI_{eff}\ )}$ [38], [39]

$\Delta_{\text{CLT Deflection}} = \frac{5\times((\text{CLT Weight} + \text{Additional Dead Load}\ )+0.4\times\text{Live Load}\ )\times 3850^4}{(384\times(EI_{eff}\ ))}$

$\Delta_{\text{CLT Deflection}} = \frac{5\times((0.63+0.5)+0.4\times 2)\times 5210^4}{(384\times(1.208\times 10^{12}\ )}$ = 15.32 mm

Creep Factor (K_2) = 2

Long term deflection = $\frac{15.32}{2.4}\times 2$ = 12.77 mm → Long term deflection

Long term deflection = 12.77 mm ≤ $\Delta^{*} = \frac{5210}{400}$ = 13.025 mm √ ok

36.9 Vibration Check

$f = \frac{3.142}{2L^2}\sqrt{\frac{(EI)_{eff}^{1m}}{\rho\ A}}$ [40]

ρ × A = m = is the mass per unit area in kg/m^2.

L = is the floor span in m.

m = linear mass of the CLT for a 1-m wide panel (kg/m).

EI_{eff} = effective bending stiffness.

$f = \frac{3.142}{2\times 5.21^2}\sqrt{\frac{1.208\times 10^{12}}{500\ \times(1\times\frac{126}{1000})}}$ = 8.02 ≥ 8Hz √ ok

37.1 CLT Floor Panel Design – Longitudinal Direction

Calculation of the longitudinal members is based on the FPInnovation CLT design guide Mechanical jointed and simplified methods.

Figure 101: Red Stag CLT Panel Cross-Section

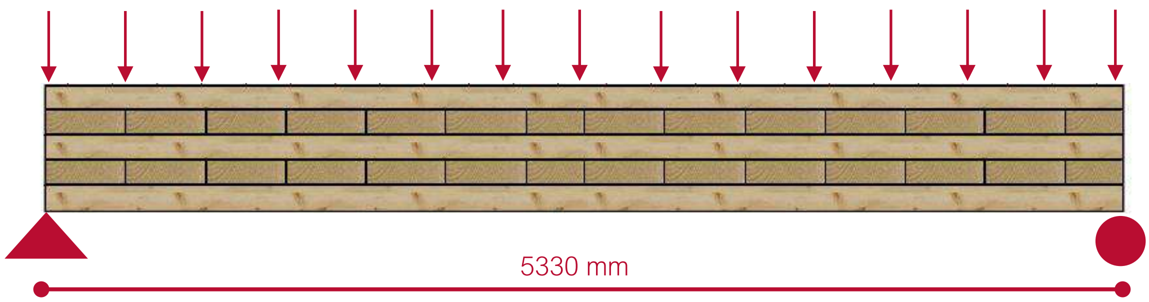

Figure 102: Red Stag CLT Panel Elevation

37.2 Assumption and Applied Loads:

Strength Reduction Factor (Ø) = 0.9 [36]

Bending Strength (F_b) = 14 MPa [36]

CLT Weight = 0.63 kPa - Calculated based on a Red Stag CLT density of 500 kg/m^3.

Additional Dead Load = 0.5 kPa

Live Load = 3.0 kPa - Refer to AS/NZS 1170.1 [37]

37.3 Calculation of the Effective Bending Stiffness using the Mechanical Jointed Beam Theory (Gamma Method)

L = Span of panels = 5330 mm = 5.33 m

b = Width of the CLT panel = 1 m [38]

h_i = Thickness of board layers in direction of action [38]

h_1 = 42 mm

h_2 = 42 mm

h_3 = 42 mm

$\overline{h_i}$ = Thickness of board layers in direction perpendicular to actions [38]

$\overline{h_1}$ = 42 mm

$\overline{h_2}$ = 42 mm

$A_i = b_i \times h_i$ [38]

$A_1 = (42\times1000) = 42000\ mm^2$

$A_2 = (42\times1000) = 42000\ mm^2$

$A_3 = (42\times1000) = 42000\ mm^2$

$I_i = \frac{b_i \times h_i{}^3}{12}$ [38]

$I_1 = \frac{b\times h_1{}^3}{12} = \frac{1000\times42^3}{12} = 6174000\ mm^4$

$I_2 = \frac{b\times h_3{}^3}{12} = \frac{1000\times42^3}{12} = 6174000\ mm^4$

$I_3 = \frac{b\times h_3{}^3}{12} = \frac{1000\times42^3}{12} = 6174000\ mm^4$

E_1 = 8000 MPa [36]

E_2 = 8000 MPa [36]

E_3 = 8000 MPa [36]

$\gamma_2 = 1$ [38]

$\gamma_1 = \frac{1}{1+\Pi^2\times\frac{E_1\times A_1}{L^2}\times\frac{\overline{h_1}}{G_R\times b}}$ [38]

$$\gamma_3 = \frac{1}{1+\Pi^2 \times \frac{E_3 \times A_3}{L^2} \times \frac{\overline{h_2}}{G_R \times b}}$$ [38]

where $\frac{h_i}{G_R \times b}$ = slip modulus due to shear deformation between layers and G_R = shear modulus perpendicular to the grain or rolling shear modulus [38].

E_0= MoE for longitudinal layers = 8000 MPa [36]	E_0= MoE for transvers layers = 6000 MPa [36]
E_{90} = 266.67 MPa	E_{90} = 200 MPa
G_0 = 500 MPa	G_0 = 375 MPa
G_R = 50 GPa [38]	G_R = 37.5 GPa [38]

L = span in mm (simple span; in direction of action //) [38]

$\gamma_2 = 1$ [38]

$$\gamma_1 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{5330^2} \times \frac{42}{37.5 \times 1000}} = 0.884$$

$$\gamma_3 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{5330^2} \times \frac{42}{37.5 \times 1000}} = 0.884$$

$$\overline{a_1} = \frac{h_1}{2} + \overline{h_1} + \frac{h_2}{2}$$ [38]

$$\overline{a_2} = \frac{h_2}{2} + \overline{h_2} + \frac{h_3}{2}$$ [38]

$$\overline{a_1} = \frac{42}{2} + 42 + \frac{42}{2} = 82 \text{ mm}$$

$$\overline{a_2} = \frac{42}{2} + 42 + \frac{42}{2} = 82 \text{ mm}$$

$$EI_{eff\,//} = \sum_{i=1}^{2} (E_i I_i + \gamma_i E_i A_i a_i^2)$$ [38]

$$EI_{eff\,//} = (E_1 I_1 + \gamma_1 E_1 A_1 a_1^2) + I_2 + (E_3 I_3 + \gamma_3 E_3 A_3 a_3^2)$$ [38]

$EI_{eff} = 4.34 \times 10^{12}$ N.mm^2

$$I_{eff} = \frac{4.34 \times 10^{12}}{8000} = 5.43 \times 10^8 \text{ mm}^4$$

37.4 Calculation of Bending Strength using the Mechanically Jointed Beams Theory (Gamma Method)

$M_r = \varnothing \times F_b \times \frac{I_{eff}}{(\delta_1 a_1 + 0.5h_1)}$ $(E_1 = E_2)$ [38]

$F_b = 14$ MPa [36]

$\varnothing = 0.9$ [36], [38]

$M_r = 0.9 \times 14 \times \frac{5.43 \times 10^8}{(0.884 \times 84 + 0.5 \times 42)} \times 10^{-6} = 71.76$ kN.m

37.5 Calculation of Bending Strength using the Simplified Method

$M_r = \varnothing \times F_b \times \frac{I_{eff}}{0.5h_1}$ [38]

$F_b = 14$ [36]

$\varnothing = 0.9$ [36], [38]

$M_r = 0.9 \times 14 \times \frac{5.43 \times 10^8}{0.5 \times 210} \times 10^{-6} = 28.81$ kN.m

37.6 Calculation of Applied Bending Moment

$M^* = \frac{(1.2 \times \text{Dead Load} + 1.5 \times \text{Live Load}) \times Span^2}{8}$ [38], [39]

$M^* = \frac{(1.35 \times \text{Dead Load}) \times Span^2}{8}$ [38], [39]

Dead Load = CLT Weight + Additional Dead Load

CLT Weight = CLT Thickness × Timber Weight = 210 × (5/1000) = 1.08 kPa.

Additional Dead Load = 0.5 kPa.

Live Load = 2 kPa on Floor

$M^* = \frac{(1.2 \times (1.08 + 0.5) + 1.5 \times 3) \times 5.33^2}{8} = 22.59$ kN.m

$M^* = \frac{(1.35 \times (1.08 + 0.5)) \times 5.33^2}{8} = 8.26$ kN.m

37.7 Bending Capacity Check

$M_{r\ \text{Mechanical jointed method}}$ = 71.76 kN.m ≥ M^*= 22.59 kN.m √ ok

$M_{r\ \text{Mechanical jointed method}}$ = 71.76 kN.m ≥ M^*= 8.26 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 65.13 kN.m ≥ M^*= 22.59 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 65.13 kN.m ≥ M^*= 8.26 kN.m √ ok

37.8 Deflection Check

$$\Delta_{\text{CLT Deflection}} = \frac{5\times(\text{Uniformly Distributed Applied Load})\times Span^4}{(384\times(EI_{eff}\,)}$$ [38], [39]

$$\Delta_{\text{CLT Deflection}} = \frac{5\times((\text{CLT Weight} + \text{Additional Dead Load}\,)+0.4\times\text{Live Load}\,)\times5330^4}{(384\times(EI_{eff}\,))}$$

$$\Delta_{\text{CLT Deflection}} = \frac{5\times((1.08+0.5)+0.4\times3)\times5330^4}{(384\times(4.34\times10^{12}\,)} = 6.66\text{ mm}$$

Creep Factor (K_2) = 2

Long term deflection = 6.66 × 2 = 13.31 mm → long term deflection

Long term deflection = 13.31 ≤ $\Delta^* = \frac{5330}{400}$ = 13.325 mm √ ok

37.9 Vibration Check

$$L \le 0.11\,\frac{(\frac{(EI)_{eff}}{10^6})^{0.293}}{m^{0.123}}$$ [41]

L = vibration -controlled span limit in m.

L = is the floor span in m.

m = linear mass of the CLT for a 1-m wide panel (kg/m).

EI_{eff} = effective bending stiffness.

$$L \le 0.11\,\frac{(\frac{4.34\times10^{12}}{10^6})^{0.293}}{(1.0\times0.210\times500)^{0.123}} = 5.47\text{ m} \ge 5.33\text{ m}$$ √ ok

38.1 CLT Floor Panel Design – Longitudinal Direction

Calculation of the longitudinal members is based on the FPInnovation CLT design guide Mechanical jointed and simplified methods.

Figure 103: Red Stag CLT Panel Cross-Section

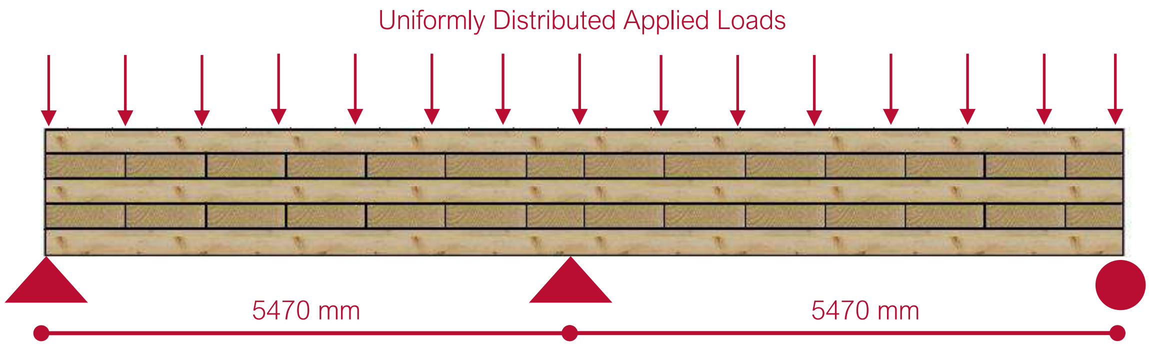

Figure 104: Red Stag CLT Panel Elevation

38.2 Assumption and Applied Loads:

Strength Reduction Factor (Ø) = 0.9 [36]

Bending Strength (F_b) = 14 MPa [36]

CLT Weight = 0.63 kPa - Calculated based on a Red Stag CLT density of 500 kg/m^3.

Additional Dead Load = 0.5 kPa

Live Load = 3.0 kPa - Refer to AS/NZS 1170.1 [37]

38.3 Calculation of the Effective Bending Stiffness using the Mechanical Jointed Beam Theory (Gamma Method)

L = Span of panels = 5470 mm = 5.47 m

b = Width of the CLT panel = 1 m [38]

h_i = Thickness of board layers in direction of action [38]

h_1 = 42 mm

h_2 = 42 mm

h_3 = 42 mm

$\overline{h_i}$ = Thickness of board layers in direction perpendicular to actions [38]

$\overline{h_1}$ = 42 mm

$\overline{h_2}$ = 42 mm

$A_i = b_i \times h_i$ [38]

$A_1 = (42\times1000) = 42000\ mm^2$

$A_2 = (42\times1000) = 42000\ mm^2$

$A_3 = (42\times1000) = 42000\ mm^2$

$I_i = \frac{b_i \times {h_i}^3}{12}$ [38]

$I_1 = \frac{b \times {h_1}^3}{12} = \frac{1000\times42^3}{12} = 6174000\ mm^4$

$I_2 = \frac{b \times {h_3}^3}{12} = \frac{1000\times42^3}{12} = 6174000\ mm^4$

$I_3 = \frac{b \times {h_3}^3}{12} = \frac{1000\times42^3}{12} = 6174000\ mm^4$

E_1 = 8000 MPa [36]

E_2 = 8000 MPa [36]

E_3 = 8000 MPa [36]

$\gamma_2 = 1$ [38]

$\gamma_1 = \frac{1}{1+\Pi^2 \times \frac{E_1 \times A_1}{L^2} \times \frac{h_1}{G_R \times b}}$ [38]

$\gamma_3 = \frac{1}{1+\Pi^2 \times \frac{E_3 \times A_3}{L^2} \times \frac{h_2}{G_R \times b}}$ [38]

where $\frac{h_i}{G_R \times b}$ = slip modulus due to shear deformation between layers and G_R = shear modulus perpendicular to the grain or rolling shear modulus [38].

E_0= MoE for longitudinal layers = 8000 MPa [36]	E_0= MoE for transvers layers = 6000 MPa [36]
E_{90} = 266.67 MPa	E_{90} = 200 MPa
G_0 = 500 MPa	G_0 = 375 MPa
G_R = 50 GPa [38]	G_R = 37.5 GPa [38]

L = span in mm (simple span; in direction of action //) [38]

$\gamma_1 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{5470^2} \times \frac{42}{37.5 \times 1000}} = 0.890$

$\gamma_3 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{5470^2} \times \frac{42}{37.5 \times 1000}} = 0.890$

$\overline{a_1} = \frac{h_1}{2} + \overline{h_1} + \frac{h_2}{2} - a_2$ [38]

$\overline{a_2} = \frac{h_2}{2} + \overline{h_2} + \frac{h_3}{2} - a_2$ [38]

$a_2 = 0$

$\overline{a_1} = \frac{42}{2} + 42 + \frac{42}{2} - 0 = 82$ mm

$\overline{a_2} = \frac{42}{2} + 42 + \frac{42}{2} - 0 = 82$ mm

$EI_{eff\,//} = \sum_{i=1}^{2} (E_i I_i + \gamma_i E_i A_i a_i^2)$ [38]

$EI_{eff\,//} = (E_1 I_1 + \gamma_1 E_1 A_1 a_1^2) + I_2 + (E_3 I_3 + \gamma_3 E_3 A_3 a_3^2)$ [38]

$EI_{eff} = 4.37 \times 10^{12}$ N.mm^2

$I_{eff} = \frac{4.37\times10^{12}}{8000} = 5.46 \times 10^{8}\ mm^{4}$

38.4 Calculation of Bending Strength using the Mechanically Jointed Beams Theory (Gamma Method)

$M_r = \varnothing\times F_b\times\frac{I_{eff}}{(\delta_1 a_1+0.5h_1)}$ $(E_1 = E_2)$ [38]

F_b = 14 MPa [36]

$\varnothing$ = 0.9 [36], [38]

$M_r = 0.9 \times 14 \times \frac{5.46 \times 10^8}{(0.890 \times 84+0.5\times42)} \times 10^{-6} = 71.84$ kN.m

38.5 Calculation of Bending Strength using the Simplified Method

$M_r = \varnothing \times F_b \times \frac{I_{eff}}{0.5h_1}$ [38]

F_b = 14 [36]

$\varnothing$ = 0.9 [36], [38]

$M_r = 0.9 \times 14 \times \frac{5.46 \times 10^8}{0.5\times210}\times10^{-6} = 65.50$ kN.m

38.6 Calculation of Applied Bending Moment

$M^* = \frac{(1.2\times\text{Dead Load}+ 1.5\times\text{Live Load})\times Span^2}{8}$ [38], [39]

$M^* = \frac{(1.35\times\text{Dead Load})\times Span^2}{8}$ [38], [39]

Dead Load = CLT Weight + Additional Dead Load

CLT Weight = CLT Thickness × Timber Weight = 210 × (5/1000) = 1.08 kPa.

Additional Dead Load = 0.5 kPa.

Live Load = 3 kPa on Floor

$M^* = \frac{(1.2\times(1.08+0.5)+ 1.5\times3)\times5.33^2}{8} = 22.59$ kN.m

$M^* = \frac{(1.35\times(1.08+0.5))\times5.33^2}{8} = 8.26$ kN.m

38.7 Bending Capacity Check

$M_{r\text{ Mechanical jointed method}}$ = 71.84 kN.m ≥ M^*= 22.59 kN.m √ ok

$M_{r\text{ Mechanical jointed method}}$ = 71.84 kN.m ≥ M^*= 8.26 kN.m √ ok

$M_{r\text{ Simplified method}}$ = 65.50 kN.m ≥ M^*= 22.59 kN.m √ ok

$M_{r\text{ Simplified method}}$ = 65.50 kN.m ≥ M^*= 8.26 kN.m √ ok

38.8 Deflection Check

$$\Delta_{\text{CLT Deflection}} = \frac{5\times(\text{Uniformly Distributed Applied Load})\times Span^4}{(384\times(EI_{eff})}$$ [38], [39]

$$\Delta_{\text{CLT Deflection}} = \frac{5\times((\text{CLT Weight} + \text{Additional Dead Load})+0.4\times\text{Live Load})\times 5470^4}{(384\times(EI_{eff}))}$$

$$\Delta_{\text{CLT Deflection}} = \frac{5\times((1.08+0.5)+0.4\times 3)\times 5470^4}{(384\times(4.37\times 10^{12})} = 6.66\text{ mm}$$

Creep Factor (K_2) = 2

Long term deflection = $\frac{7.34}{2.4}\times 2$ = 6.12 mm → long term deflection

Long term deflection = 6.12 ≤ $\Delta^* = \frac{5470}{400}$ = 13.675 mm √ ok

38.9 Vibration Check

$$L \leq 0.11\frac{(\frac{(EI)_{eff}}{10^6})^{0.293}}{m^{0.123}}$$ [41]

L = vibration -controlled span limit in m.

L = is the floor span in m.

m = linear mass of the CLT for a 1-m wide panel (kg/m).

EI_{eff} = effective bending stiffness.

$$L \leq 0.11\frac{(\frac{4.37\times 10^{12}}{10^6})^{0.293}}{(1.0\times 0.210\times 500)^{0.123}} = 5.47\text{ m} \geq 5.47\text{ m}$$ √ ok

39.1 CLT Floor Panel Design – Longitudinal Direction

Calculation of the longitudinal members is based on the FPInnovation CLT design guide Mechanical jointed and simplified methods.

Figure 105: Red Stag CLT Panel Cross-Section

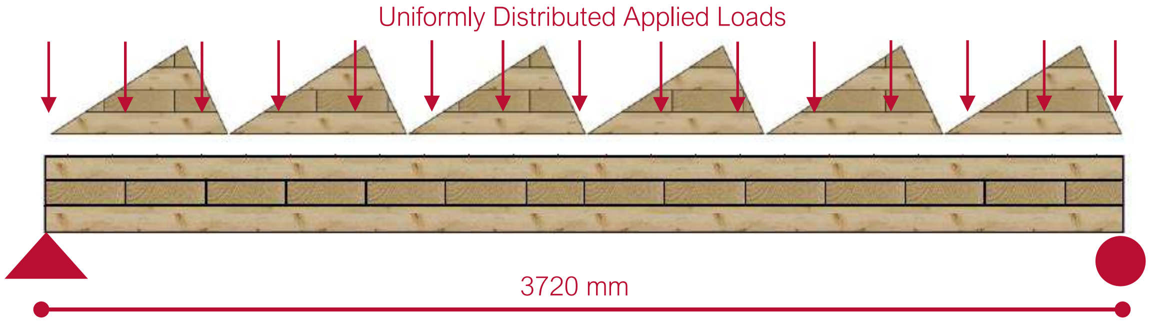

Figure 106: Red Stag CLT Panel Elevation

39.2 Assumption and Applied Loads:

Strength Reduction Factor (Ø) = 0.9 [36]

Bending Strength (F_b) = 14 MPa [36]

CLT Weight = 0.63 kPa - Calculated based on a Red Stag CLT density of 500 kg/m^3.

Additional Dead Load (Trade & Riser Weight) = 0.3 kPa

Live Load = 3.0 kPa - Refer to AS/NZS 1170.1 [37]

39.3 Calculation of the Effective Bending Stiffness using the Mechanical Jointed Beam Theory (Gamma Method)

L = Span of panels = 3850 mm = 3.72 m

b = Width of the CLT panel = 1 m [38]

h_i = Thickness of board layers in direction of action [38]

h_1 = 42 mm

h_2 = 42 mm

$\overline{h_i}$ = Thickness of board layers in direction perpendicular to actions [38]

$\overline{h_1}$ = 42 mm

$A_i = b_i \times h_i$ [38]

$A_1 = (42\times1000) = 42000 \text{ mm}^2$

$A_2 = (42\times1000) = 42000 \text{ mm}^2$

$I_1 = \frac{b_i \times {h_i}^3}{12}$ [38]

$I_1 = \frac{b \times {h_1}^3}{12} = \frac{1000\times42^3}{12} = 6174000 \text{ mm}^4$

$I_2 = \frac{b \times {h_3}^3}{12} = \frac{1000\times42^3}{12} = 6174000 \text{ mm}^4$

E_1 = 8000 MPa [36]

E_2 = 8000 MPa [36]

$\gamma_1 = \frac{1}{1+\Pi^2\times\frac{E_1\times A_1}{L^2}\times\frac{\overline{h_1}}{G_R\times b}}$ [38]

$\gamma_2 = \frac{1}{1+\Pi^2\times\frac{E_3\times A_3}{L^2}\times\frac{\overline{h_2}}{G_R\times b}}$ [38]

where $\frac{h_i}{G_R \times b}$ = slip modulus due to shear deformation between layers and G_R = shear modulus perpendicular to the grain or rolling shear modulus [38].

E_0= MoE for longitudinal layers = 8000 MPa [36]	E_0= MoE for transvers layers = 6000 MPa [36]
E_{90} = 266.67 MPa	E_{90} = 200 MPa
G_0 = 500 MPa	G_0 = 375 MPa
G_R = 50 GPa [38]	G_R = 37.5 GPa [38]

L = span in mm (simple span; in direction of action //) [38]

$$\gamma_1 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{3720^2} \times \frac{42}{37.5 \times 1000}} = 0.882$$

$$\gamma_2 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{3720^2} \times \frac{42}{37.5 \times 1000}} = 0.882$$

$$\overline{a_1} = \frac{h_1}{2} + \frac{h_1}{2}$$ [38]

$$\overline{a_1} = \frac{h_2}{2} + \frac{h_1}{2}$$ [38]

$$\overline{a_1} = \frac{42}{2} + \frac{42}{2} = 42 \text{ mm}$$

$$\overline{a_2} = \frac{42}{2} + \frac{42}{2} = 42 \text{ mm}$$

$$EI_{eff\,//} = \sum_{i=1}^{2}(E_i I_i + \gamma_i E_i A_i {a_i}^2)$$ [38]

$$EI_{eff\,//} = (E_1 I_1 + \gamma_1 E_1 A_1 {a_1}^2) + (E_2 I_2 + \gamma_2 E_2 A_2 {a_2}^2)$$ [38]

EI_{eff}=(8000×6174000+0.882×8000×42000×42^2)+(8000×6174000+0.882×42000×8000×42^2) = $5.72\times10^{11}+5.72\times10^{11}$= 1.145×10^{12} N.mm^2

$$I_{eff} = \frac{1.145\times10^{12}}{8000} = 1.43 \times 10^8 \text{ mm}^4$$

39.4 Calculation of Bending Strength using the Mechanically Jointed Beams Theory (Gamma Method)

$M_r = Ø \times F_b \times \frac{I_{eff}}{(\delta_1 a_1 + 0.5 h_1)}$ $(E_1 = E_2)$ [38]

F_b = 14 MPa [36]

Ø = 0.9 [36], [38]

$M_r = 0.9 \times 14 \times \frac{1.145 \times 10^8}{(0.882 \times 42 + 0.5 \times 42)} \times 10^{-6} = 31.05$ kN.m

39.5 Calculation of Bending Strength using the Simplified Method

$M_r = Ø \times F_b \times \frac{I_{eff}}{0.5 h_1}$ [38]

F_b = 14 [36]

Ø = 0.9 [36], [38]

$M_r = 0.9 \times 14 \times \frac{1.43 \times 10^8}{0.5 \times 126} \times 10^{-6} = 28.63$ kN.m

39.6 Calculation of Applied Bending Moment

$M^* = \frac{(1.2 \times \text{Dead Load} + 1.5 \times \text{Live Load}) \times Span^2}{8}$ [38], [39]

$M^* = \frac{(1.35 \times \text{Dead Load}) \times Span^2}{8}$ [38], [39]

Dead Load = CLT Weight + Additional Dead Load

CLT Weight = CLT Thickness × Timber Weight = 126 × (5/1000) = 0.63 kPa.

Additional Dead Load = 0.5 kPa.

Live Load = 3 kPa on Stair Stringer

$M^* = \frac{(1.2 \times (0.63+0.3) + 1.5 \times 3) \times 3.725^2}{8} = 9.77$ kN.m

$M^* = \frac{(1.35 \times (0.63+0.3)) \times 3.725^2}{8} = 2.43$ kN.m

39.7 Bending Capacity Check

$M_{r\ \text{Mechanical jointed method}}$ = 31.05 kN.m ≥ M^*= 9.77 kN.m √ ok

$M_{r\ \text{Mechanical jointed method}}$ = 31.05 kN.m ≥ M^*= 2.43 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 28.62 kN.m ≥ M^*= 9.77 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 28.62 kN.m ≥ M^*= 2.43 kN.m √ ok

39.8 Deflection Check

$$\Delta_{\text{CLT Deflection}} = \frac{5\times(\text{Uniformly Distributed Applied Load})\times Span^4}{(384\times(EI_{eff})}$$ [38], [39]

$$\Delta_{\text{CLT Deflection}} = \frac{5\times((\text{CLT Weight} + \text{Additional Dead Load})+0.4\times\text{Live Load})\times 3720^4}{(384\times(EI_{eff}))}$$

$$\Delta_{\text{CLT Deflection}} = \frac{5\times((0.63+0.3)+0.4\times 3)\times 3720^4}{(384\times(1.145\times 10^{12})} = 4.64 \text{ mm}$$

Creep Factor (K_2) = 2

Long term deflection = 4.64 × 2 = 9.28 mm → long term deflection

Long term deflection = 9.28 ≤ $\Delta^* = \frac{3720}{400}$ = 9.30 mm √ ok

39.9 Vibration Check

$$L \leq 0.11\,\frac{\left(\frac{(EI)_{eff}}{10^6}\right)^{0.293}}{m^{0.123}}$$

L = vibration -controlled span limit in m.
m = linear mass of the CLT for a 1-m wide panel (kg/m).
EI_{eff} = effective bending stiffness.

$$L \leq 0.11\,\frac{\left(\frac{1.145\times 10^{12}}{10^6}\right)^{0.293}}{(1.0\times 0.126\times 500)^{0.123}} = 3.94 \text{ m}$$

Vibration span = 3.94 ≥ Maximum length of the CLT panels = 3.72 m √ ok

40.1 CLT Roof Panel Design – Longitudinal Direction

Calculation of the longitudinal members is based on the FPInnovation CLT design guide Mechanical jointed and simplified methods.

Figure 107: Red Stag CLT Panel Cross-Section

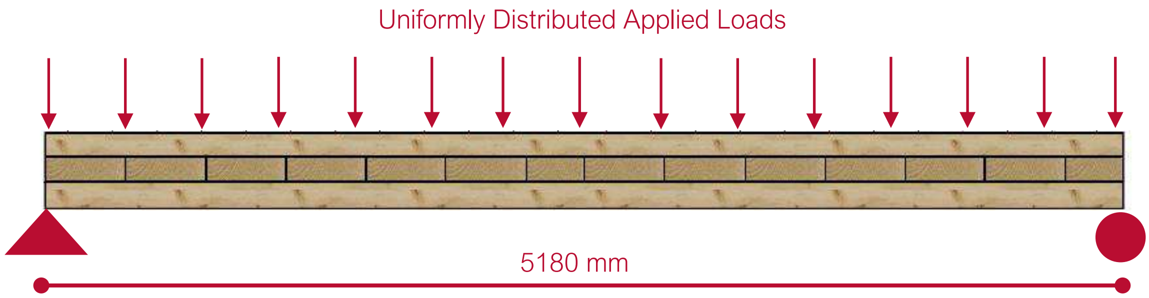

Figure 108: Red Stag CLT Panel Elevation

40.2 Assumption and Applied Loads:

Strength Reduction Factor (Ø) = 0.9 [36]

Bending Strength (F_b) = 14 MPa [36]

CLT Weight = 0.63 kPa - Calculated based on a Red Stag CLT density of 500 kg/m^3.

Additional Dead Load = 0.1 kPa

Live Load = 0.25 kPa - Refer to AS/NZS 1170.1 [37]

40.3 Calculation of the Effective Bending Stiffness using the Mechanical Jointed Beam Theory (Gamma Method)

L = Span of panels = 5180 mm = 5.18 m

b = Width of the CLT panel = 1 m [38]

h_i = Thickness of board layers in direction of action [38]

h_1 = 42 mm

h_2 = 42 mm

$\overline{h_i}$ = Thickness of board layers in direction perpendicular to actions [38]

$\overline{h_1}$ = 42 mm

$A_i = b_i \times h_i$ [38]

A_1 = (42×1000) = 42000 mm^2

A_2 = (42×1000) = 42000 mm^2

$I_1 = \frac{b_i \times {h_i}^3}{12}$ [38]

$I_1 = \frac{b \times {h_1}^3}{12} = \frac{1000 \times 42^3}{12}$ = 6174000 mm^4

$I_2 = \frac{b \times {h_3}^3}{12} = \frac{1000 \times 42^3}{12}$ = 6174000 mm^4

E_1 = 8000 MPa [36]

E_2 = 8000 MPa [36]

$\gamma_1 = \frac{1}{1+\Pi^2 \times \frac{E_1 \times A_1}{L^2} \times \frac{\overline{h_1}}{G_R \times b}}$ [38]

$\gamma_2 = \frac{1}{1+\Pi^2 \times \frac{E_3 \times A_3}{L^2} \times \frac{\overline{h_2}}{G_R \times b}}$ [38]

where $\frac{h_i}{G_R \times b}$ = slip modulus due to shear deformation between layers and G_R = shear modulus perpendicular to the grain or rolling shear modulus [38].

E_0= MoE for longitudinal layers = 8000 MPa [36]	E_0= MoE for transvers layers = 6000 MPa [36]
E_{90} = 266.67 MPa	E_{90} = 200 MPa
G_0 = 500 MPa	G_0 = 375 MPa
G_R = 50 GPa [38]	G_R = 37.5 GPa [38]

L = span in mm (simple span; in direction of action //) [38]

$\gamma_1 = \frac{1}{1+\frac{3.14^2\times8000\times42000}{5180^2}\times\frac{42}{37.5\times1000}} = 0.935$

$\gamma_2 = \frac{1}{1+\frac{3.14^2\times8000\times42000}{5180^2}\times\frac{42}{37.5\times1000}} = 0.935$

$\overline{a}_1 = \frac{h_1}{2} + \frac{h_1}{2}$ [38]

$\overline{a}_1 = \frac{h_2}{2} + \frac{h_1}{2}$ [38]

$\overline{a}_1 = \frac{42}{2} + \frac{42}{2} = 42$ mm

$\overline{a}_2 = \frac{42}{2} + \frac{42}{2} = 42$ mm

$EI_{eff\,//} = \sum_{i=1}^{2}(E_i I_i + \gamma_i E_i A_i a_i{}^2)$ [38]

$EI_{eff\,//} = (E_1 I_1 + \gamma_1 E_1 A_1 a_1{}^2) + (E_2 I_2 + \gamma_2 E_2 A_2 a_2{}^2)$ [38]

$EI_{eff}=(8000\times6174000+0.935\times8000\times42000\times42^2)+(8000\times6174000+0.935\times42000\times8000\times42^2)$

$= 6.038\times10^{11}+6.038\times10^{11}= 1.207\times10^{12}$ N.mm^2

$I_{eff} = \frac{1.207\times10^{12}}{8000} = 1.509\times10^{8}$ mm^4

40.4 Calculation of Bending Strength using the Mechanically Jointed Beams Theory (Gamma Method)

$M_r = \varnothing\times F_b\times\frac{I_{eff}}{(\delta_1 a_1+0.5h_1)}$ $(E_1 = E_2)$ [38]

$F_b = 14$ MPa [36]

$\varnothing = 0.9$ [36], [38]

$M_r = 0.9\times14\times\frac{1.509\times10^8}{(0.935\times42+0.5\times42)}\times10^{-6} = 31.55$ kN.m

40.5 Calculation of Bending Strength using the Simplified Method

$M_r = Ø \times F_b \times \frac{I_{eff}}{0.5h_1}$ [38]

$F_b = 14$ [36]

$Ø = 0.9$ [36], [38]

$M_r = 0.9 \times 14 \times \frac{1.509 \times 10^8}{0.5 \times 126} \times 10^{-6} = 30.19$ kN.m

40.6 Calculation of Applied Bending Moment

$M^* = \frac{(1.2 \times \text{Dead Load} + 1.5 \times \text{Live Load}) \times Span^2}{8}$ [38], [39]

$M^* = \frac{(1.35 \times \text{Dead Load}) \times Span^2}{8}$ [38], [39]

Dead Load = CLT Weight + Additional Dead Load

CLT Weight = CLT Thickness × Timber Weight = 126 × (5/1000) = 0.63 kPa.

Additional Dead Load = 0.1 kPa.

Live Load = 0.25 kPa on Roof

$M^* = \frac{(1.2 \times (0.63+0.1) + 1.5 \times 0.25) \times 5180^2}{8} = 4.20$ kN.m

$M^* = \frac{(1.35 \times (0.63+0.1)) \times 5180^2}{8} = 3.67$ kN.m

40.7 Bending Capacity Check

$M_{r\ \text{Mechanical jointed method}}$ = 31.55 kN.m ≥ M^*= 4.20 kN.m √ ok

$M_{r\ \text{Mechanical jointed method}}$ = 31.55 kN.m ≥ M^*= 3.67 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 30.19 kN.m ≥ M^*= 4.20 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 30.19 kN.m ≥ M^*= 3.67 kN.m √ ok

40.8 Deflection Check

$\Delta_{\text{CLT Deflection}} = \frac{5\times(\text{Uniformly Distributed Applied Load})\times Span^4}{(384\times(EI_{eff}))}$ [38], [39]

$\Delta_{\text{CLT Deflection}} = \frac{5\times((\text{CLT Weight} + \text{Additional Dead Load}) + 0.4\times\text{Live Load})\times 8150^4}{(384\times(EI_{eff}))}$

$\Delta_{\text{CLT Deflection}} = \frac{5\times((0.63+0.1)+0.4\times0.25)\times5180^4}{(384\times(1.207\times10^{12}))}$ = 6.44 mm

Creep Factor (K_2) = 2

Long term deflection = 6.44 × 2 = 12.89 mm → long term deflection

Long term deflection = 12.89 ≤ $\Delta^* = \frac{5180}{400}$ = 12.95 mm √ ok

41.1 CLT Roof Panel Design – Longitudinal Direction

Calculation of the longitudinal members is based on the FPInnovation CLT design guide Mechanical jointed and simplified methods.

Figure 109: Red Stag CLT Panel Cross-Section

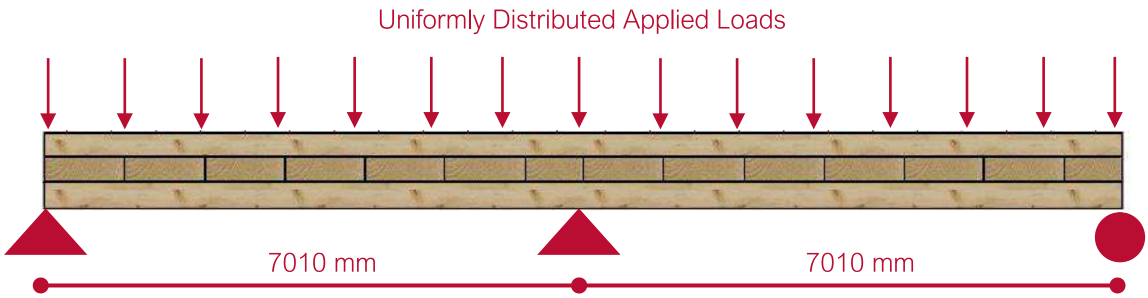

Figure 110: Red Stag CLT Panel Elevation

41.2 Assumption and Applied Loads:

Strength Reduction Factor (Ø) = 0.9 [36]

Bending Strength (F_b) = 14 MPa [36]

CLT Weight = 0.63 kPa - Calculated based on a Red Stag CLT density of 500 kg/m^3.

Additional Dead Load = 0.1 kPa

Live Load = 0.25 kPa - Refer to AS/NZS 1170.1 [7]

41.3 Calculation of the Effective Bending Stiffness using the Mechanical Jointed Beam Theory (Gamma Method)

L = Span of panels = 7010 mm = 7.01 m

b = Width of the CLT panel = 1 m [38]

h_i = Thickness of board layers in direction of action [38]

h_1 = 42 mm

h_2 = 42 mm

$\overline{h_i}$ = Thickness of board layers in direction perpendicular to actions [38]

$\overline{h_1}$ = 42 mm

$A_i = b_i \times h_i$ [38]

A_1 = (42×1000) = 42000 mm^2

A_2 = (42×1000) = 42000 mm^2

$I_1 = \frac{b_i \times {h_i}^3}{12}$ [38]

$I_1 = \frac{b \times {h_1}^3}{12} = \frac{1000 \times 42^3}{12}$ = 6174000 mm^2

$I_2 = \frac{b \times {h_3}^3}{12} = \frac{1000 \times 42^3}{12}$ = 6174000 mm^2

E_1 = 8000 MPa [36]

E_2 = 8000 MPa [36]

$\gamma_1 = \frac{1}{1+\Pi^2 \times \frac{E_1 \times A_1}{L^2} \times \frac{\overline{h_1}}{G_R \times b}}$ [38]

$\gamma_2 = \frac{1}{1+\Pi^2 \times \frac{E_3 \times A_3}{L^2} \times \frac{\overline{h_2}}{G_R \times b}}$ [38]

where $\frac{h_i}{G_R \times b}$ = slip modulus due to shear deformation between layers and G_R = shear modulus perpendicular to the grain or rolling shear modulus [38].

E_0= MoE for longitudinal layers = 8000 MPa [36]	E_0= MoE for transvers layers = 6000 MPa [36]
E_{90} = 266.67 MPa	E_{90} = 200 MPa
G_0 = 500 MPa	G_0 = 375 MPa
G_R = 50 GPa [38]	G_R = 37.5 GPa [38]

L = span in mm (simple span; in direction of action //) [38]

$\gamma_1 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{7010^2} \times \frac{42}{37.5 \times 1000}}$ = 0.9636

$\gamma_2 = \frac{1}{1+\frac{3.14^2 \times 8000 \times 42000}{7010^2} \times \frac{42}{37.5 \times 1000}}$ = 0.9636

$a_1 = \frac{h_1}{2} + \frac{\overline{h_1}}{2}$ [38]

$a_1 = \frac{h_2}{2} + \frac{\overline{h_1}}{2}$ [38]

$a_1 = \frac{42}{2} + \frac{42}{2}$ = 42 mm

$a_2 = \frac{42}{2} + \frac{42}{2}$ = 42 mm

$EI_{eff\,//} = \sum_{i=1}^{2}(E_i I_i + \gamma_i E_i A_i a_i^2)$ [38]

$EI_{eff\,//} = (E_1 I_1 + \gamma_1 E_1 A_1 a_1^2) + (E_2 I_2 + \gamma_2 E_2 A_2 a_2^2)$ [38]

$EI_{eff} = (8000 \times 6174000 + 0.9636 \times 8000 \times 42000 \times 42^2) + (8000 \times 6174000 + 0.9636 \times 8000 \times 42000 \times 42^2)$

$= 1.241 \times 10^{12}$ N.mm^2

$I_{eff} = \frac{1.241 \times 10^{12}}{8000} = 1.55 \times 10^8$ mm^4

41.4 Calculation of Bending Strength using the Mechanically Jointed Beams Theory (Gamma Method)

$M_r = \varnothing \times F_b \times \frac{I_{eff}}{(\delta_1 a_1 + 0.5 h_1)}$ $(E_1 = E_2)$ [38]

F_b = 14 MPa [36]

$\varnothing$ = 0.9 [36], [38]

$M_r = 0.9 \times 14 \times \frac{1.51 \times 10^8}{(0.9636 \times 42 + 0.5 \times 42)} \times 10^{-6}$ = 31.55 kN.m

41.5 Calculation of Bending Strength using the Simplified Method

$M_r = \varnothing \times F_b \times \frac{I_{eff}}{0.5 h_1}$ [38]

F_b = 14 [36]

$\varnothing$ = 0.9 [36], [38]

$M_r = 0.9 \times 14 \times \frac{1.55 \times 10^8}{0.5 \times 126} \times 10^{-6}$ = 31.80 kN.m

41.6 Calculation of Applied Bending Moment

$M^* = \frac{(1.2 \times \text{Dead Load} + 1.5 \times \text{Live Load}) \times Span^2}{8}$ [38], [39]

$M^* = \frac{(1.35 \times \text{Dead Load}) \times Span^2}{8}$ [38], [39]

Dead Load = CLT Weight + Additional Dead Load

CLT Weight = CLT Thickness × Timber Weight = 126 × (5/1000) = 0.63 kPa.

Additional Dead Load = 0.1 kPa.

Live Load = 0.25 kPa on Roof

$M^* = \frac{(1.2 \times (0.63+0.1) + 1.5 \times 0.25) \times 7.01^2}{8}$ = 7.68 kN.m

$M^* = \frac{(1.35 \times (0.63+0.1)) \times 7.01^2}{8}$ = 6.73 kN.m

41.7 Bending Capacity Check

$M_{r\ \text{Mechanical jointed method}}$ = 31.80 kN.m ≥ M^*= 7.68 kN.m √ ok

$M_{r\ \text{Mechanical jointed method}}$ = 31.80 kN.m ≥ M^*= 6.73 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 31.03 kN.m ≥ M^*= 7.68 kN.m √ ok

$M_{r\ \text{Simplified method}}$ = 31.03 kN.m ≥ M^*= 6.73 kN.m √ ok

41.8 Deflection Check

$\Delta_{\text{CLT Deflection}} = \frac{5 \times (\text{Uniformly Distributed Applied Load}) \times Span^4}{(384 \times (EI_{eff}\ )}$ [38], [39]

$\Delta_{\text{CLT Deflection}} = \frac{5 \times ((\text{CLT Weight} + \text{Additional Dead Load}) + 0.4 \times \text{Live Load}) \times 7010^4}{(384 \times (EI_{eff}))}$

$\Delta_{\text{CLT Deflection}} = \frac{5 \times ((0.63+0.1) + 0.4 \times 0.25) \times 7010^4}{(384 \times (1.241 \times 10^{12})}$ = 21.03 mm

Creep Factor (K_2) = 2

Long term deflection = $\frac{21.03}{2.4}$× 2 = 17.52 mm → Long term deflection

Long term deflection = 17.52 mm ≤ $\Delta^* = \frac{7010}{400}$ = 17.52 mm √ ok

Section 11

Cross Laminated Timber Acoustic Performance

Make it better

Red Stag CLT Design Guide V1.3
September 2022

RED STAG WOOD SOLUTIONS

42. Overview

Considering the management of noise transfer through buildings is important for ensuring a sense of comfort. Acoustic performance of buildings should be considered during the early phases of the design process, subject to the Sound Transmission Class (STC) and Impact Insulation Class (ICC) of the building type. Cross Laminated Timber (CLT) has a large number of benefits compared to traditional building materials, including but not limited to: speed of construction, lighter/reduced foundations, sequesters carbon, renewable and environmentally friendly, cost effective; however, as it is lighter, acoustic management is very important to mitigate the transfer of unwanted sound (refer to *Figure 111*).

The acoustic section of this design guide details the options for acoustic management using Red Stag CLT.

43. Sound Transmission and Insulation

Sound striking the surface of a building element will be partly reflected and partly transmitted into the element. Depending on the construction of the building element, some of the sound waves will be absorbed, and some will be transmitted through the element and/or into adjacent elements. The ability of building elements or structures to reduce sound transmission is called 'Sound Insulation' [44] (refer to *Figure 111*).

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44. Airborne and Impact Sound

Sound transmission is divided into two types: airborne sound sources and impact sound sources. Airborne sound sources are sounds which transmit sound energy to a partition through the air, whereas impact sound sources transmit sound energy through direct contact with a structure. In both cases, the sound energy is radiated into the air. Sources of airborne sound include, speech and music, and sources of impact sound include footsteps and slamming doors [44] (refer to *Figure 111*).

The insulation of sound generated by airborne sound sources is known as airborne sound insulation, and the insulation of sound generated by impact sound sources is known as impact sound insulation.

45. Direct and Flanking Transmission

Often sound is considered to be transmitted directly through a separating building element, but sound can also be transmitted along other paths in a building structure. Any sound transmitted to the receiver not directly through the separating element is referred to as flanking transmission. These in-direct or 'flanking' paths between source and receiver, are harder to predict and can often significantly affect performance. An example is sound carried via a common floor slab: even if the wall directly between the rooms transmits an insignificant amount of sound, some noise will still be heard in the receiving room via the floor. Airborne and impact sound transmission are usually made up of sound travelling via direct and flanking paths [44] (refer to *Figure 111*).

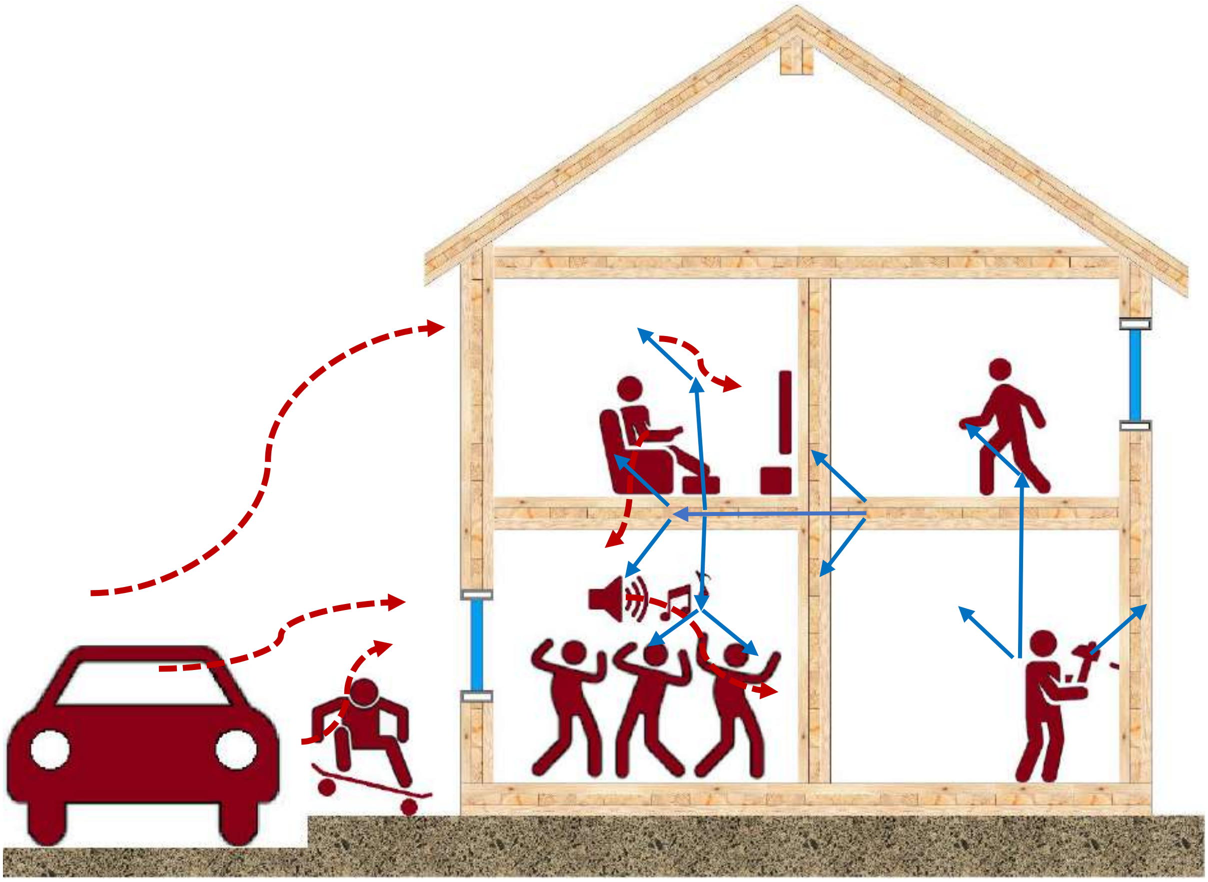


Figure 111: Examples of impact and airborne sound.

In order to better compare building products and materials, sound insulation is generally described using a single number. There are two complementary systems in common use in New Zealand: Sound Transmission Class (STC) and Impact Insulation Class (IIC) [44].

STC ratings relate to the transmission of airborne noise, and IIC ratings relate to the transmission of impact noise.

As a general guide, the level of acoustic privacy expected by an STC rating is:

- STC < 30: Poor sound control with little privacy.
- STC 30 – 40: Allows normal conversations to be heard in adjacent spaces.
- STC 40–50: Allows raised voices to be heard in adjacent spaces.
- STC >50: Provides a reasonable acoustic privacy.

The performance requirements of the New Zealand Building Code clause G6 Airborne and impact sound sets minimum sound insulation requirements for dwelling units of:

- STC ≥ 55 for inter-tenancy walls and floors.
- IIC ≥ 55 for inter-tenancy floors.

Red Stag completed a series of acoustic tests on its CLT and associated CLT build ups via an accredited third party laboratory to confirm the acoustic performance.

All third-party acoustic testing was completed via an accredited laboratory within an acoustical chamber (refer to *Figure 112*).

Figure 112: Accredited laboratory acoustical chamber.

46.1 Red Stag CLT Panel Assembly for Acoustic Test

Red Stag tested its 126 mm three layer CLT and 210 mm five layer CLT at the University of Auckland laboratory. The acoustic test setup configured the Red Stag CLT panels with lap joints to simulate a typical installation connection detail in a representative building (refer to *Figure 113* and *Figure 114*).

Figure 113: 126 mm thick three-layer Red Stag CLT panel with lap joint installed in the acoustic chamber at the testing laboratory.

Figure 114: 210 mm thick five-layer Red Stag CLT panel with lap joint installed in the acoustic chamber at the testing laboratory.

126 mm and 210 mm thick Red Stag CLT panels have been tested independently and in a series of flooring systems (build ups). The STC and IIC results of the tested flooring configurations are summarised in *Table 36* to *Table 45*. *Figure 115* to *Figure 121* illustrate the combinations of tested floor system components with Red Stag CLT.

Figure 115: Three-layer Red Stag CLT panel with lap joint.

Figure 116: Five-layer Red Stag CLT panel with lap joint.

Figure 117: Strandboard layer.

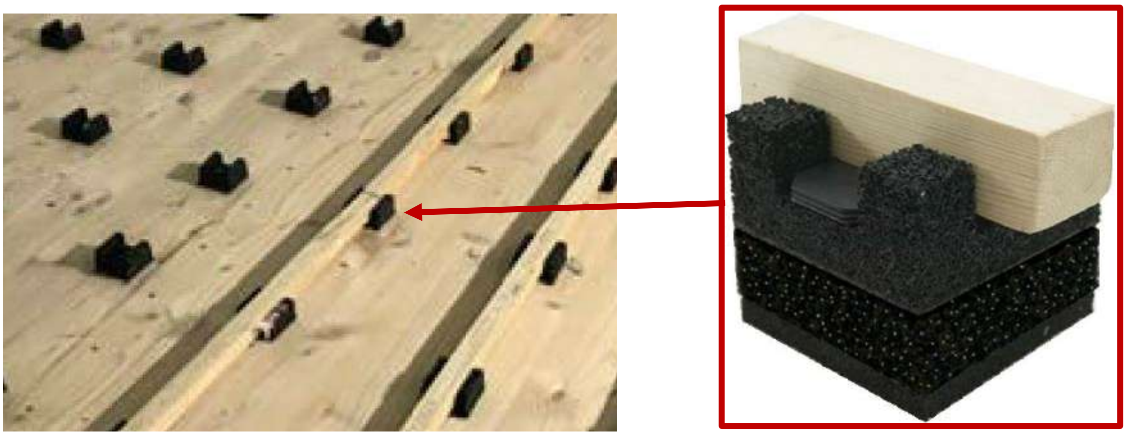


Figure 118: Acoustic cradles.

Figure 119: Cradle system with thermal insulation.

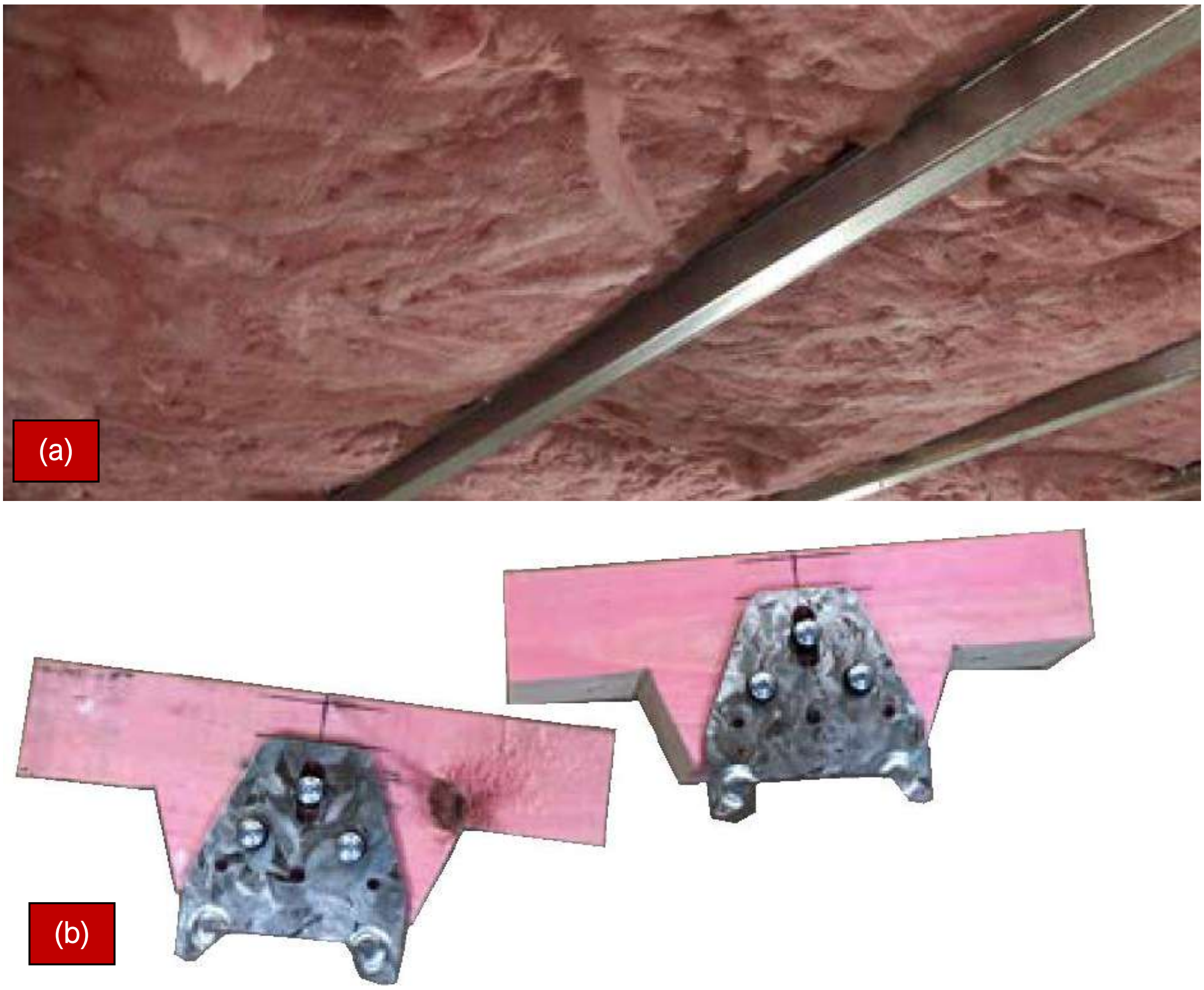


Figure 120: a) Rondo metal ceiling batten with thermal insulation; b) Gib quiet clip tying the metal ceiling batten to the underside of the flooring system.

Figure 121: Gib Fireline.

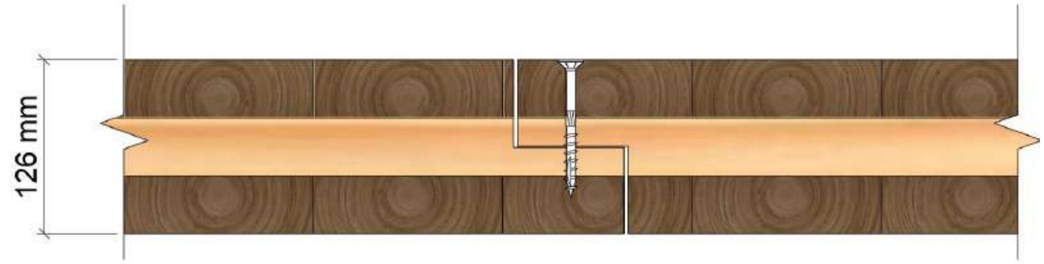
Table 36: Combination 1 (Bare 126 mm Thick Red Stag CLT Panel).		
		
Floor: Red Stag CL3/126 CLT flooring comprising: 40 mm x 45 mm LVL perimeter battens, one lap joint through the centre with screw fixing only.		
Insulation: NIL		
Linings: NIL		
Total Thickness: 126 mm	**STC:** 35 dB	**IIC:** 20 dB

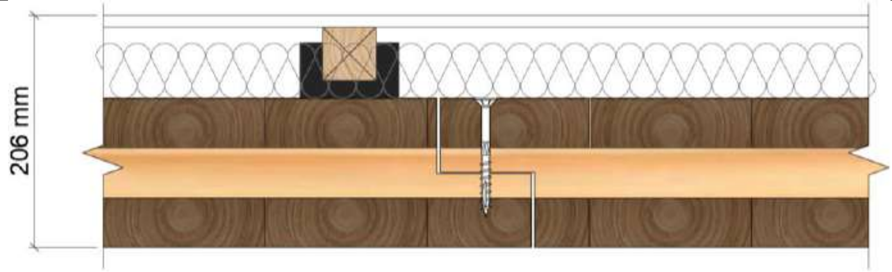
Table 37: Combination 1: Bare 126 mm Thick Red Stag CLT Panel		
		
Layout Specifications		
Flooring: One layer of 20 mm Laminex Strandfloor screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten and Cradle LVL battens. Battens spaced at 400 mm centres seated in Batten and Cradle rubber cradles spaced at 450 mm centres.		
Insulation: 50 mm thick R1.2 Pink Batts fibreglass insulation.		
Mid Floor: 126 mm thick Red Stag CL3/126 Cross Laminated Timber (CLT) flooring comprising two panels lap jointed through the centre. CLT screw fixed along lap joint at 200 mm centres and sealed around perimeter only.		
Insulation: NIL		
Linings: NIL		
Total Thickness: 206 mm	**STC:** 52 dB	**IIC:** 41 dB

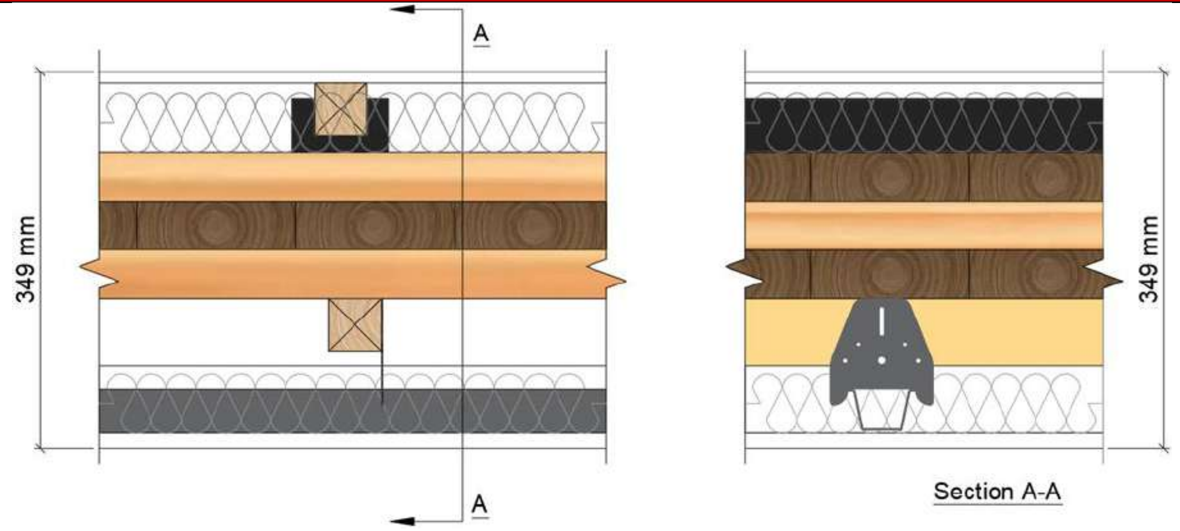
Table 38: Combination 3.		
		
Layout Specifications		
Flooring: One layer of 20 mm Laminex Strandfloor screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten and Cradle LVL battens. Battens spaced at 400 mm centres seated in Batten and Cradle rubber cradles spaced at 450 mm centres.		
Insulation: 50 mm thick R1.2 Pink Batts fibreglass insulation.		
Mid Floor: 126 mm thick Red Stag CL3/126 Cross Laminated Timber (CLT) flooring comprising two panels lap jointed through the centre. CLT screw fixed along lap joint at 200 mm centres and sealed around perimeter only.		
Insulation 90 mm thick R2.2 Pink Batts fibreglass insulation.		
Linings: One layer of 13 mm GIB Fyreline plasterboard screw fixed to 35 mm Rondo furring channels spaced at 600 mm centres in GIB Quiet clips spaces at 1200 mm centres. GIB Quiet clips screw fixed to custom timber mounts screw fixed to the CLT panel (total ceiling cavity depth: 130 mm).		
Total Thickness: 349 mm	**STC:** 64 dB	**IIC:** 47 dB

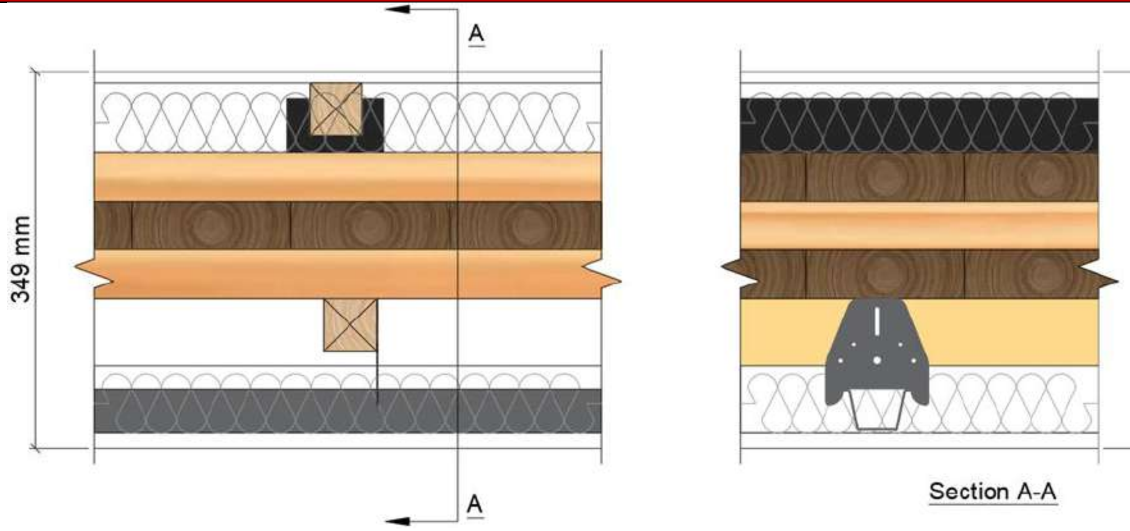
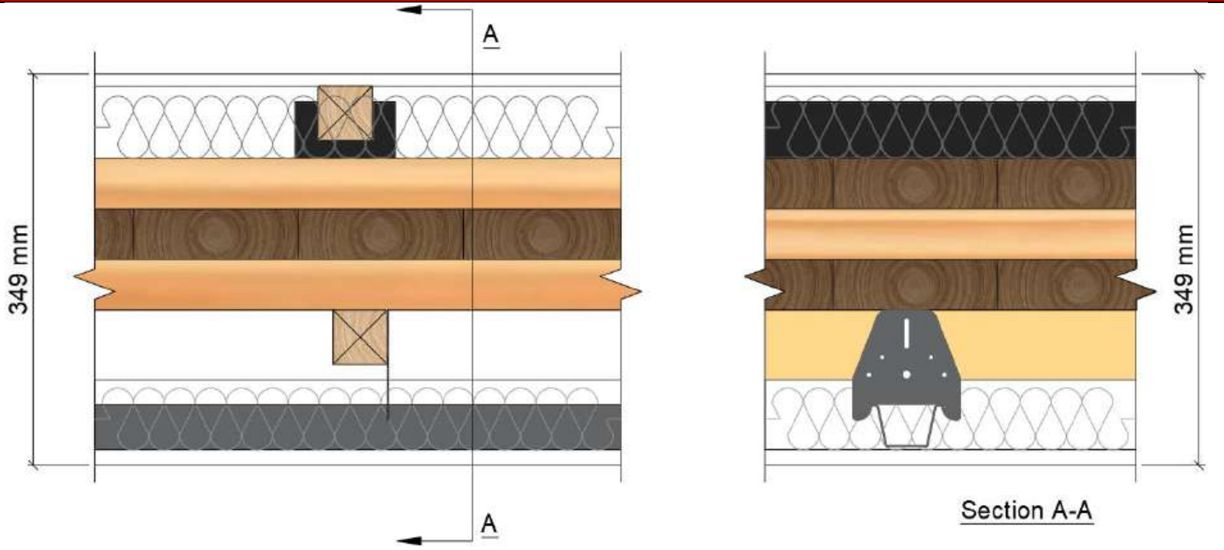
Table 39: Combination 4.		
		
Layout Specifications		
Flooring: One layer of 20 mm Laminex Strandfloor screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten and Cradle LVL battens. Battens spaced at 400 mm centres seated in Batten and Cradle rubber cradles spaced at 450 mm centres.		
Insulation: 50 mm thick R1.2 Pink Batts fibreglass insulation.		
Mid Floor: 126 mm thick Red Stag CL3/126 Cross Laminated Timber (CLT) flooring comprising two panels lap jointed through the centre. CLT screw fixed along lap joint at 200 mm centres and sealed around perimeter only.		
Insulation: 90 mm thick R2.2 Pink Batts fibreglass insulation.		
Linings: Two layers of 13 mm GIB Fyreline plasterboard screw fixed to 35 mm Rondo furring channels spaced at 600 mm centres in GIB Quiet clips spaces at 1200 mm centres. GIB Quiet clips screw fixed to custom timber mounts screw fixed to the CLT panel (total ceiling cavity depth: 130 mm).		
Total Thickness: 349 mm	**STC:** 67 dB	**IIC:** 56 dB

Table 40: Combination 5.



Layout Specifications

Flooring:

One layer of 20 mm Laminex Superpine MR Particleboard screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten and Cradle LVL battens. Battens spaced at 400 mm centres seated in Batten and Cradle rubber cradles spaced at 450 mm centres.

Insulation:

50 mm thick R1.2 Pink Batts fibreglass insulation.

Mid Floor:

126 mm thick Red Stag CL3/126 Cross Laminated Timber (CLT) flooring comprising two panels lap jointed through the centre. CLT screw fixed along lap joint at 200 mm centres and sealed around perimeter only.

Insulation:

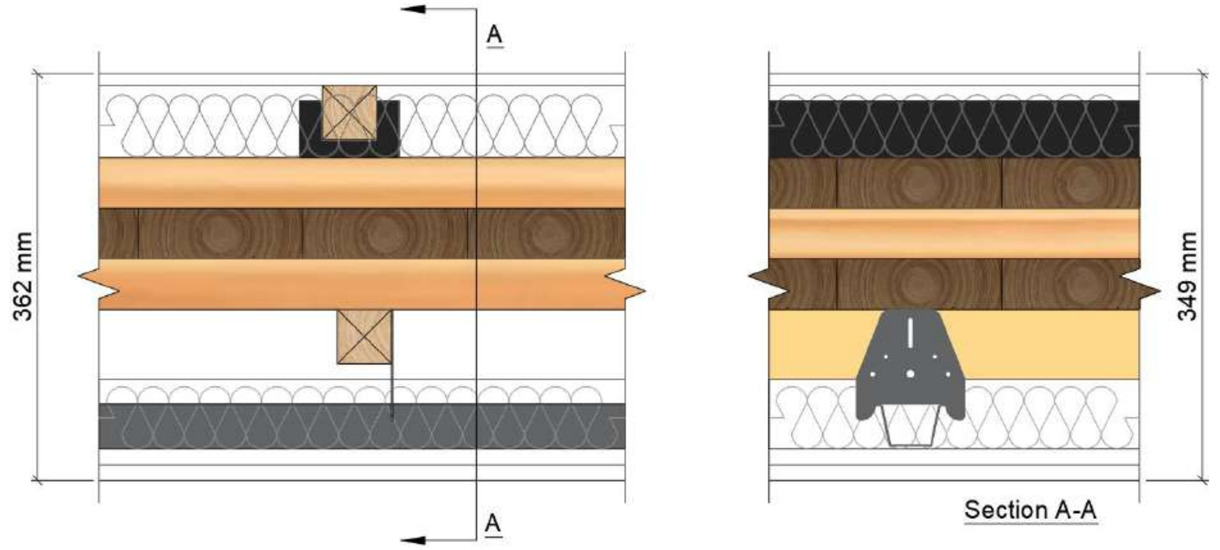
90 mm thick R2.2 Pink Batts fibreglass insulation.

Linings:

One layer of 13 mm GIB Fyreline plasterboard screw fixed to 35 mm Rondo furring channels spaced at 600 mm centres in GIB Quiet clips spaces at 1200 mm centres. GIB Quiet clips screw fixed to custom timber mounts screw fixed to the CLT panel (total ceiling cavity depth: 130 mm).

Total Thickness: 362 mm	**STC:** 65 dB	**IIC:** 55 dB

Table 41: Combination 6.



Layout Specifications		
Flooring: One layer of 20 mm James Hardie Secura Interior Flooring screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten and Cradle LVL battens. Battens spaced at 400 mm centres seated in Batten and Cradle rubber cradles spaced at 450 mm centres.		
Insulation: 50 mm thick R1.2 Pink Batts fibreglass insulation.		
Mid Floor: 126 mm thick Red Stag CL3/126 Cross Laminated Timber (CLT) flooring comprising two panels lap jointed through the centre. CLT screw fixed along lap joint at 200 mm centres and sealed around perimeter only.		
Insulation: 90 mm thick R2.2 Pink Batts fibreglass insulation.		
Linings: Two layers of 13 mm GIB Fyreline plasterboard screw fixed to 35 mm Rondo furring channels spaced at 600 mm centres in GIB Quiet clips spaces at 1200 mm centres. GIB Quiet clips screw fixed to custom timber mounts screw fixed to the CLT panel (total ceiling cavity depth: 130 mm).		
Total Thickness: 362 mm	**STC:** 66 dB	**IIC:** 55 dB

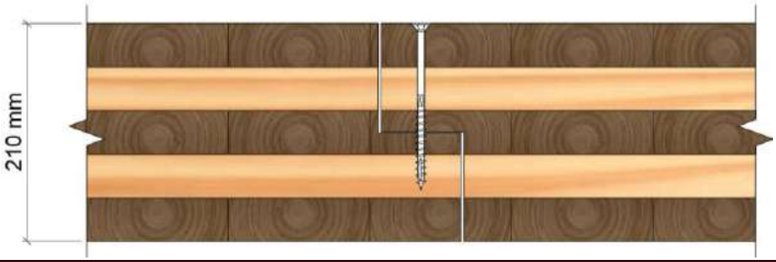
Table 42: Combination 7 (Bare 210 mm Thick Red Stag CLT Panel).		
		
Layout Specifications		
Flooring: 210 mm thick Red Stag CL5/210 Cross Laminated Timber (CLT) flooring comprising three lap jointed uniformly spaced panels. CLT screw fixed along the two lap joints at 200 mm centres and sealed around perimeter only.		
Insulation: NIL		
Linings: NIL		
Total Thickness: 210 mm	**STC:** 39 dB	**IIC:** 24 dB

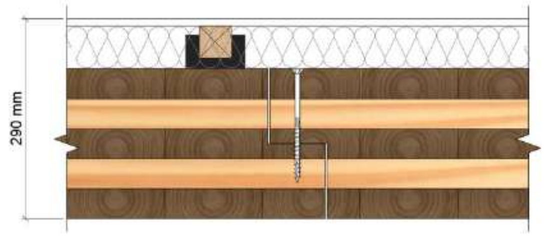
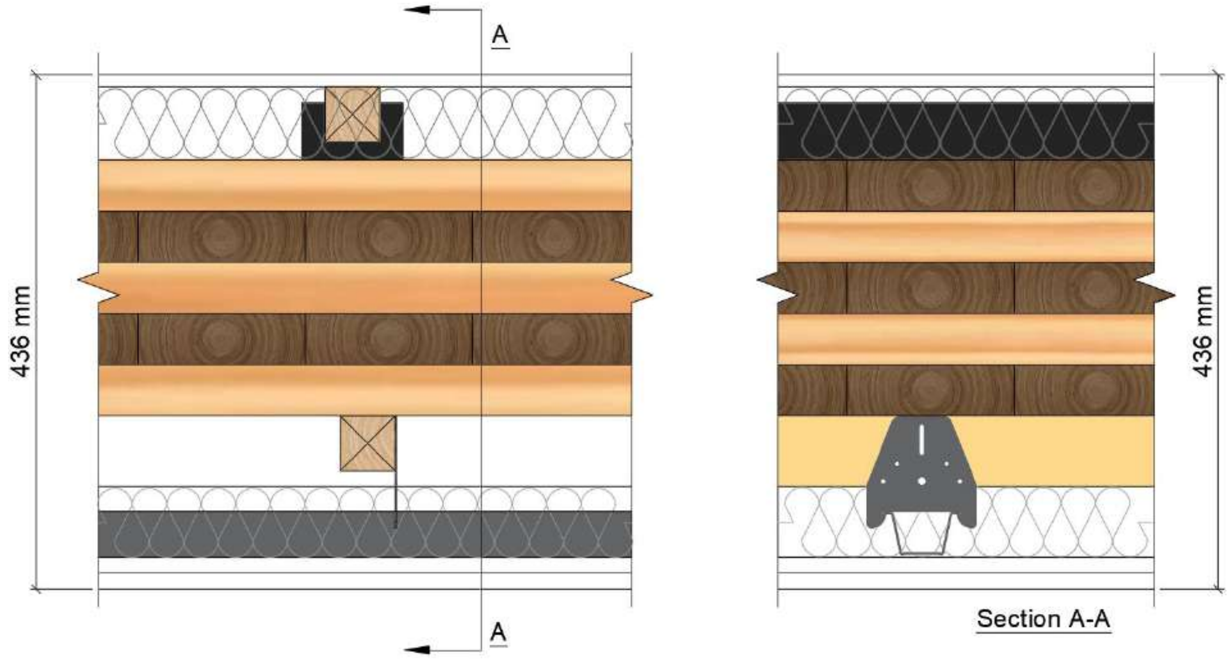
Table 43: Combination 8.		
		
Layout Specifications		
Flooring One layer of 20 mm Laminex Strandfloor screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten and Cradle LVL battens. Battens spaced at 400 mm centres seated in Batten and Cradle rubber cradles spaced at 450 mm centres.		
Insulation: 50 mm thick R1.2 Pink Batts fibreglass insulation.		
Floor: 210 mm thick Red Stag CL5/210 Cross Laminated Timber (CLT) flooring comprising three uniformly spaced panels lap jointed together. CLT screw fixed along the two lap joints at 200 mm centres and sealed around perimeter only.		
Insulation: 90 mm thick R2.2 Pink Batts fibreglass insulation.		
Linings: One layer of 13 mm GIB Fyreline plasterboard screw fixed to 35 mm Rondo furring channels spaced at 600 mm centres in GIB Quiet clips spaces at 1200 mm centres. GIB Quiet clips screw fixed to custom timber mounts screw fixed to the CLT panel (total ceiling cavity depth: 120 mm).		
Total Thickness: 290 mm	**STC:** 54 dB	**IIC:** 44 dB

Table 44: Combination 9.



Layout Specifications

Flooring
One layer of 20 mm Laminex Strandfloor screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten.

Insulation
50 mm thick R1.2 Pink Batts fibreglass insulation.

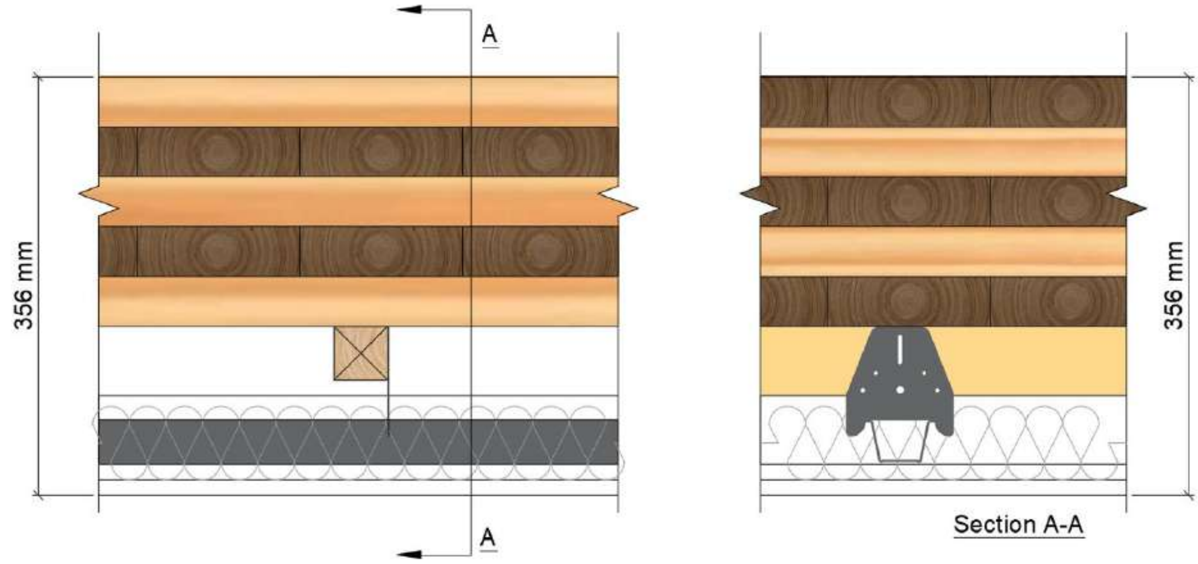
Floor:
210 mm thick Red Stag CL5/210 Cross Laminated Timber (CLT) flooring comprising three lap jointed uniformly spaced panels. CLT screw fixed along the two lap joints at 200 mm centres and sealed around perimeter only.

Insulation
90 mm thick R2.2 Pink Batts fibreglass insulation.

Linings
Two layers of 13 mm GIB Fyreline plasterboard screw fixed to 35 mm Rondo furring channels spaced at 600 mm centres in GIB Quiet clips spaces at 1200 mm centres. GIB Quiet clips screw fixed to custom timber mounts screw fixed to the CLT panel (total ceiling cavity depth: 120 mm).

Total Thickness: 356 mm	**STC:** 66 dB	**IIC:** 60 dB

Table 45: Combination 10.



Layout Specifications		
Flooring 210 mm thick Red Stag CL5/210 Cross Laminated Timber (CLT) flooring comprising three lap jointed uniformly spaced panels. CLT screw fixed along the two lap joints at 200 mm centres and sealed around perimeter only.		
Insulation 90 mm thick R2.2 Pink Batts fibreglass insulation.		
Mid Floor: 210 mm thick Red Stag CL5/210 Cross Laminated Timber (CLT) flooring comprising three lap jointed uniformly spaced panels. CLT screw fixed along the lap joints at 200 mm centres and sealed around perimeter only.		
Insulation 90 mm thick R2.2 Pink Batts fibreglass insulation.		
Linings: Two layers of 13 mm GIB Fyreline plasterboard screw fixed to 35 mm Rondo furring channels spaced at 600 mm centres in GIB Quiet clips spaces at 1200 mm centres. GIB Quiet clips screw fixed to custom timber mounts screw fixed to the CLT panel (total ceiling cavity depth: 120 mm).		
Total Thickness: 356 mm	**STC:** 64 dB	**IIC:** 54 dB

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