Red Stag CLT Design Guide

Red Stag CLT Design Guide V1.5
September 2024

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.

Content

Section 1: Cross Laminated Timber - Overview & Introduction

Section 2: Cross Laminated Timber - Application & Product Specification

Section 3: Cross Laminated Timber - Connections

Section 4: Cross Laminated Timber - Fire Design

Section 5: Cross Laminated Timber – Thermal Performance

Section 6: Cross Laminated Timber – Penetrations & Chasing

Section 7: Cross Laminated Timber – Quality Assurance

Section 8: Cross Laminated Timber – Complexity Guide

Section 9: Cross Laminated Timber – Screws & Connectors

Section 10: Cross Laminated Timber – Design Calculations

Section 11: Cross Laminated Timber Acoustic Performance

Section 12: Red Stag Engineered Wood Product Specifications

Section 13: Red Stag CLT Composite Products

Section 14: Red Stag CLT Beam

References

Section 1

Cross Laminated Timber Overview & Introduction

Red Stag CLT Design Guide V1.5
September 2024

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), Light Timber Frame (LTF) and Truss (F&T), advanced stick panelisation and cassette systems. Refer to *Figure 2.*

Figure 2: Red Stag LTF & Truss and panelisation manufacturing plant in Hamilton.

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 3* shows panoramic views of the Red Stag EWP manufacturing process in Rotorua.

Figure 3: 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.

Structural Finger Joints (FJ) are used to connect short pieces of wood (shook) together to form boards of greater length. The joint is composed of several meshing wedges or "fingers" of wood in two adjacent pieces, which are held together with structural adhesives. Vertical joints are where the fingers are visible across the face of the board, while horizontal joints only show a single perpendicular line across the face of the board (refer to *Figure 4a to Figure 4c*). Red Stag products are primarily comprised of vertical FJ, but in the future, they will be a combination of horizontal and vertical FJ. *Figure 4d* shows a typical CLT panel, composed of FJ timber laminations that are glued together at 90° configuration. Profile of Red Stag finger joint is presented in *Figure 5*.

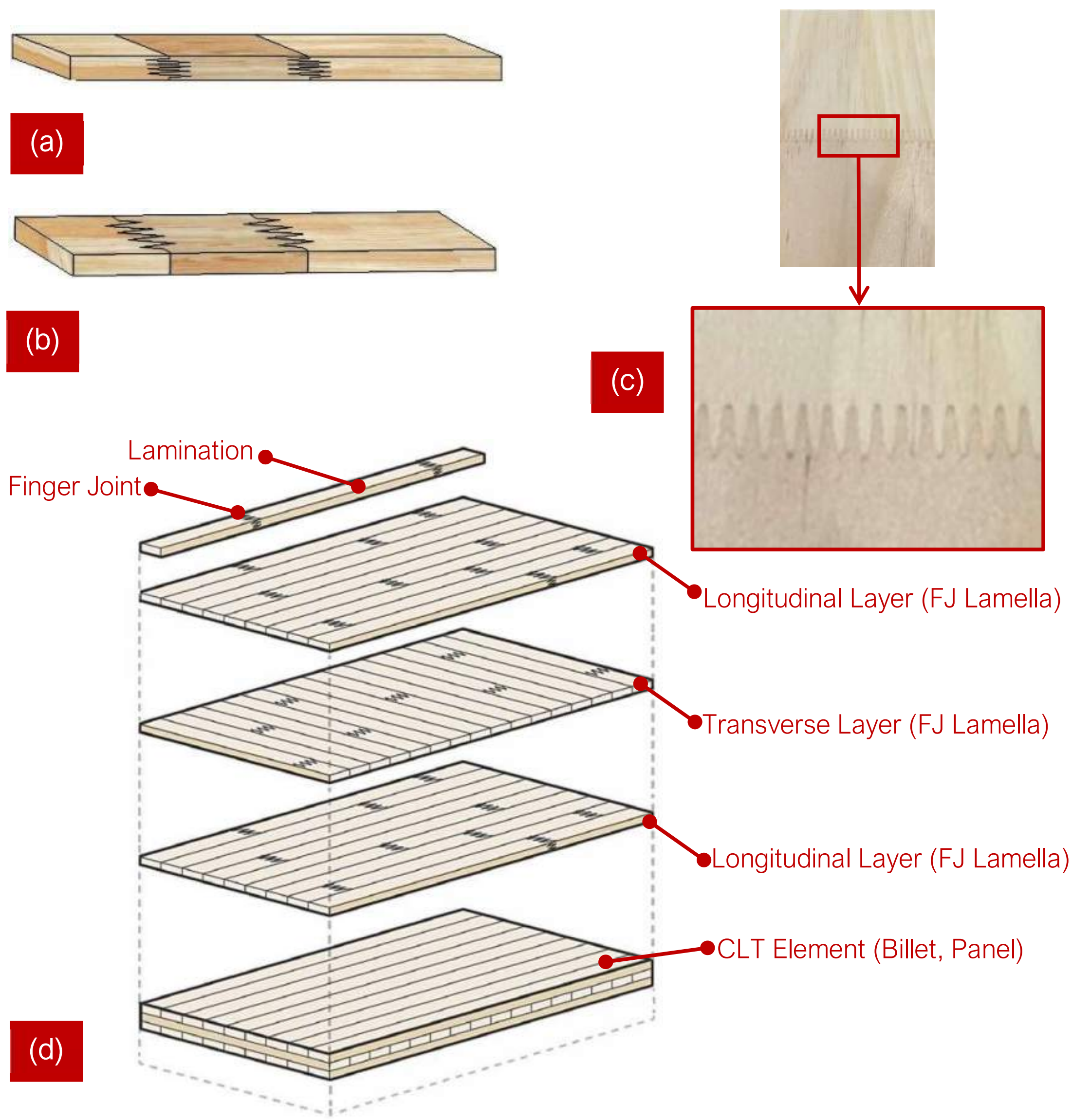


Figure 4: FJ details; a) Horizontal FJ; b) Vertical FJ; c) Red Stag FJ; d) Schematic view of FJ lamella forming a CLT panel.

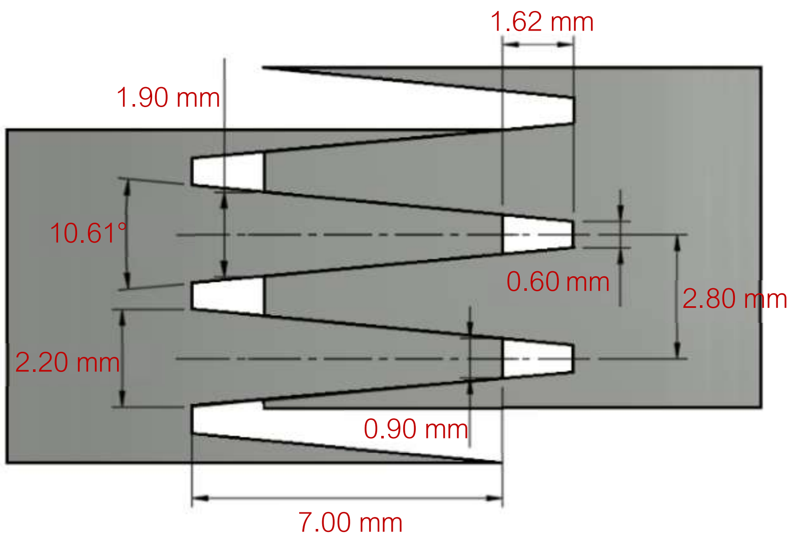


Figure 5: Typical Red Stag Finger Joint (FJ) profile.

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.

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 6*).

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 6: 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 noise, 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 global construction industry is a significant contributor to atmospheric greenhouse gas (GHG) emissions. In accordance with the Paris Agreement, global carbon emissions need to be reduced by 50% by 2050 (with respect to 1990) to keep the global average temperature rise well below 2 °C.

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 [1]. 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 [2].

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 [3].

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 7*).

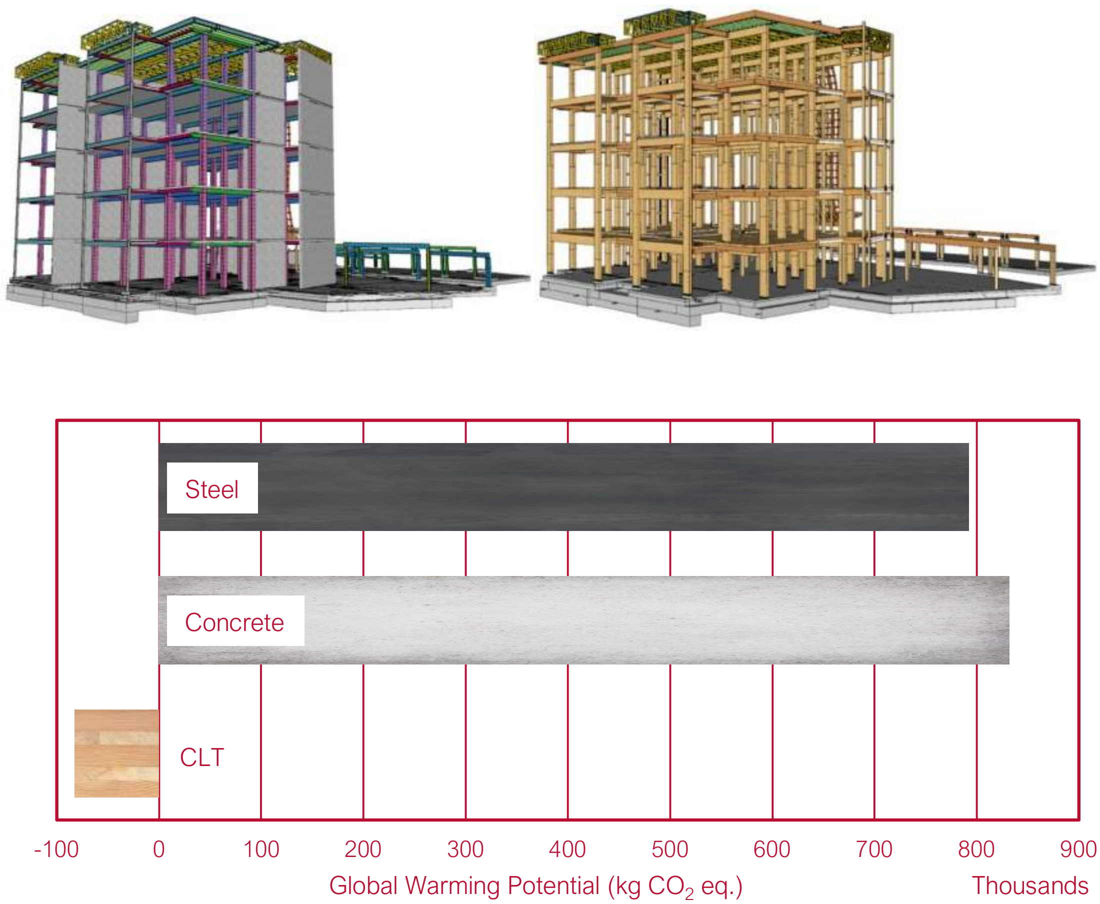


Figure 7: Embodied Carbon of Timber Building Versus Concrete and Steel Building.

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 [4]. 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) [5] 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 8* to *Figure 10*).

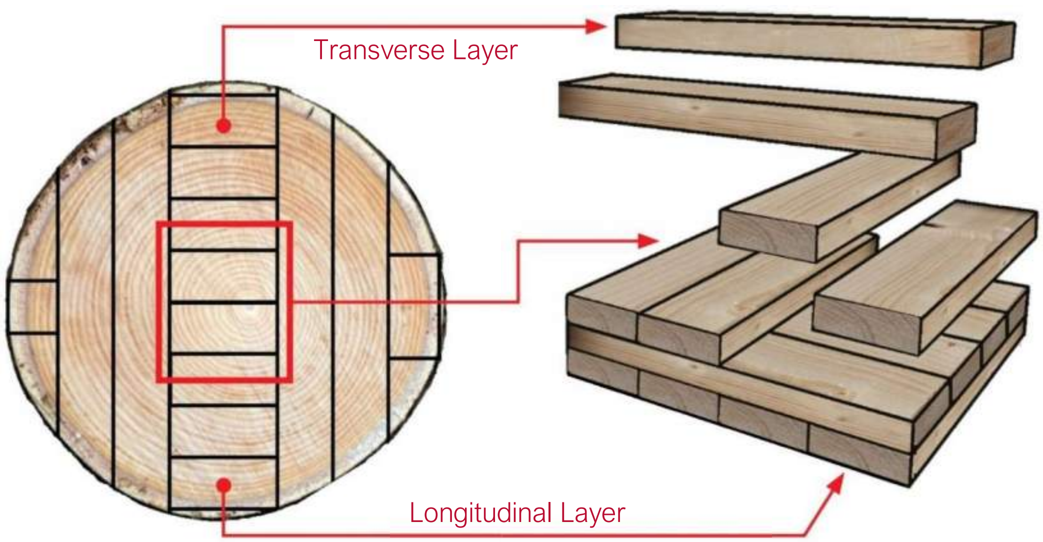


Figure 8: Sawn Log. *Figure 9:* Arranging Board.

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.

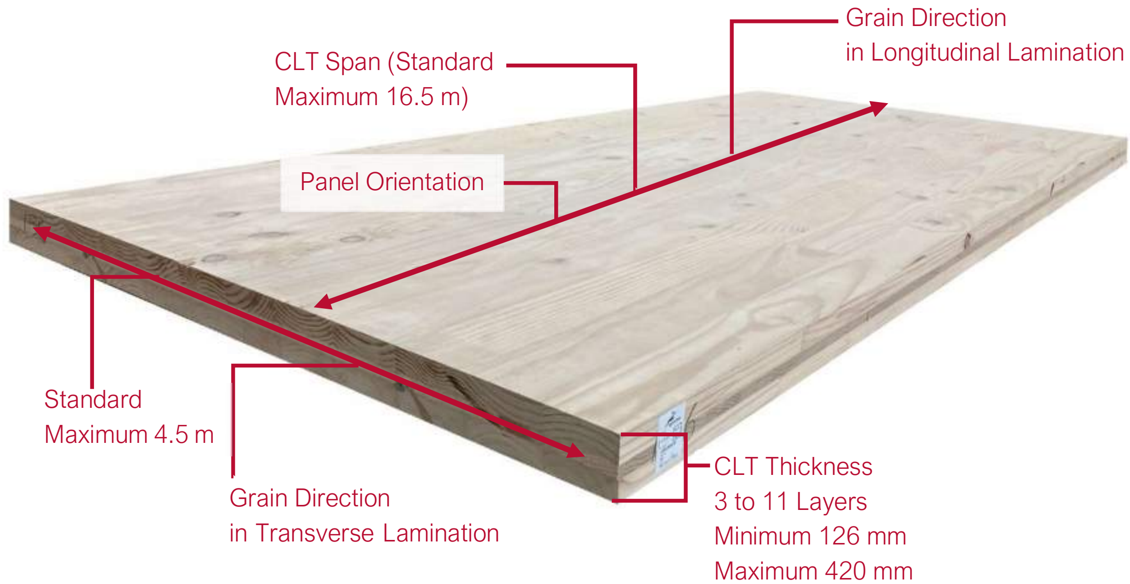


Figure 10: Red Stag CLT panel.

Red Stag Timber (RST) generally produces three different grades of timber for the CLT process. The average MoE of each lamella is tested twice by RST and sorted into four grades (currently sub 6 GPa, 6-8 GPa, 8-10 GPa, +10 GPa), and packets are created for each grade.

Table 1: CLT Structural Material Strength Properties.

Red Stag Material Strength Properties.			
Structural Properties	Longitudinal Laminates		Transverse Laminates
Modulus of Elasticity (MoE) [b] [45]	8.0 – 9.99 GPa [45]	10.0 – 11.99 GPa [45]	6.0 – 7.99 GPa [45]
Available lamella thickness	42 mm & 20 mm	42 mm & 20 mm	42 mm & 20 mm
Material Strength Properties Standard.			
Bending Strength [a] [6]	14 MPa [7]	20 MPa [7]	10 MPa [7]
Compression Parallel to Grain [6]	18 MPa [7]	20 MPa [7]	15 MPa [7]
Compression perpendicular to Grain [6]	8.9 MPa	10.0 MPa	8.9 MPa
Tension Strength [6]	6.0 MPa [7]	8.0 MPa [7]	4.0 MPa [7]
Normal Shear [6]	3.8 MPa [7]	3.8 MPa [7]	3.8 MPa [7]

[a] Refer to NZS 3603:1993 & AS/NZS 1720.1:2022 [6] ,[49].
[b] Refer to Red Stag Timber internal test result [45].

Red Stag predominantly focuses on two timber grades for the longitudinal and transverse layers of Red Stag CLT panels which are tested to ensure that specifications in *Table 1* are met. Please note that layers in the longitudinal direction are the most critical for Red Stag CLT panel performance and Red Stag uses a higher MoE timber board for those layers, while the transverse layers can typically have a lower grade without any adverse performance.

To guarantee the quality of the Red Stag CLT, Red Stag have commenced testing two samples per 1000 billets with third party laboratories.

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 12 - Figure 17*, 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 University of Auckland and SCION confirmed that the Red Stag CLT panels have a sufficient level of stiffness and strength to carry applied structural loads (refer to *Figure 12*) [7]. 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.

Red Stag is continuing its standard large-scale experimental tests and research on Red Stag CLT products to ensure the quality and structural performance for various applications (refer to *Figure 11*).

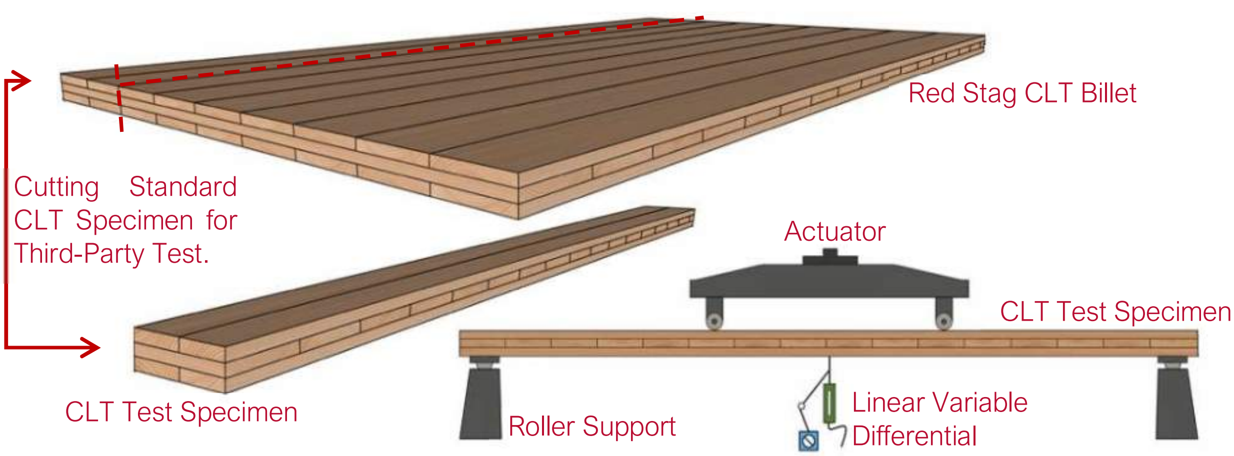
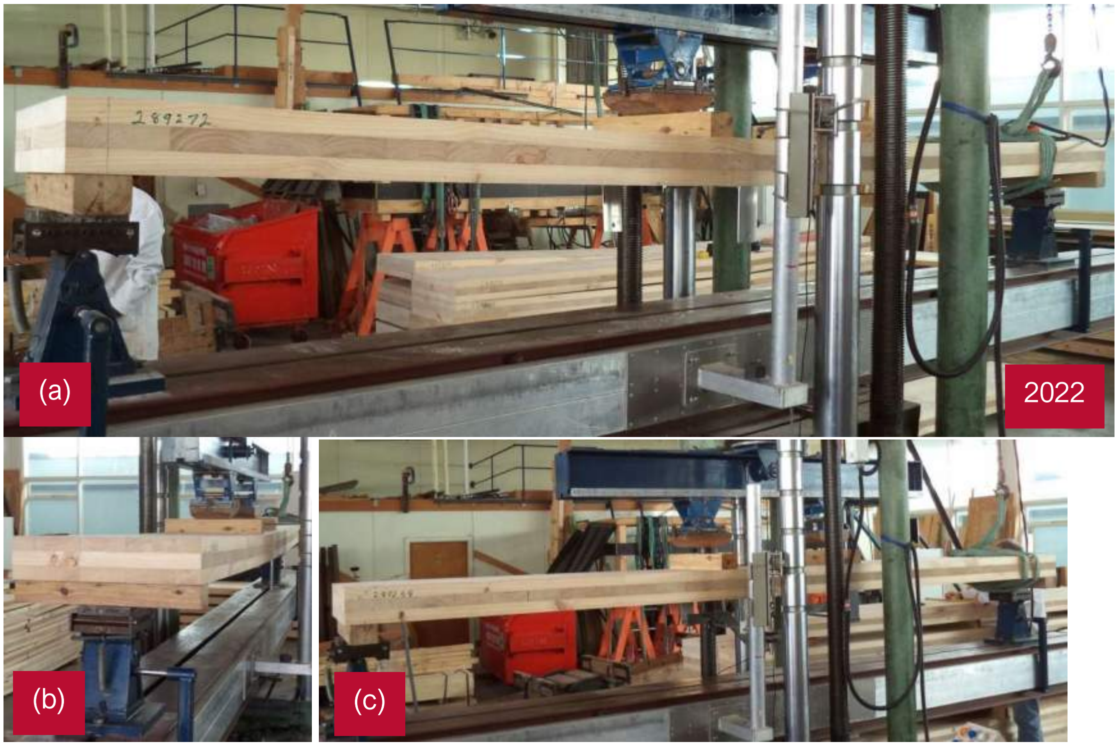


Figure 11: Standard large-scale test specimen preparation for mechanical testing by third party.


(a)
2022
(b)
(c)


(a)
2019
(b)
(c)

Figure 12: Large scale mechanical testing conducted by SCION; (a) Long span testing; (b) Median span testing; (c) Short span testing.

Red Stag has completed large-scale test research on Red Stag CLT composite sections in conjunction with its clients to confirm the suitability of Red Stag systems in advance projects. Testing has included 8.6 m CLT- GLT composite I-Beam systems to support the manufacture of 9 x 9 m grid commercial timber buildings. Refer to *Figure 13*.

Audited testing with third party's confirmed the composite action of the CLT/GLT beam confirmation with a combination of screws and adhesive created a high performing single solid composite beam for carrying large structural loads.

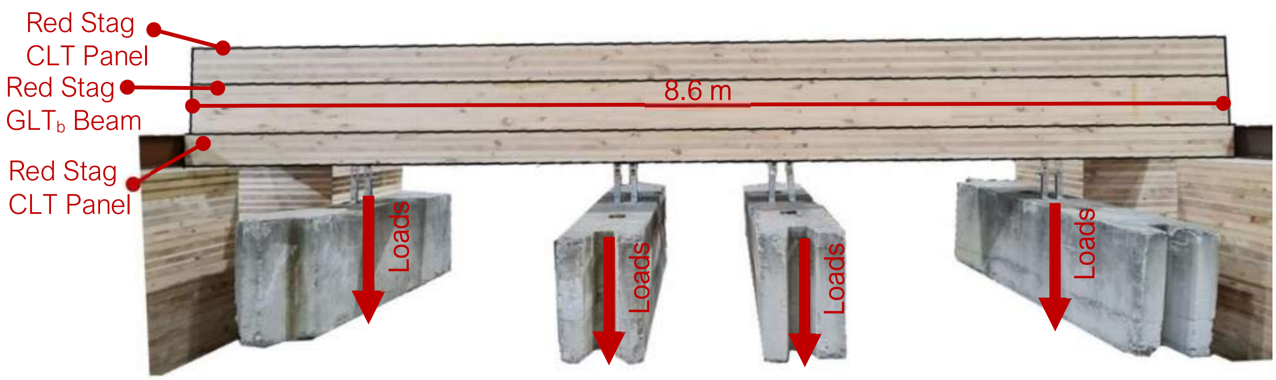


Figure 13: Full scale long term deflection and creep test on Red Stag CLT- GLT composite I-Beam system.

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 [8] under the standard allowable limit, confirming the glue line bonds are sufficiently durable (refer to *Figure 16*). 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.

Please note Red Stag is doing at least one delamination test for each billet to prove the glue bond quality before delivery of the products. CLT should be carefully managed during the installation and construction phases. The risk of glue bond damage and delamination will increase if CLT panels remain exposed to the elements (e.g. rain, sun, etc) during transportation, installation and post construction.

Prolonged periods of wetting or cyclical and repeated wetting and drying events can cause delamination and distortion of the CLT, which may degrade its performance. When the MC of the timber lamella in CLT are exposed directly to rain, wind, sun radiation fluctuations, the stresses on glue bonds between the boards are significantly amplified outside of the design performance. Consequently, the risk of delamination will increase (refer to *Figure 14*).

When the CLT panel is drying or absorbing moisture, the glue bond area tries to resist the differential in the shrinkage of various lamellas. If the induced load is high enough, it can break the bonding between lamellas and cause delamination (refer to *Figure 15 and Figure 16*).

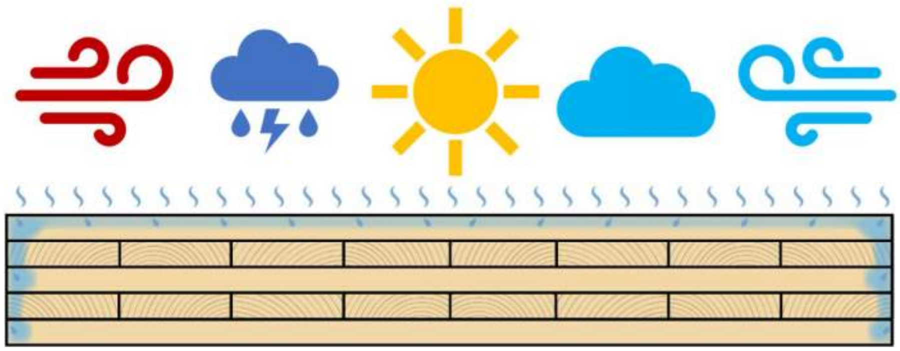


Figure 14: Drying mechanisms for wetted CLT panel include wind, sun, temperature, and heated or dried air.

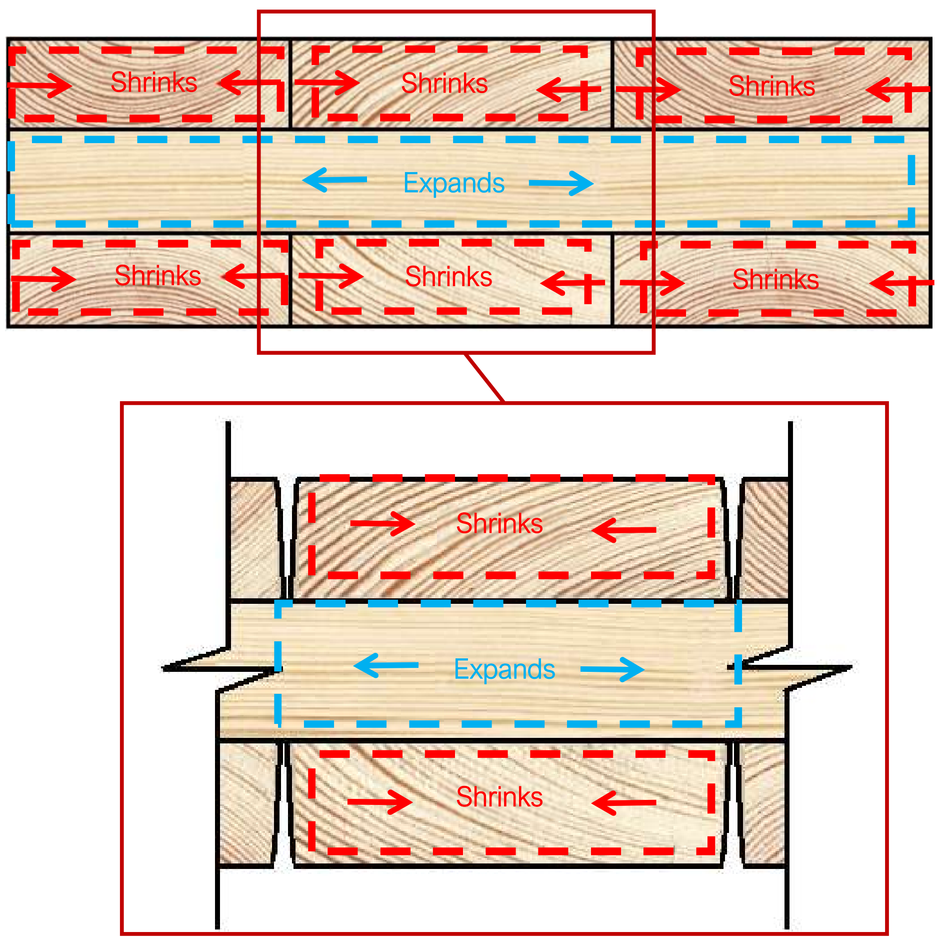


Figure 15: Lamella shrinkage that can lead to delamination phenomenon in CLT panel.

Test specimens after delamination test [9]

Figure 16: 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 17*). 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 17: 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 for various applications are shown in *Figure 18*.

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].

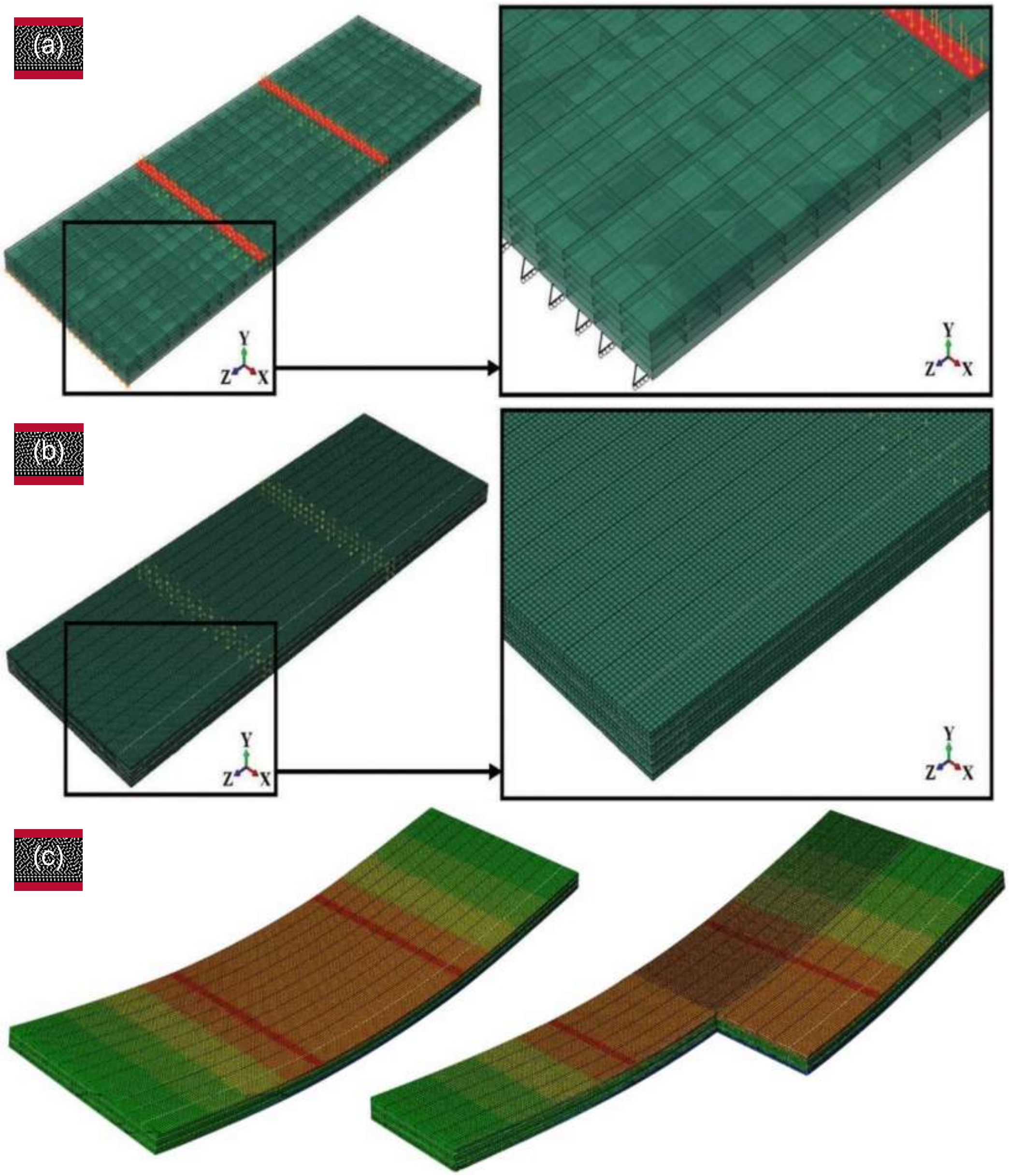


Figure 18: Typical boundary conditions and Finite Element (FE) mesh numerical model using ABAQUS [19] software; (a) FE model boundary conditions (Load and support); (b) FE mesh; (c & d) CLT panel numerical model to determine the deflection and stresses under various load conditions.

[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 19*). 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 19*). 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 19 – Figure 21*).

Figure 19: Delamination testing machine.

Figure 20: Finger joint test equipment and setup.

Figure 21: CLT beam bending testing machine and setup; (a) Isometric end elevation; (b) Front elevation.

Section 2
Cross Laminated Timber Application & Products Specification

Make it better

Red Stag CLT Design Guide V1.5
September 2024

5. Red Stag CLT Panel Applications

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 various type of residential to commercial multi storey buildings and industrial structures (refer to *Figure 22)*.

Figure 22: Various type CLT composite structures; (a) Multi storey building; (b) CLT portal frames; (c) Hybrid CLT warehouse.

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 23*). 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 24*).

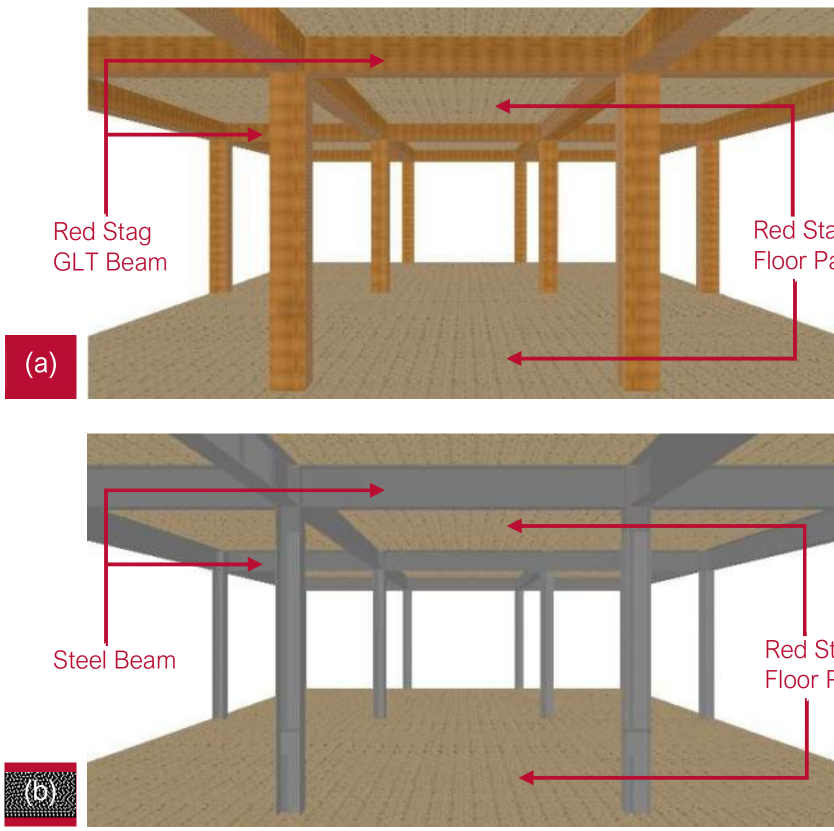


Figure 23: Red Stag CLT floor panel applications in timber or composite structures; (a) Timber system structure; (b) Steel-timber composite structure.

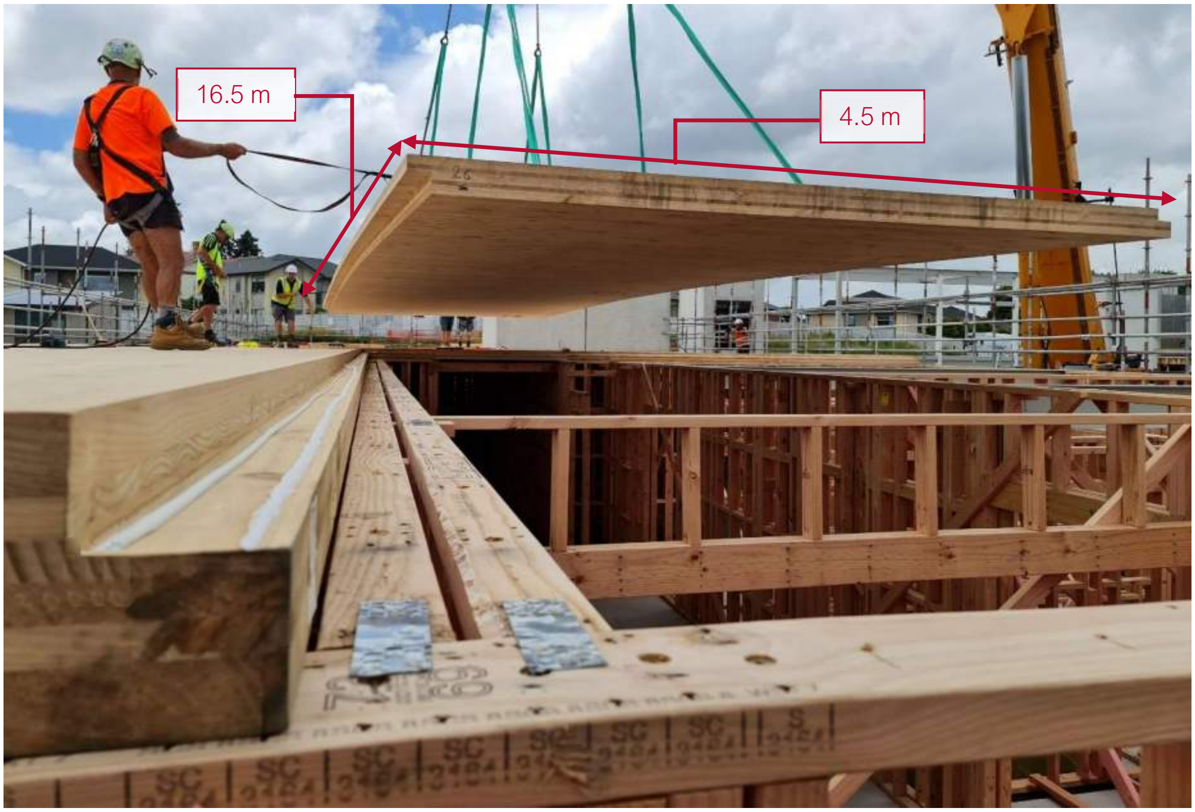
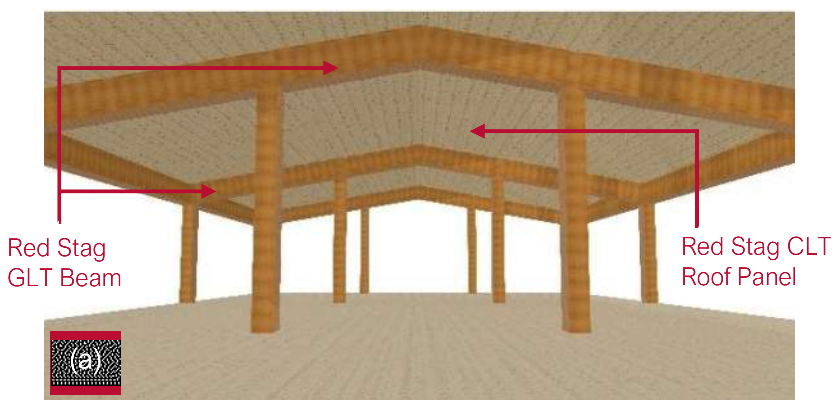


Figure 24: Red Stag CLT floor panels being installed onto Red Stag frames. Installation shows an example of a 75 square meter Red Stag CLT panel being effortlessly installed on site.

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 (refer to *Figure 25*) [22].



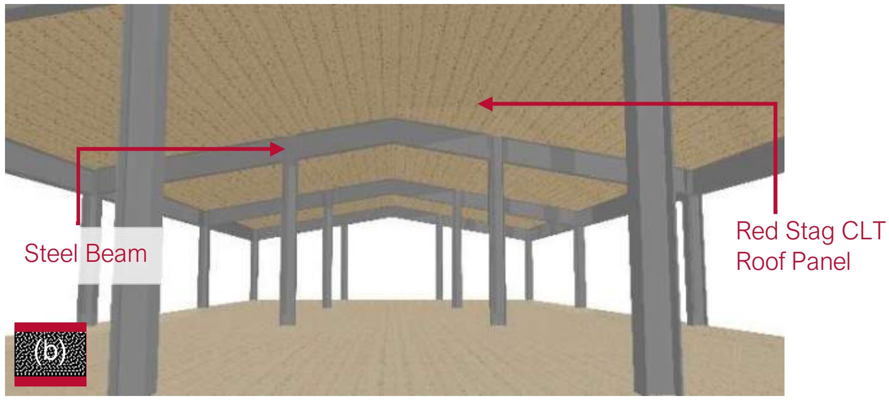


Figure 25: Red Stag CLT roof panel applications in timber or composite structures; (a) Timber system structure; (b) Steel-timber composite structure.

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 26*).

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.

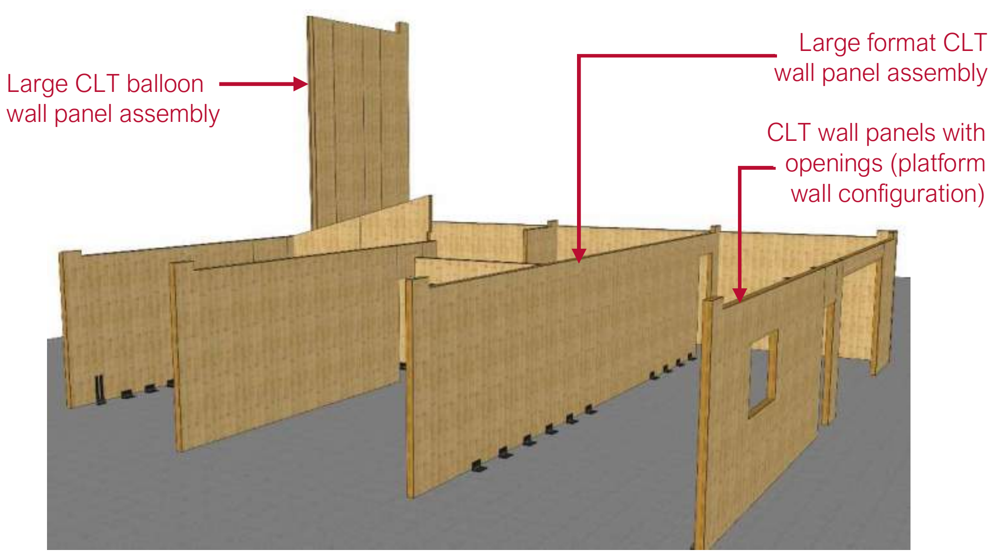


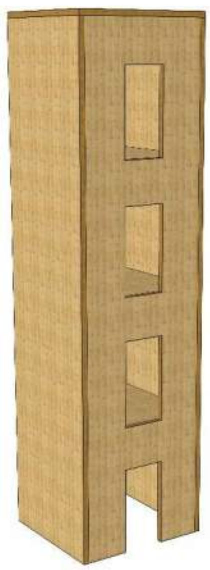
Figure 26: Red Stag CLT Wall panel applications.

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 27*).

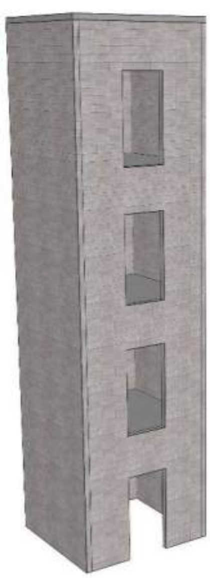
Figure 27: CLT Lift shaft (a) Multi-storey building with CLT lift shafts; (b) Interior view of a CLT lift shaft; (c) Red Stag lift shaft wall installation.

5.4.1 Advantages of Red Stag CLT Lift Shaft Walls



Red Stag CLT
Lift shaft wall

VS.



Concrete
Lift shaft wall

- Simple and panelised design of Red Stag CLT lift shaft walls reduces the number of elements to facilitate installation.
- Coordination of Red Stag lift shaft walls with other building elements to ensure proper for new and existing construction during assembly of Red Stag lift shaft wall.
- Red Stag lift shaft wall could be design and cut based on project specifications and requirements.
- Significant weight reduction compared to concrete option which is lead to foundation cost reduction and lower seismic requirements.
- Red Stag lift shaft walls have great fire resistance rating and acoustic performance which easily meets or exceeds minimum building standard requirements.
- Single or double visual grade of Red Stag lift shaft wall panels are available based on architectural requirements and appearance classifications of the project.
- Precise CNC cutting off-site of Red Stag CLT lift shaft walls and low dimensional tolerance reducing number of labours, workload to match elements at construction site and providing a safer working environment.
- Red Stag can coordination with project engineer and installer of CLT panels to address assembly sequences and logistics prior to start production and delivery of CLT lift shaft walls.
- Rapid assembly of Red Stag CLT lift shaft wall panels provides schedule flexibility and reduces cost related installation equipment and eliminate necessity for high-capacity cranes in most cases.
- Regularly CLT lift shaft walls are thick options compare to attached CLT floor and has low noise mitigation plan.
- Reduction in number of elements in Red Stag CLT lift shaft wall led to lower inspection requirements during and after installation compared to Concrete lift shaft wall.

CLT lift shaft walls can be designed to be integrated with the balance of the CLT floors, roofs, stairs, and beams to resist both gravity and seismic lateral loads.

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 (refer to *Figure 28*).

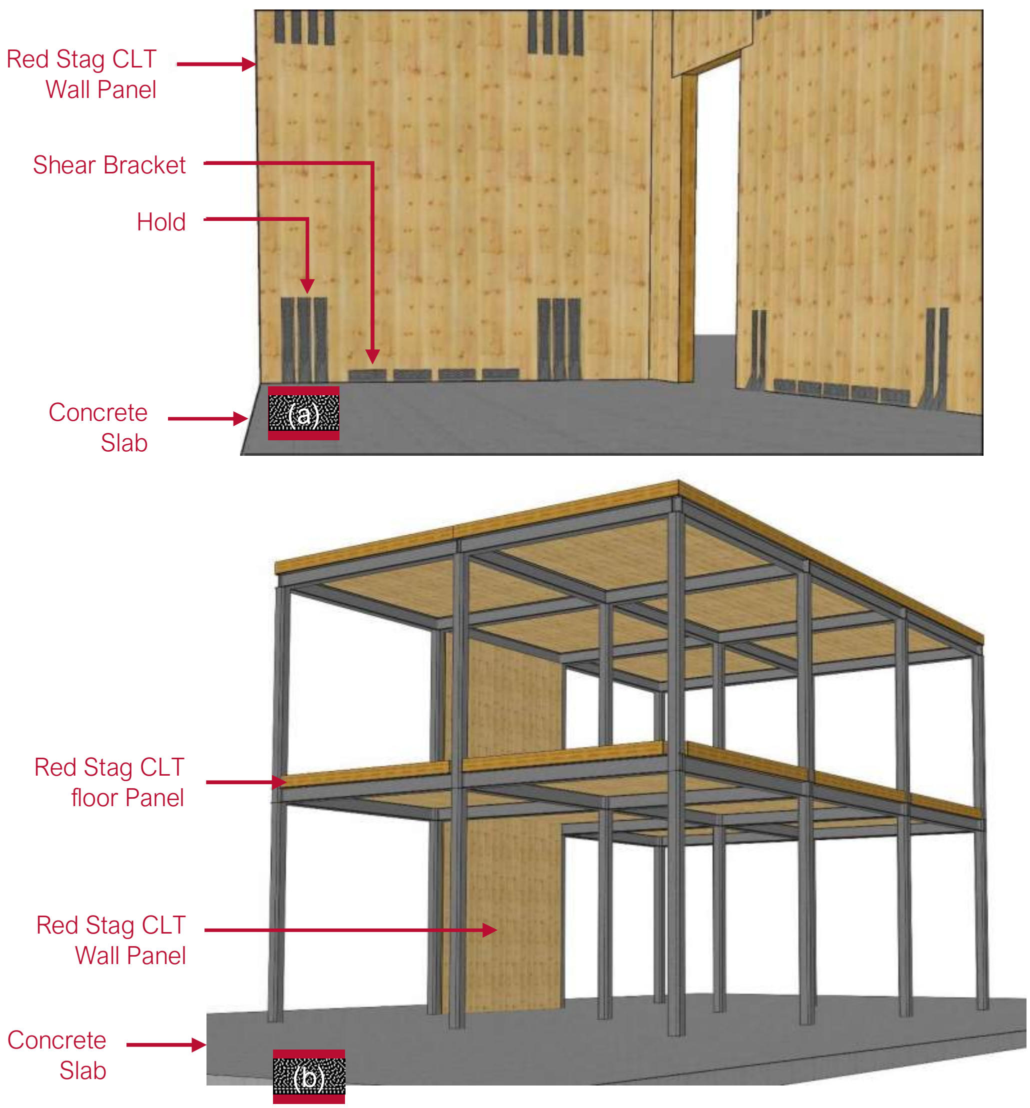


Figure 28: (a) CLT shear wall hold down system; (b) CLT panel diaphragm.

The main sources of lateral loads on buildings are strong winds and earthquakes. These loads are resisted by Lateral Load Resisting System (LLRS) of the building. As shown in

Figure 29, the main LLRS in buildings are floor and roof diaphragms, which are referred to as the horizontal elements, and walls or frames, which are the vertical elements. The diaphragms usually transfer the lateral loads from each floor level to the vertical systems below. The CLT diaphragm design procedure is illustrated by a simplified flow chart in *Figure 30*.

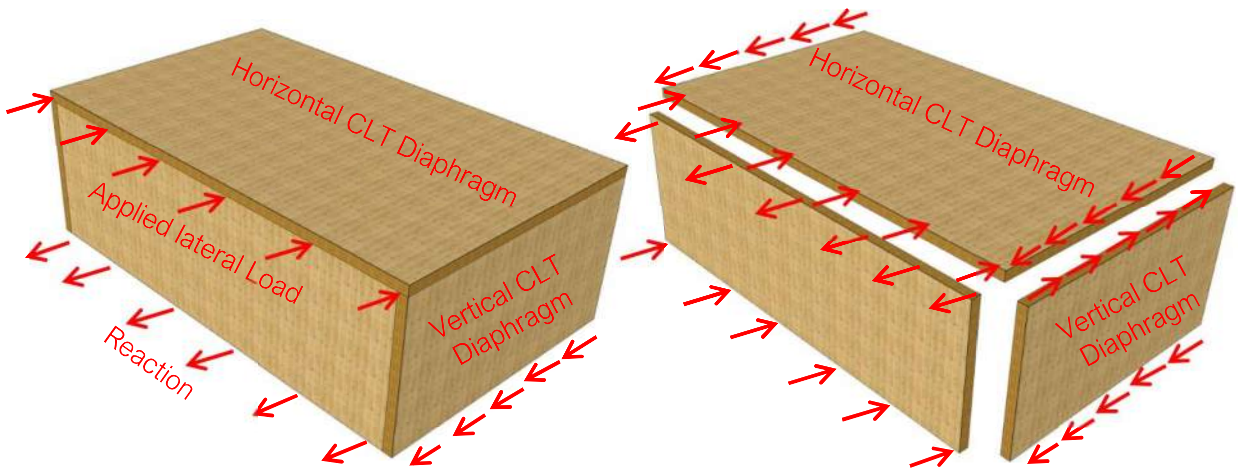
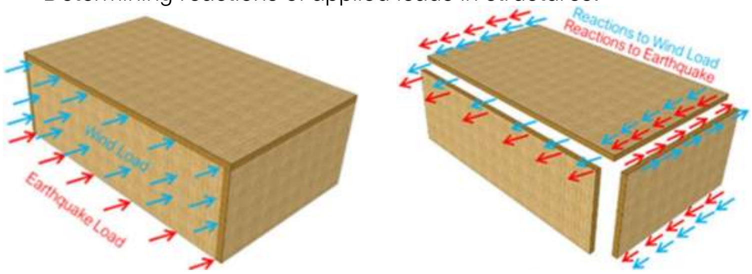


Figure 29: Diagram of load transfer stabilising wall panels.

Figure 30: Design flow chart of CLT Diaphragm.

Determining applied loads on diaphragms.

- External lateral applied loads like earthquake and wind loads.
- Determining reactions of applied loads in structures.

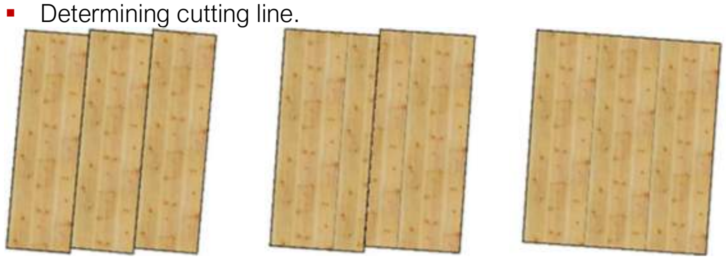


Applied Loads   Reactions

Step One

Checking diaphragm aspect ratio based on possible Red Stag panel options.

- Checking shear wall dimensions.
- Determining cutting line.



Lower aspect ratio →→→→→→→→→→→→→ Higher aspect ratio

Step Two

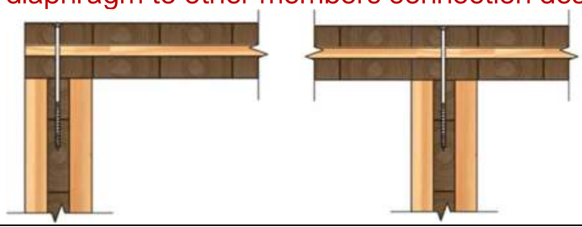
Panel to panel connection design.

- Connection options: Lap joint, spline joint, double spline joint, butt joint.
- Fastener Design.

Number of fasteners   Type of fasteners   Type of connections

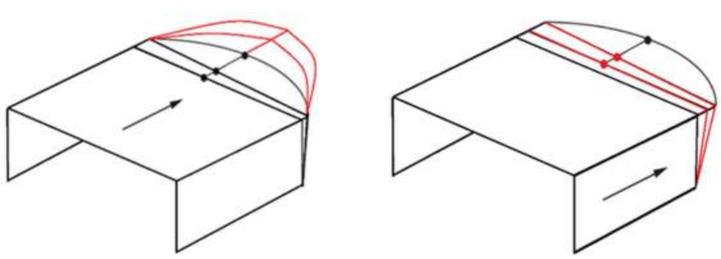
Step Three

CLT diaphragm to other members connection design.



Step Four

Calculating strength, deflection, and flexibility of diaphragm.



Diaphragm deflection   CLT wall deflection.

Step Five

The use of CLT panels as structural floor and roof panels has seen incredible growth in both residential and commercial timber buildings in New Zealand over the past decade.

CLT roof and floor systems need to be carefully designed and engineered to ensure diaphragms adequately resist horizontal loads as a result of wind and seismic events (refer to *Figure 31*). CLT diaphragms transmit lateral loads to the vertical lateral load-resisting elements such as shear walls. The first and last CLT panel in the diaphragm system will transfer loads to the structure below. Note that in a proper design, the fasteners and connection systems should be designed and checked for horizontal loads in two directions in addition to the vertical static loads. The effect of horizontal loads on the CLT floor diaphragm for two directions is shown in *Figure 32* and *Figure 33*.

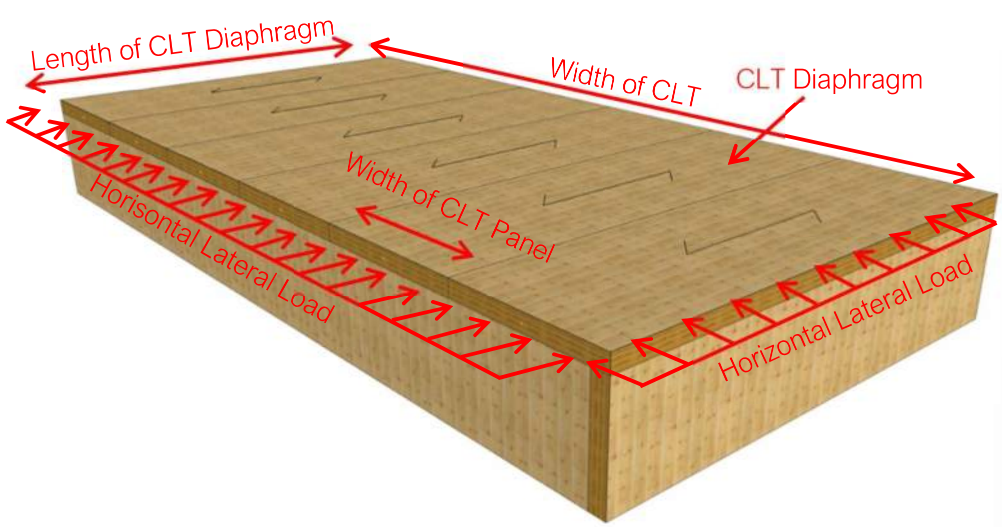


Figure 31: CLT floor diaphragm.

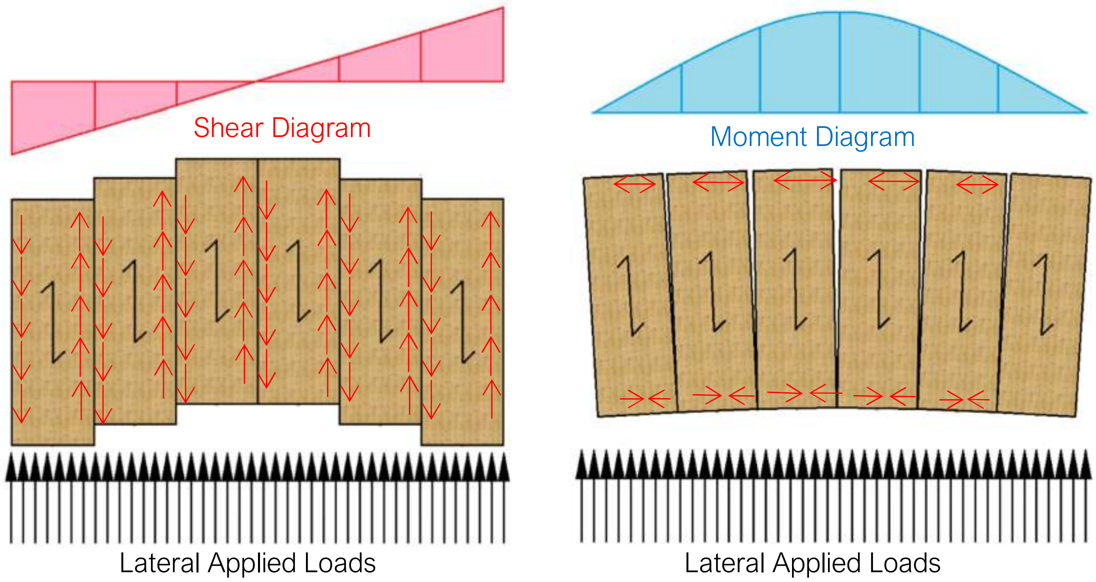


Figure 32: Shear along CLT panel to CLT panel connection; (b) Tension and compression force due to bending perpendicular to the grain.

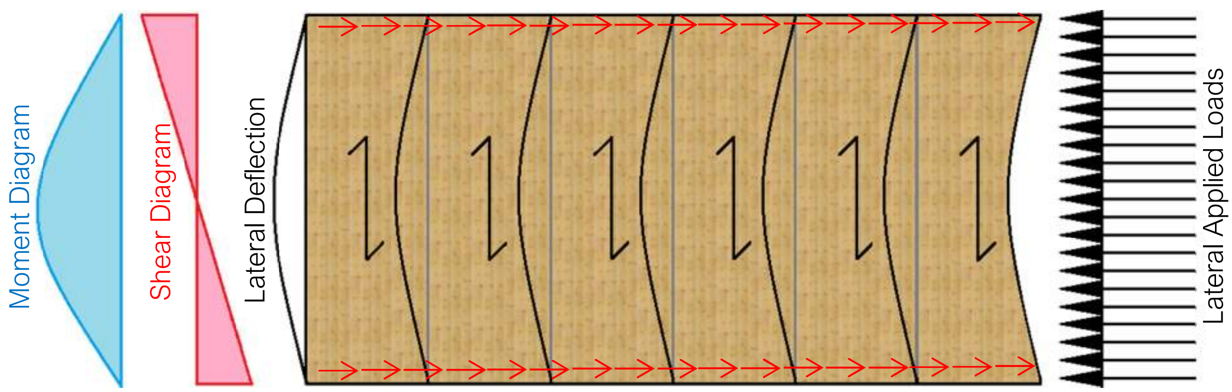


Figure 33: Bending and shear due to bending parallel to grain.

In-plane shear strength of a CLT roof or floor diaphragms are typically limited by the strength of connections between panels and connections at boundary elements rather than the strength of the CLT panels. Examples for CLT floor to CLT floor connections are shown in *Figure 34*. In projects with high lateral horizontal loads, careful design of the panel connections and fasteners is crucial. Higher lateral horizontal loads may require wider or more robust joint interfaces (refer to *Figure 35* and *Figure 36*). Increasing the number of screw fixings in lap or spline joints can raise the shear strength of the connection (refer to *Figure 37*).

Figure 34: CLT floor to CLT floor panel connection; a) Lap joint; b) Spline joint.

Figure 35: CLT floor to floor connection; a) Lap joint; b) Wider lap joint with two rows of screws.

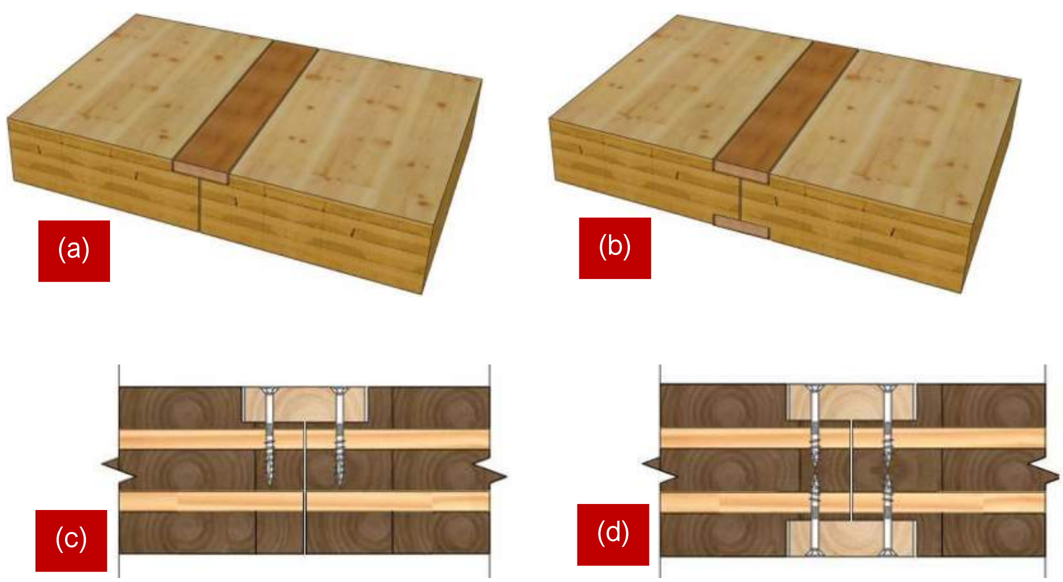


Figure 36: Spline Joints panel to panel connection; (a) Single spline joint; (b) Double spline joint; (c) Single spline joint screw arrangement; (d) Double spline joint screw arrangement.

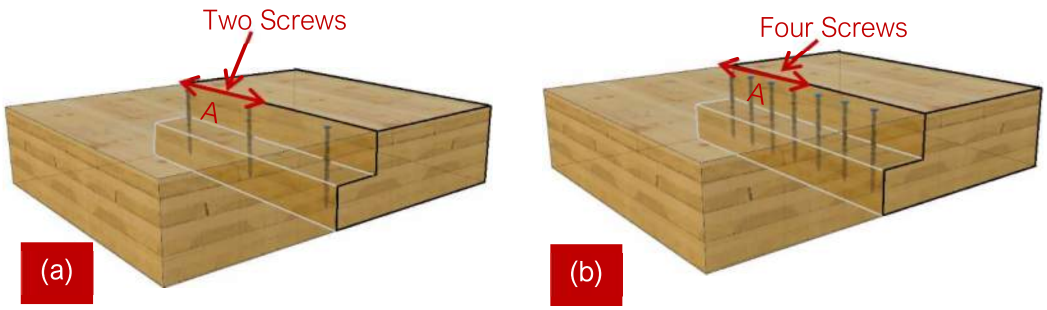


Figure 37: Changing screw spacing to increase shear strength of connection; (a) Large spacing (b) Smaller spacing.

In CLT floor diaphragm systems, CLT floor to CLT floor connections should be designed to resist shear, tension and compression as a result of horizontal lateral loads, while ensuring static gravity loads are managed (not a major concern in solid CLT diaphragm flooring systems) (refer to *Figure 38*).

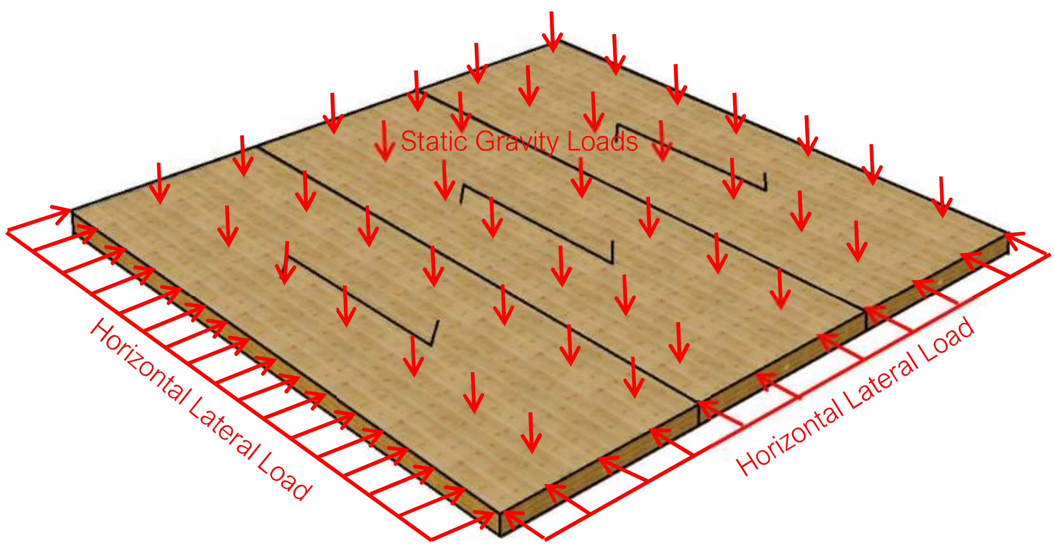


Figure 38: Applied loads on CLT floor diaphragm and panel to panel connections.

Panels near the compression boundary are pushed closer together, while panels near the tension boundary are pulled apart. Panels in shear rotate slightly and shift in response to the shear stresses. At areas of local compression between panels, if the compression is resisted by the spline as shown in *Figure 39*, it may create a prying or buckling reaction in the spline, which may reduce the ultimate shear strength or ductility of the spline connection (refer to *Figure 39*).

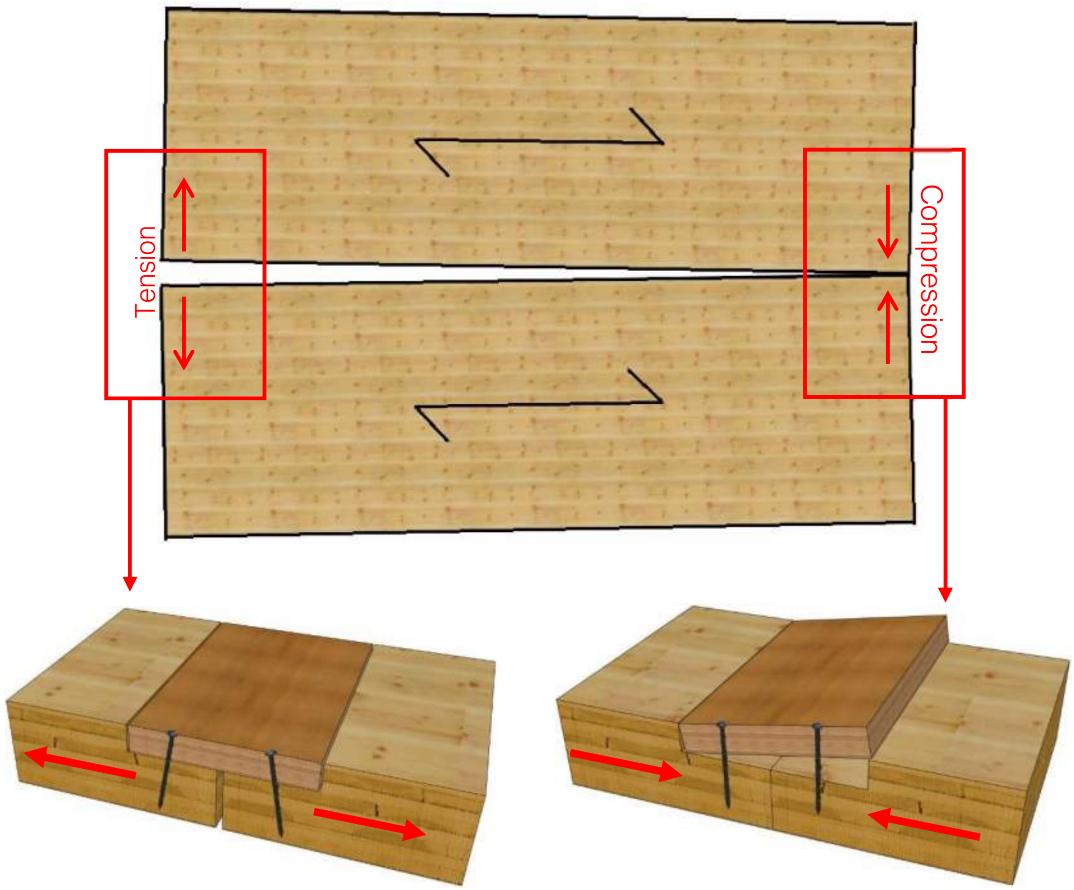


Figure 39: Potential behaviour of spline joint connections in a CLT floor diaphragm under high loads.

Installation of tension plates perpendicular to CLT panel load span direction at the ends of panel-to-panel connections can be a quickly installed, cost effective, and a structurally strong connection for CLT diaphragms to minimise shear and lever effect in fasteners and under applied horizontal loads. An example of installed tension plates in one of Red Stag's projects is shown in *Figure 40*.

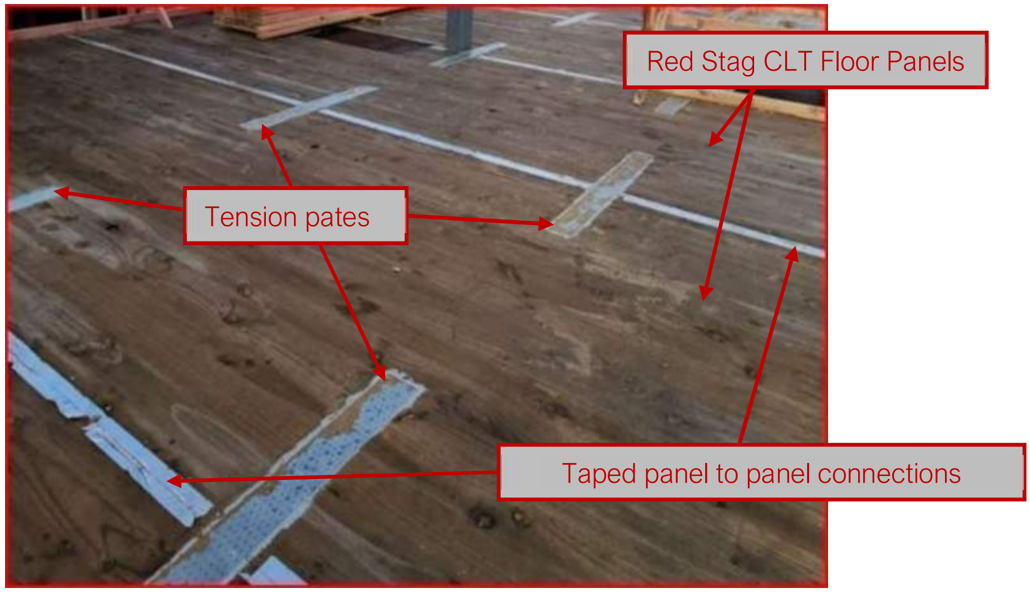


Figure 40: Application of tension plate in Red Stag CLT diaphragm.

There has been some dynamic testing performed of spline joints with screw fasteners at the University of British Columbia. The research suggests that spline joints with inclined screws loaded axially typically exhibit high initial stiffness and ultimate static capacity but are prone to non-ductile failure. Spline joints with screws installed at 90 degrees and loaded in shear, exhibited lower initial stiffness and ultimate static capacity but failed in a more ductile fashion.

In most instances, it is reasonable to consider CLT floor and roof systems to act as rigid diaphragms with lateral loads distributed to the vertical resisting elements based on their relative stiffness. It is recommended that the aspect ratio (Length/Width) of the rigid CLT diaphragm are 2:1 or 3:1 if there is a non-composite concrete topping. If the aspect ratio exceeds these limits but is not more than 4:1, the CLT diaphragm may be modelled as semi-rigid.

CLT shear wall members are suited for in-plane loads of high shear strength and stiffness.

Horizontal lateral loads transferred from CLT floor diaphragms to a CLT shear walls with related force equilibrium is shown in *Figure 41*.

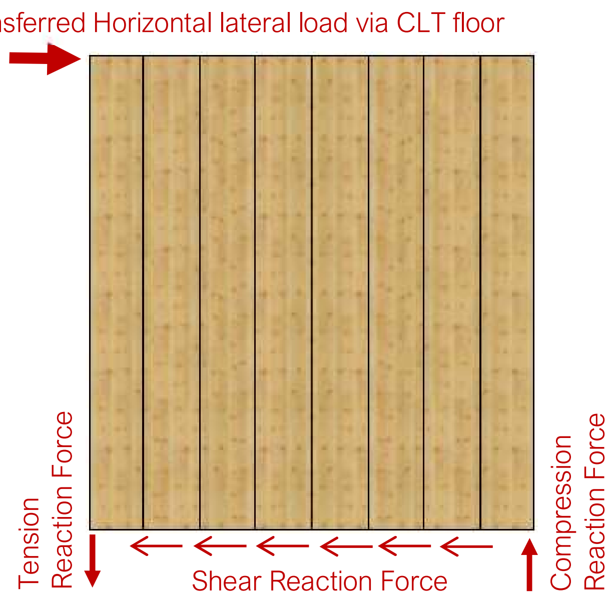


Figure 41: Force equilibrium for CLT wall panel.

The shear strength and stiffness of a CLT shear wall member composed of several elements are governed by the load-deformation behaviour of the edge connections. The load-carrying capacity of the CLT member and the shear connection, are not balanced and the high shear capacity of the CLT member cannot be exploited. To close the gap between the shear capacities of CLT shear walls, various types of CLT connections have been developed. The most common examples are presented in Section 3 (Cross Laminated Timber Connections).

Lateral loads, horizontal and vertical reaction forces in the lower edges of the CLT walls due to the overturning moment are presented in *Figure 42a* and *Figure 43b*. The CLT wall can be prevented from lifting by loading or through anchors (direct or indirect through adjacent connected elements). The design of the anchor for a wall panel depends on the size of the horizontal force that the wall has to resist, the weight of the structure above, and the element's connection with adjacent walls. *Figure 42c* and *Figure 43d* show how a connection system can affect the behaviour of CLT shear walls.

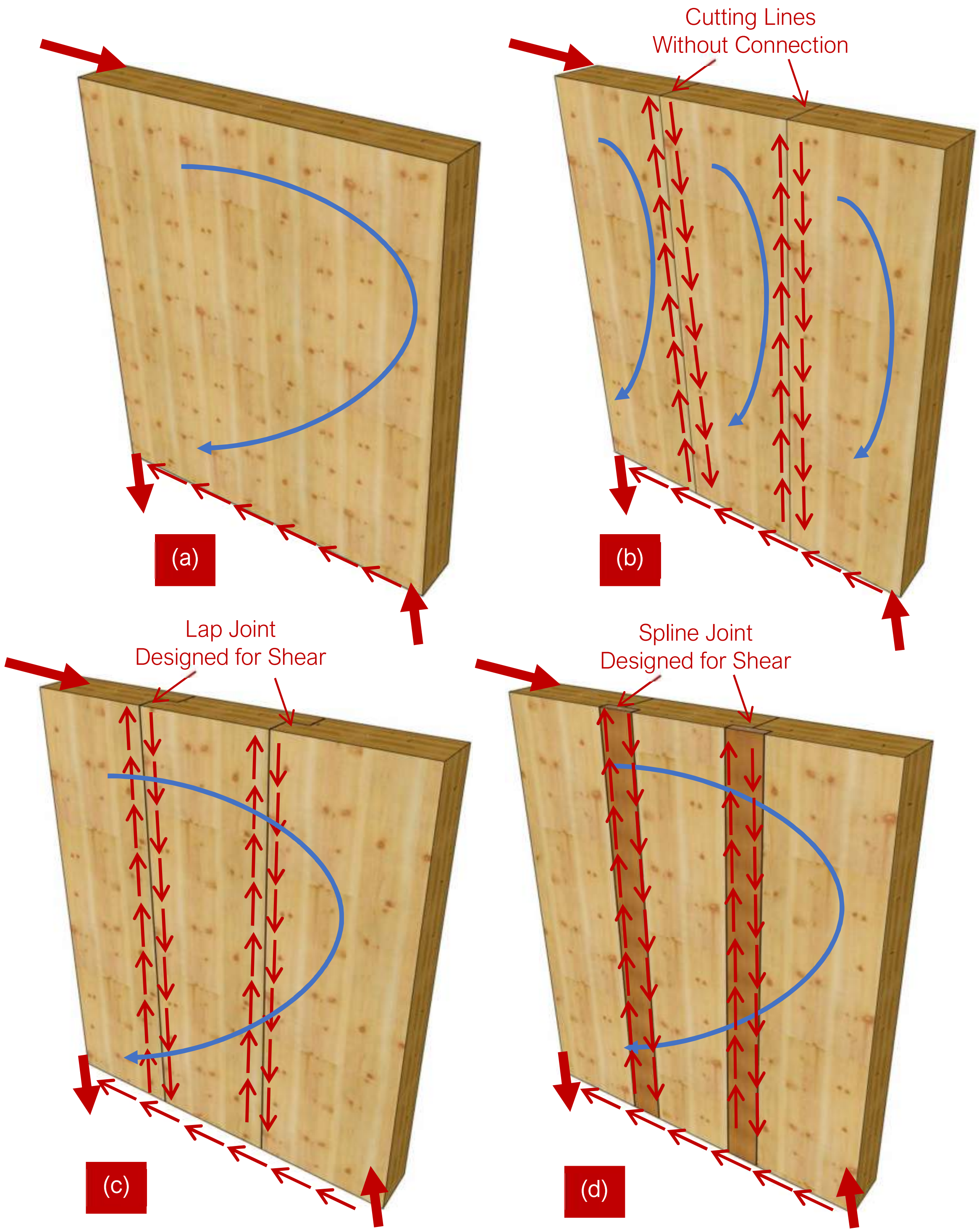


Figure 42: Influence of various connection designs on overturning of CLT shear wall panels.

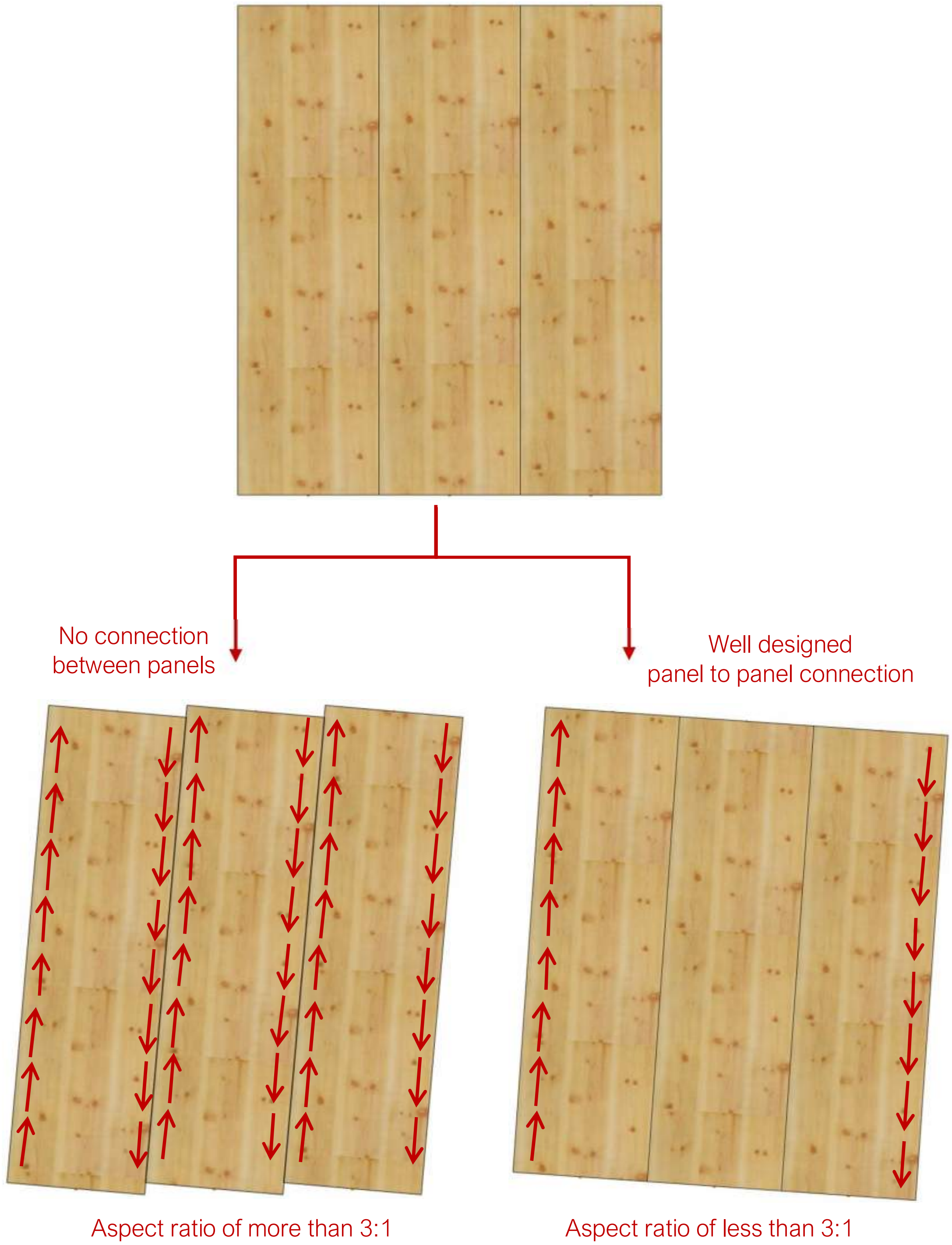


Figure 43: Illustration of rocking behaviour of individual shear wall panels and a well connect CLT shear wall system.

Red Stag have the capability to manufacture and machine CLT panels in a range of sizes and recipes to accommodate various design requirements and seismic performance criteria for mid to high-rise structures. *Figure 44* summarises the aspect ratio of CLT shear walls based on varying CLT panel lengths and widths.

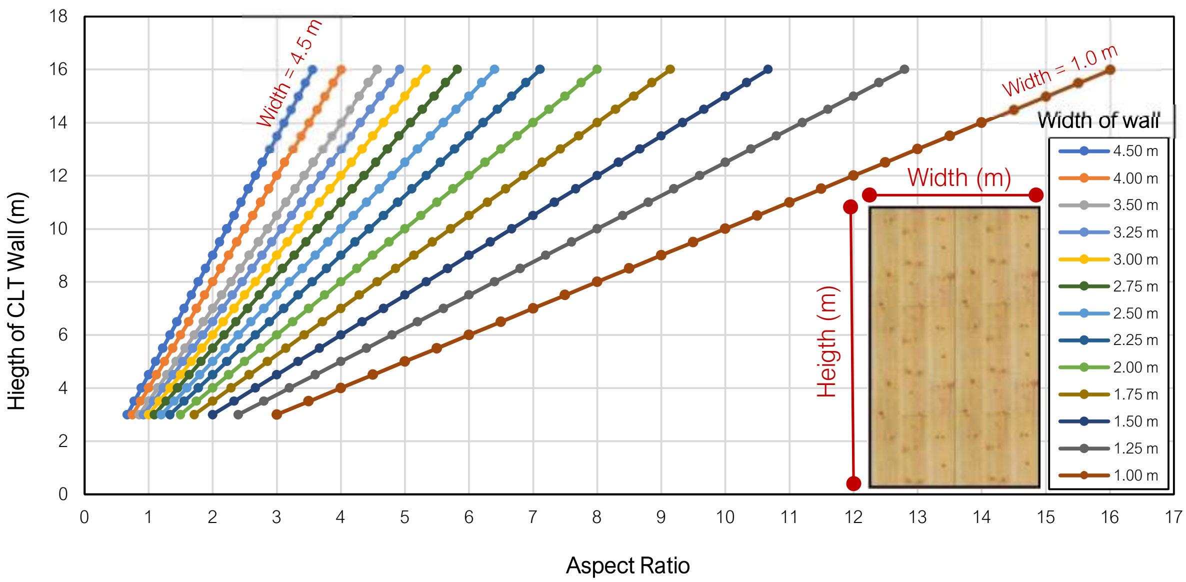


Figure 44: Red Stag CLT panel aspect ratio diagram.

CLT shear wall connections to floor systems are commonly achieved with brackets and hold downs to resist sliding and uplift, respectively. The vertical wall panel-to-panel connections typically use splines or half-lap joints (refer to *Figure 45*).

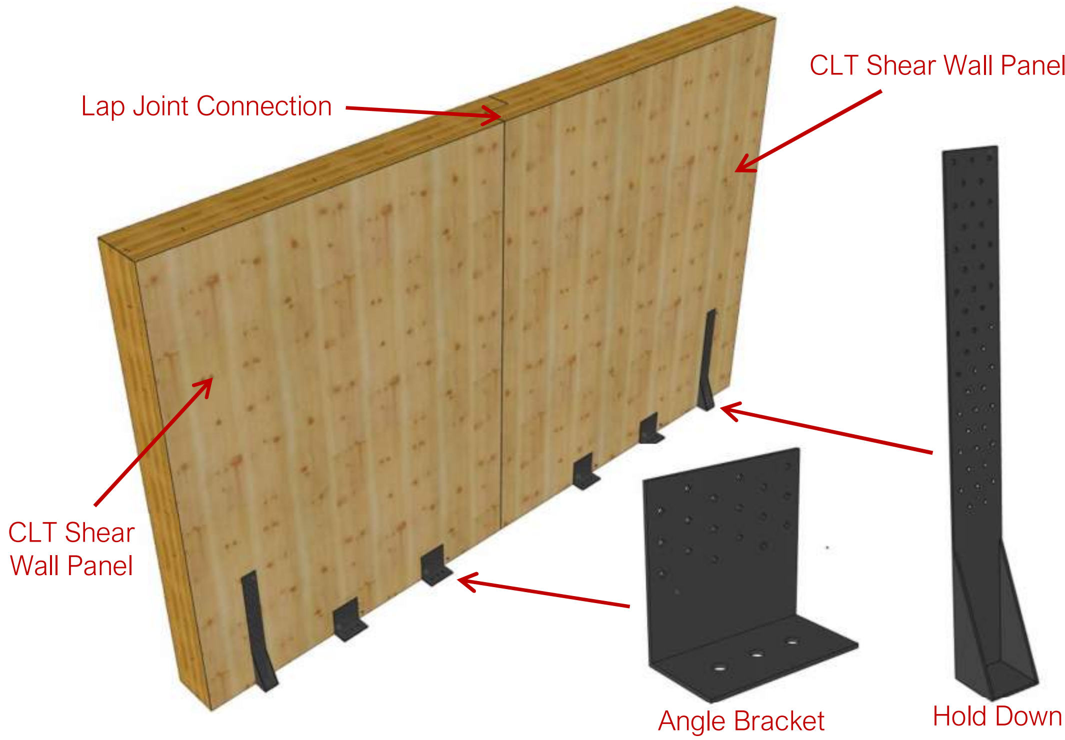


Figure 45: CLT shear wall connections.

5.6 CLT Balloon Versus Platform Construction Systems

CLT balloon and platform assembly techniques are two main construction installation systems for CLT projects.

The main difference between platform and balloon construction is inter floor break lines. Balloon CLT walls extend through intermediary floors. Platform CLT walls on the other hand, typically only span between a single level (sandwiched between floors). Refer to *Figure 46*.

The majority of low-rise CLT buildings are designed with platform walls, where the vertical continuity of the walls is interrupted at each story by horizontal CLT floor panels. At the ground floor, the vertical CLT wall panels are typically connected directly to the reinforced concrete foundation, or a horizontal timber beam interposed between the concrete foundation and vertical CLT wall panels.

The balloon technique is more common for mid to high-rise buildings. In the CLT balloon construction technique the vertical continuity of the CLT wall panels is not interrupted by the floors at each story. Rather, the floors connect internally via a beam, corbel or similar.

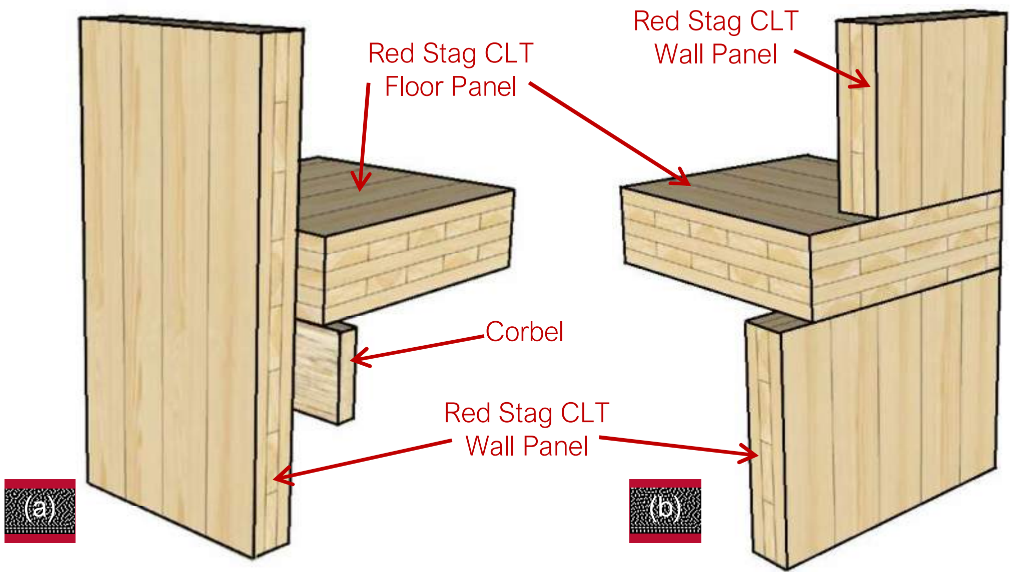


Figure 46: Assembly techniques; (a) CLT balloon construction system; (b) CLT platform construction system.

Horizontal lateral loads that are transferred through the CLT structure and related force equilibrium for the two assembly mechanisms (CLT balloon and platform construction systems) are shown in *Figure 47*.

For supported CLT floors in a platform construction system, the connection between the CLT floor structure and the CLT wall resting on top must be designed for a shear force equivalent to the horizontal load on the CLT wall above it. For suspended CLT floors in a balloon construction system, the connection between the CLT floor structure and the CLT wall needs to be designed for the horizontal force from the CLT floor structure to be transferred to the CLT wall.

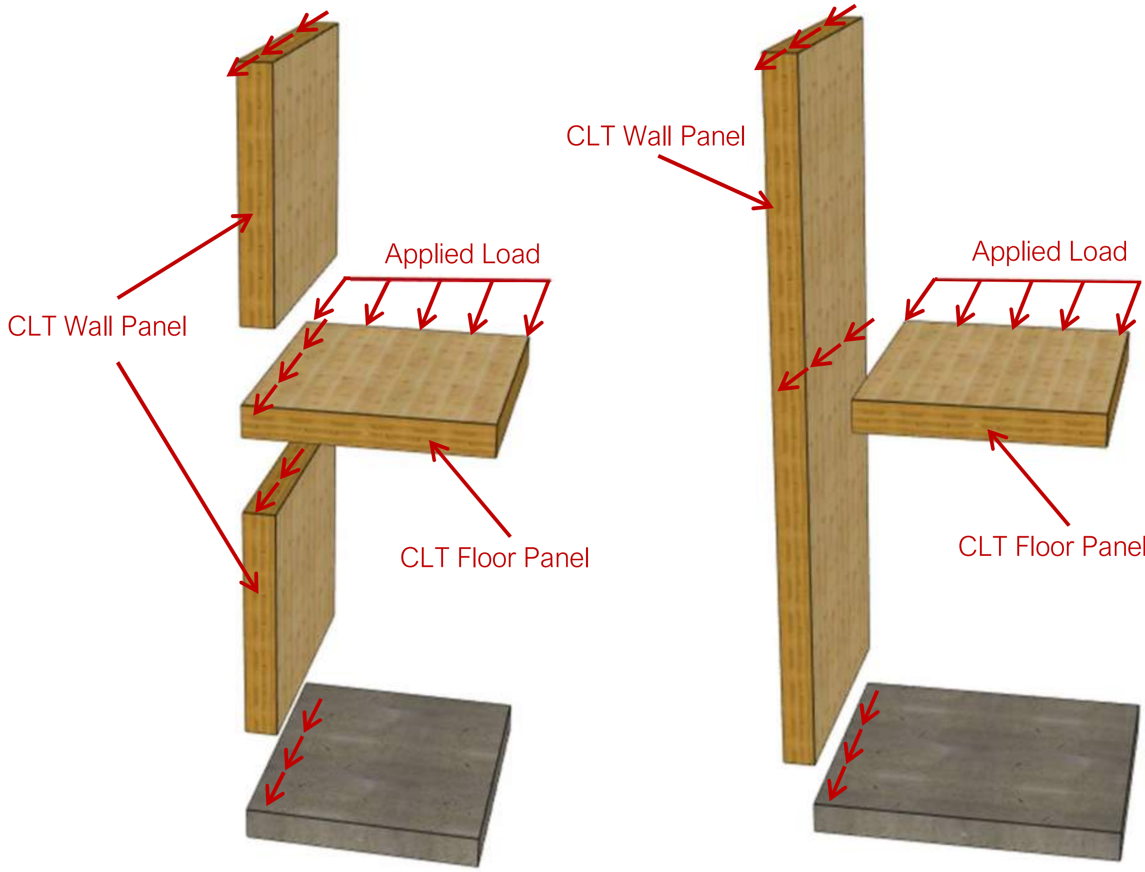


Figure 47: Transfer of horizontal forces between CLT floor panels and CLT walls for platform and balloon construction options.

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 *to* . 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] (refer to *Figure 48*). 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 15* 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].

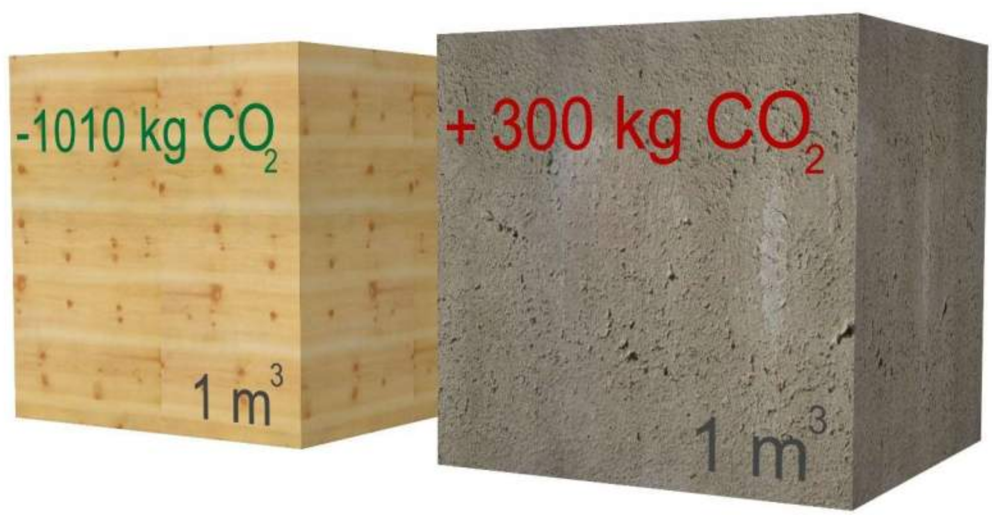


Figure 48: CLT versus Concrete [14-17].

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.

8. Red Stag CLT Panel Specifications

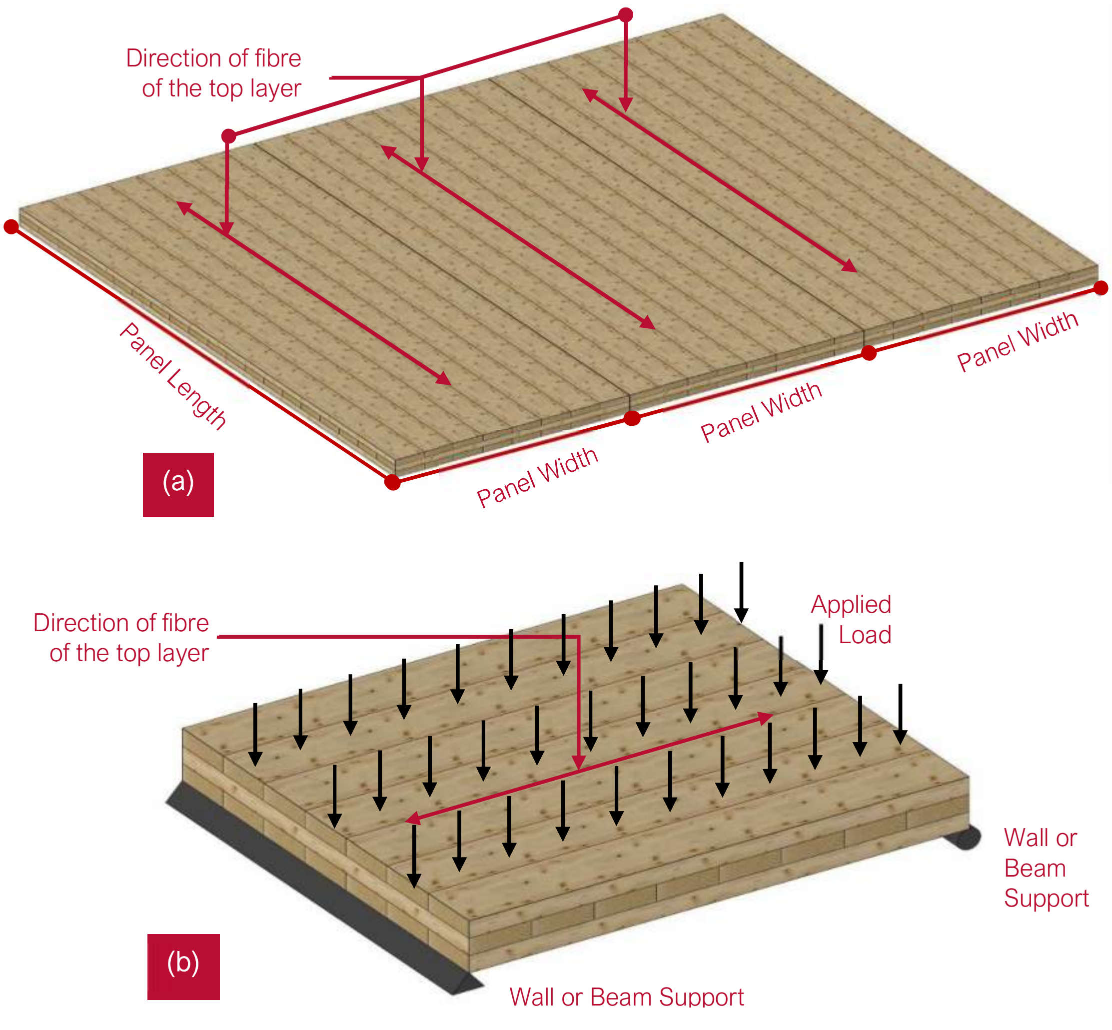
Table 4: Three (3) Layer CLT Panel Specifications		
Recipe Priority [a]	1	2
Panel Recipe	CL3/126	CL3/104
Layer 1, MoE 8 GPa	42 mm	42 mm
Layer 2, MoE 6 GPa	42 mm	20 mm
Layer 3, MoE 8 GPa	42 mm	42 mm
Panel Self Weight (Static Load)	0.63 kPa	0.52 kPa
Panel Thickness	126 mm	104 mm
Removed CO_2 from Atmosphere [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.		

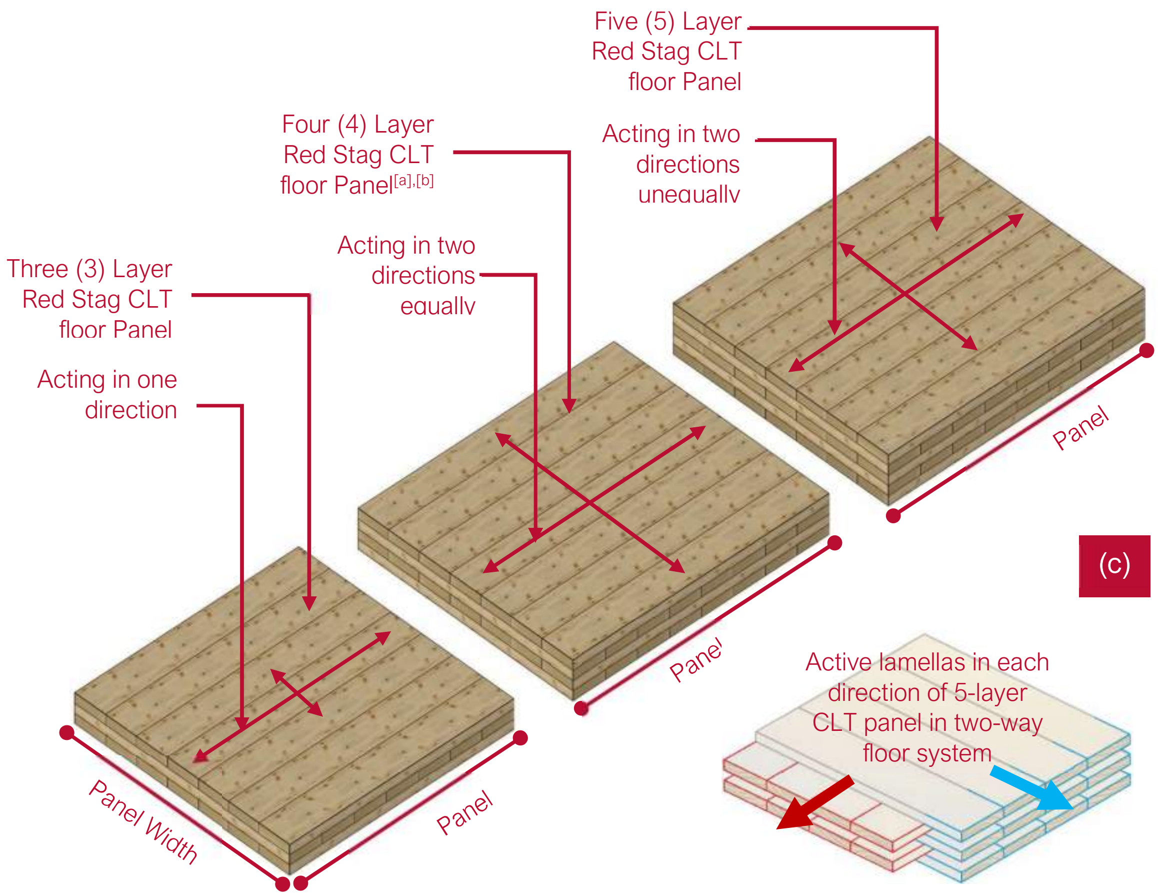
Table 5: Five (5) Layer CLT Panel Specifications		
Recipe Priority [a]	1	2
Panel Title	CL5/210	CL5/166
Layer 1, MoE 8 GPa	42 mm	42 mm
Layer 2, MoE 6 GPa	42 mm	20 mm
Layer 3, MoE 8 GPa	42 mm	42 mm
Layer 4, MoE 6 GPa	42 mm	20 mm
Layer 5, MoE 8 GPa	42 mm	42 mm
Panel Self Weight (Static Load)	1.05 kPa	0.83 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	CL7/294	CL7/228
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 49a* and *Figure 49b*), 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 49c*). Please note that the three (3) layer CLT panel in *Figure 49c* is for illustration purposes only, as at least four layers are required for a two-way action. The panel design and orientation affects the structural performance of the CLT panel to transfer loads in two directions flooring system (refer to *Figure 49d*).





[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.

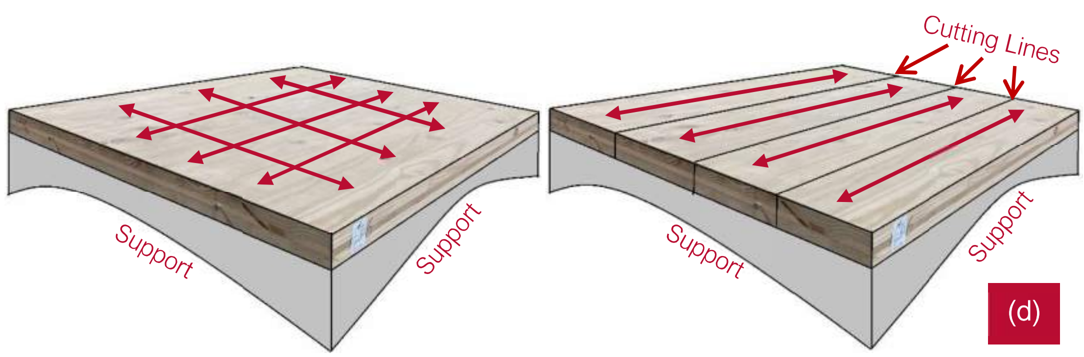


Figure 49: CLT Floor assemblies (a & b) for three (3) layer CLT panels acting in one direction; (c) one five (5) layer CLT panel acting in both directions. Minimum of five layers of lamella are required to guaranty the CLT performs as a two-way CLT system. "Panel width" depends on the manufacturer and 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 KREUZINGER method presented in the FPInnovations CLT design guide to design its CLT panels for roof or floor applications. The KREUZINGER method takes rolling shear deformation in the transverse laminate(s) into account (refer to *Figure 50*). Dissimilar to the long spans in CLT roof or floor panels, shorter spans have a higher proportion of rolling shear deformation.

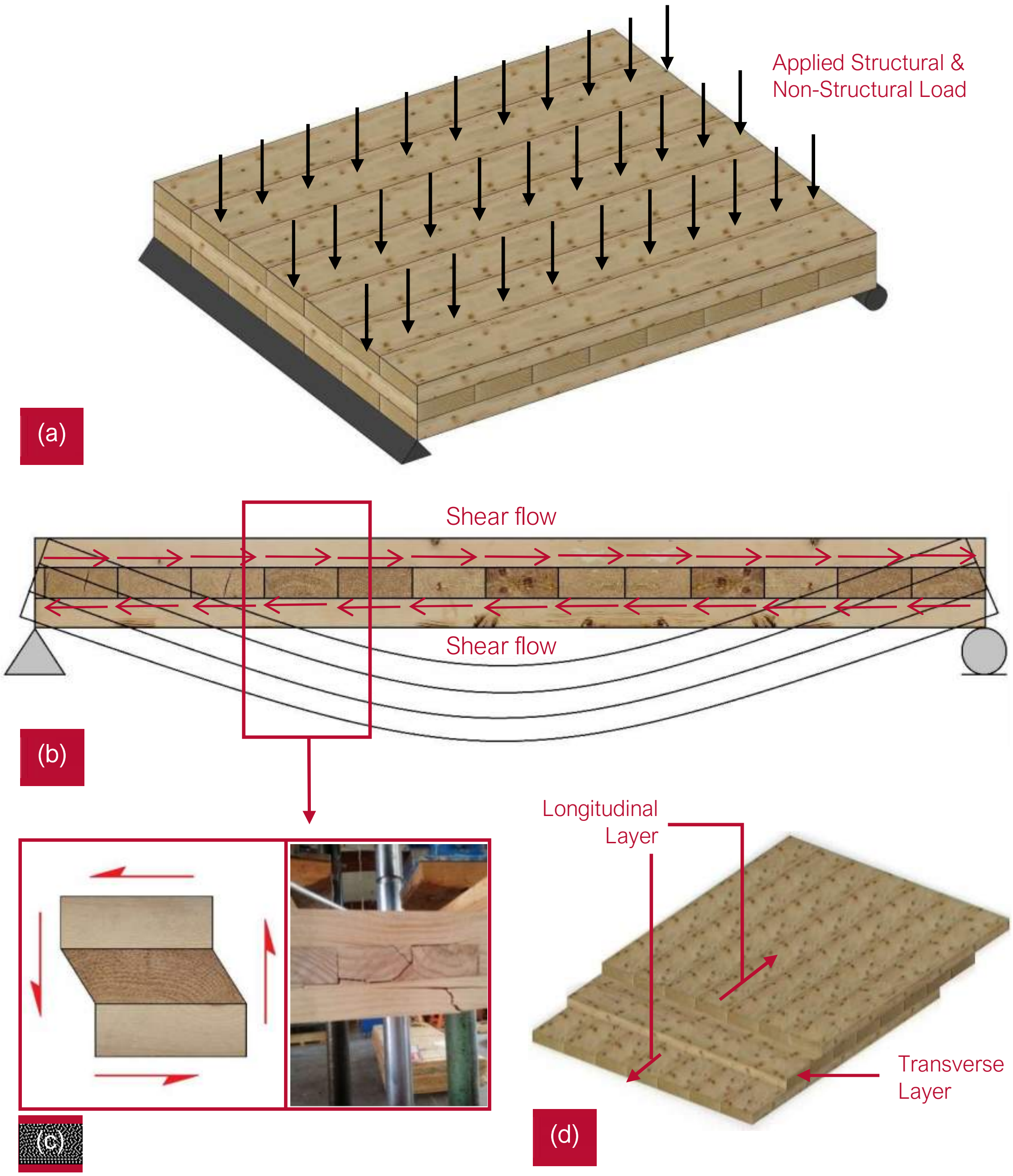


Figure 50: Rolling shear phenomenon; (a) Loaded CLT panel; (b) Shear flow through the panel; (c) Effect of rolling shear; (d) Rolling shear translation to transverse layer.

Although rolling shear strength can be calculated indirectly from the MoE of the boards based on FP Innovation CLT handbook [11, 45, 46], Red Stag is conducting regular third-party testing to ensure the suitable rolling shear characteristics of Red Stag CLT panels.

Rolling shear strength and stiffness testing of Red Stag CLT panels are derived from bending testing based on section C.2.3 of BS EN 16351:2021 (Timber structures – Cross laminated timber -Requirements). Red Stag CLT specimens were tested by a qualified third party laboratory, as presented in *Figure 51*. Using the test method, the third party laboratory recorded applied loads, midspan deflections relative to end supports (W_{Global}) and centre of span (W_{Local}).

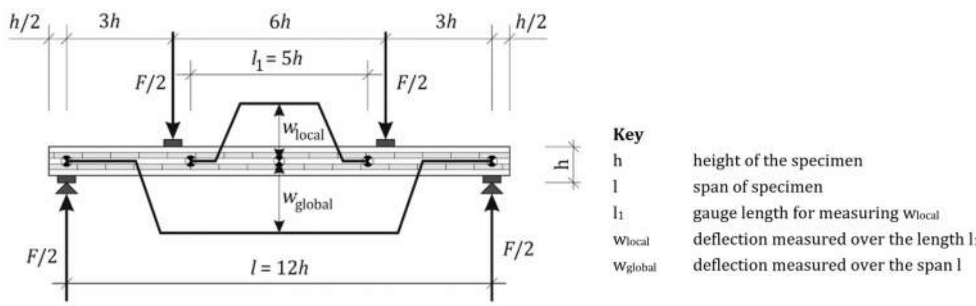


Figure 51: Rolling shear strength and stiffness test configuration based on section C.2.3 of BS EN 16351:2021.

Red Stag targets testing two samples (One for Rolling shear strength and stiffness and one for bending strength) per 1000 billets with third parties to ensure ongoing product performance and quality (refer to *Figure 51* and *Figure 52*).

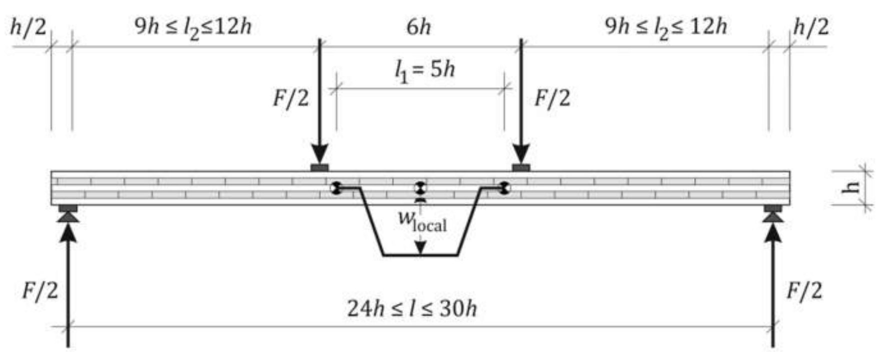


Figure 52: Bending test configuration based on section C.2.1 of BS EN 16351:2021.

The calculation based on recorded test results by the University of Auckland from Red Stag 210 mm thick CLT panels (16 x 2.520 m intermediate span floor tests) generated a rolling shear strength over the declared value in BS EN 16351:2021.

Section 4.1.5.1 of BS EN 16351:2021 states that CLT panels with lamella thickness, which have a thickness of up to 47 mm (including), which are not structurally edge bonded and comprise laminations having a ratio of nominal lamination width to nominal lamination thickness $b_l/t_l < 4$, then the characteristic rolling shear strength may be declared as 0.7 N/mm^2. Red Stag's results exceeded the standard. The average rolling shear strength (f_r) for the tested panels with lamella b_l/t_l ratio less than three (3) exceeded an average of 1.61 N/mm^2.

This confirmed that the commonly adopted assumption of 0.7 N/mm^2 rolling shear strength in BS EN 16351 standard or 1.2 N/mm^2 rolling shear assumption for Re Stag CLT span tables are very conservative for Red Stag CLT. The test observations showed that the majority of the specimens failed in bending and rolling shear is not a major concern with Red Stag CLT panel design.

Please note Rolling Shear is considered the effect of coupled shear flows on the top and bottom side of transverse boards (refer to *Figure 53a, Figure 53b*) which are created by the maximum shear that was measured by the third party Laboratory.

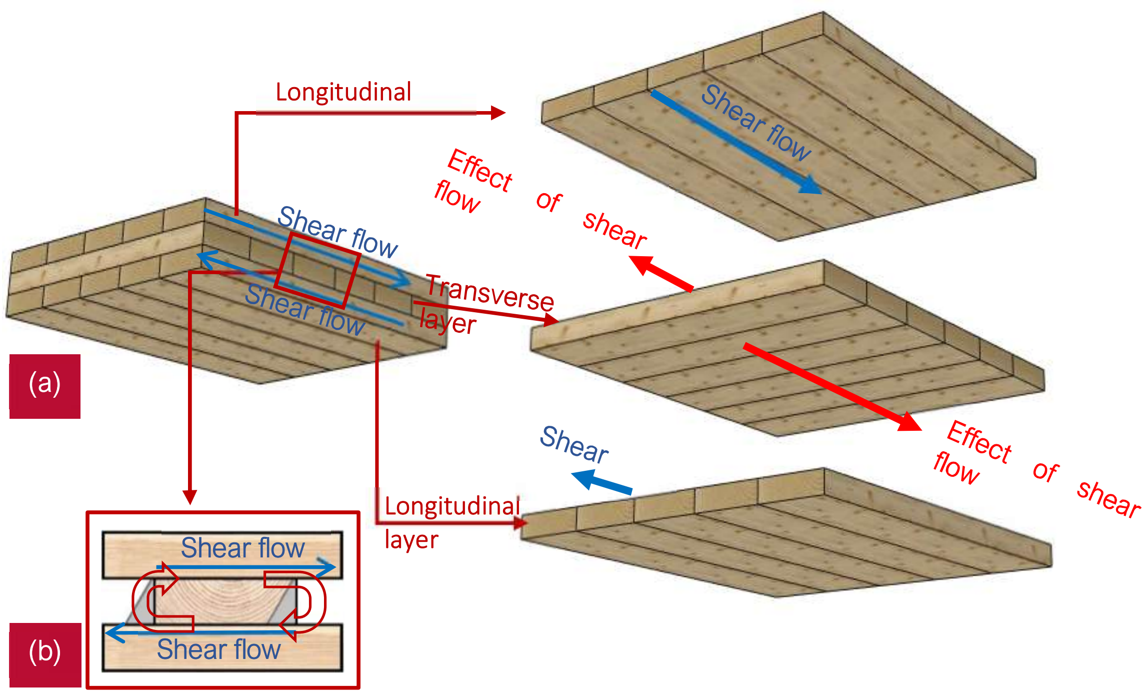


Figure 53: Rolling Shear; a) Red Stag CLT panel with detailed shear flow in the longitudinal and transverse layers.

Although the intermediate span testing aligned with the current version of BS NE 16351, Red Stag tested a shorter span of five-layer CLT panels to put more pressure on the structural performance of Red Stag products. A great shear capacity was observed and again, the calculation shows that the assumption of 0.7 N/mm^2 rolling shear strength is very conservative for engineers. 16 five-layer specimens of Red Stag CLT panels with a 5250 mm span were tested by the University of Auckland Structural Laboratory. The test results show that the bending performance of all samples is better than the referenced structural Glue Laminated Timber (GLT) beams. Refer to *Figure 54* and *Figure 55*.

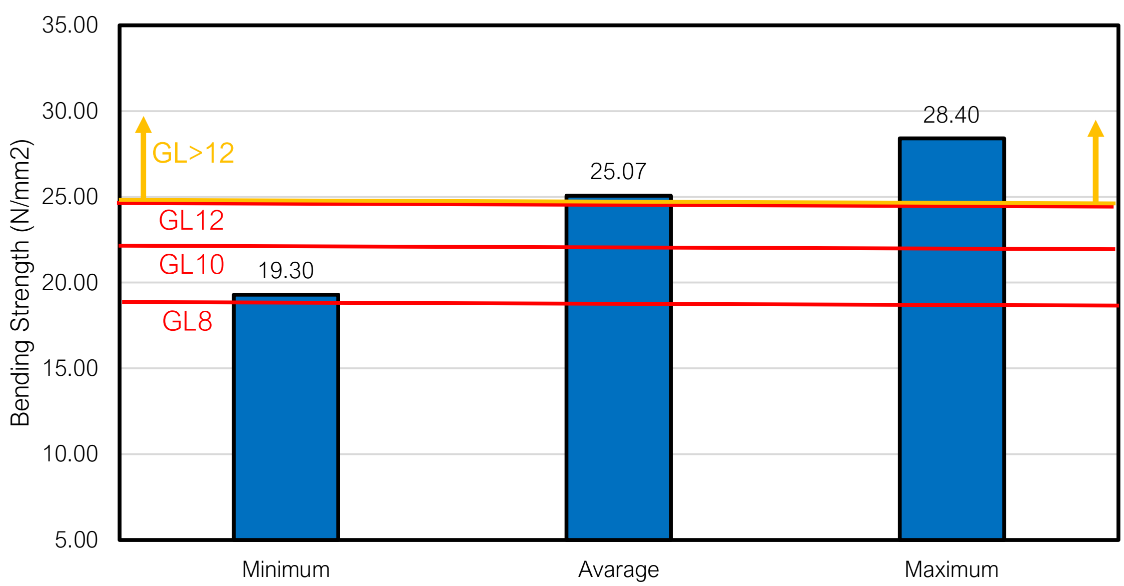


Figure 54: Bending Strength of 210 mm Red Stag CLT panel.

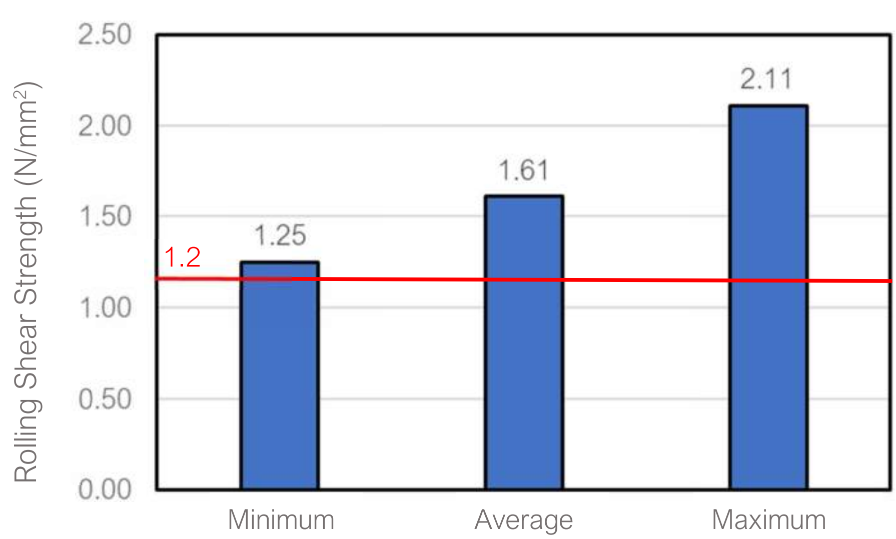


Figure 55: Rolling shear strength of 210 mm Red Stag CLT panel (16 tests).

Red Stag not only tested five-layer CLT panels for rolling shear in compliance with the current version of BS NE 16351, but also tested three-layer CLT panels to confirm t the structural performance of the primary Red Stag panel configurations. Testing was repeated for intermediate and short span 135 mm thick CLT panels, with the results are summarised in *Figure 56 and Figure 57*.

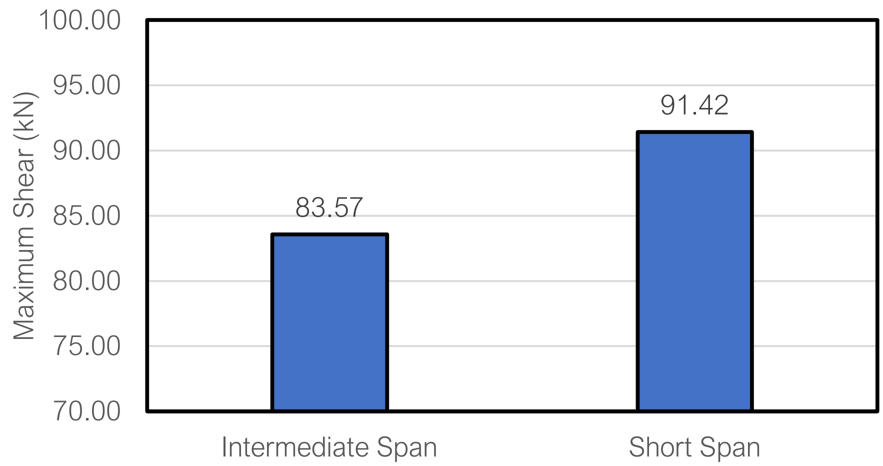


Figure 56: Maximum load carrying capacity of 210 mm thick Red Stag CLT panel.

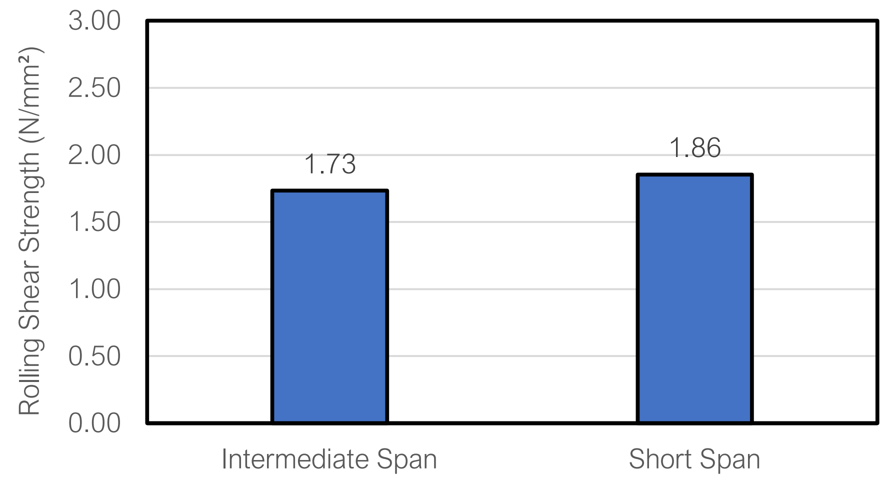


Figure 57: Rolling shear strength of CL3/135 Red Stag CLT panels (135 mm thick).

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:

Uniformly distributed loads

For Long Term Loading: 1.35 G

For Medium Term Loading: 1.2 G + 1.5 Q

Concentrated loads

1.5 Qc

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.

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

Δ: Midspan deflection calculation 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) and frequency checks are additional important factors that need 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:**

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

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:**

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

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].

9.1.1 Red Stag CLT Floors Deflection Check to Control Vibration

Load-deflection test results from two-point bending tests are converted to 1 kN equivalent single point load to make it comparable with recommended midspan deflection of floors, which is restricted to 1 - 2 mm under 1 kN load based on New Zealand Design Action Standards (AS/NZS 1170). Presented average deflection test results in *Figure 58* for 1.502 m and 3.78 m span test specimens confirmed vibration performance of Red Stag CLT panels for floor applications.

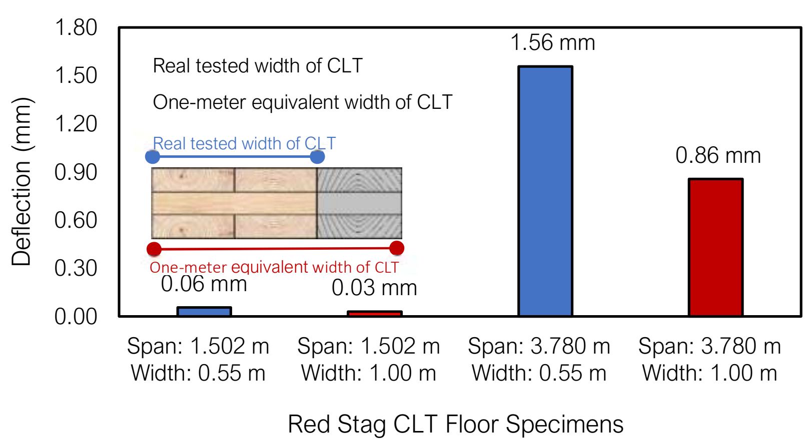


Figure 58: Red Stag CLT floor vibration checks under 1 kN loading.

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 59* - *Figure 60*) 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.

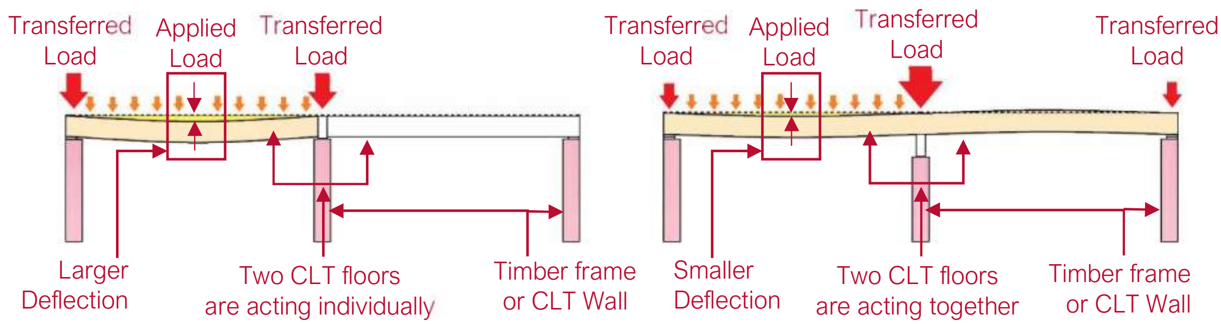
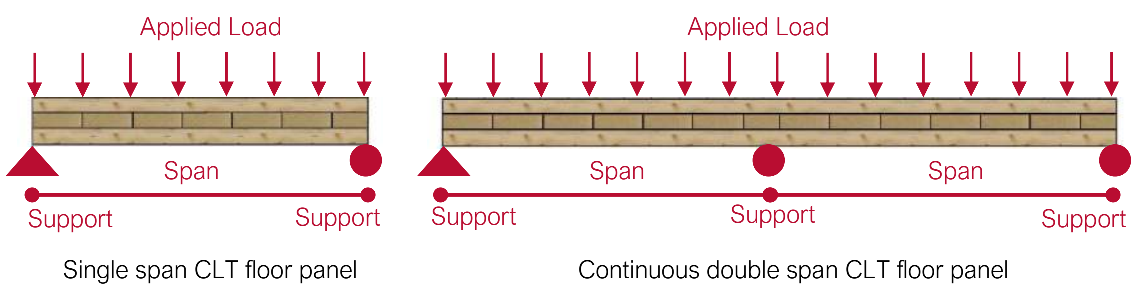


Figure 59: Comparison of deflections between single and double span CLT panels for roof or floor applications [21].



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

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

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

Figure 60: 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.

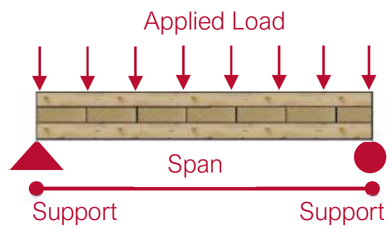
An optimised list of CLT panel configurations for floor and roof applications are summarised in *Table 4* to *Table 6*. The maximum span for cantilever, simply supported and continuous CLT floors and roofs based on the FPInnovation CLT design guide, and the New Zealand design action standard (AS/NZS 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

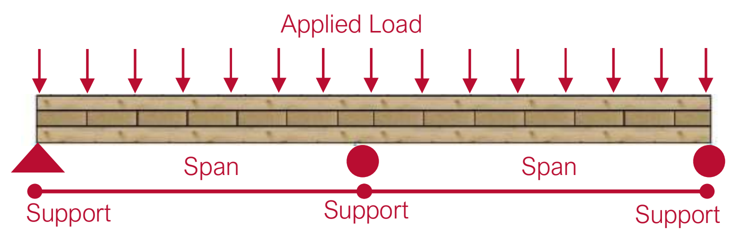
Structural Properties	Longitudinal Laminates	Transverse Laminates
Modulus of Elasticity (MoE)	8.0 GPa	6.0 GPa
Bending Strength	14 MPa	10 MPa
Compression Parallel to Grain	18 MPa	15 MPa
Compression perpendicular to Grain	8.9 MPa	8.9 MPa
Tension Strength	6.0 MPa	4.0 MPa
Normal Shear	3.8 MPa	3.8 MPa
Refer to NZS 3603:1993 [7] and 1720:2022 [49].		

9.3.1 Three (3) Layer CLT Roof Panel

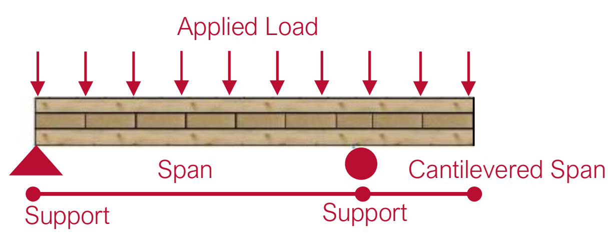
- Applied Loads: Imposed Load = 0.25 kPa, Snow Load = 0 kPa or 3 kPa, CLT Dead Load, Refer to *Table 4.*
- Vibration calculation not considered for roof applications.



Single span (Simply Supported) CLT panel



Double Span (Continuous Two Spans) CLT panel



Cantilevered CLT panel

Table 8: Single Span Three (3) Layer CLT Roof Specification [a, b, c, d, g, h, I, j, k]

Recipe Priority [a]	Panel Title	Thickness	Applied Load (kPa)					
			Live Load (Imposed Load) 0.25 kPa			Live Load (Imposed Load) 1. 5 kPa		
			Super Imposed Dead Load			Super Imposed Dead Load		
			0.25 kPa	0.50 kPa	1.0 kPa	0.25 kPa	0.50 kPa	1.0 kPa
1	CL3/126	126 mm	5.00 m [e]	5.00 m [e]	4.40 m [f]	5.00 m [e]	5.00 m [e]	4.40 m [f]
2	CL3/104	104 mm	4.30 m [e]	4.30 m [e]	3.80 m [f]	4.30 m [e]	4.30 m [e]	3.80 m [f]

a) Not designed for floor applications.
b) Designed for 0.25 and 1.50 kPa live load, 500 kg/m^3 weight for CLT, 0.25 kPa, 0.50 kPa, 1.0 kPa additional super imposed dead load.
c) Vibration calculation not considered for roof applications.
d) Roofs are designed for 500 kg/m3 for CLT only (refer to *Table 4*).
e) Span limited by serviceability limit state deflection (Wind).
f) Span limited by serviceability limit state deflection (Gravity).
g) Red Stag design limits for roof are not constrained to this table. If specific floor designs are required, please contact Red Stag.
h) The maximum cantilever span is no less than 2.5 times of the cantilever length.
i) Refer to *Section 10* for Red Stag CLT roof design example.
j) Wind loads are considered with local pressure factor of 1.5.
k) Roofs are designed for 0.90 kPa snow loads.

Table 9: Double Span Three (3) Layer CLT Roof Specification [a, b, c, d, g, h, l, j, k]

Recipe Priority [a]	Panel Title	Thickness	Applied Load (kPa)					
			Live Load (Imposed Load) 0.25 kPa			Live Load (Imposed Load) 1. 5 kPa		
			Super Imposed Dead Load			Super Imposed Dead Load		
			0.25 kPa	0.50 kPa	1.0 kPa	0.25 kPa	0.50 kPa	1.0 kPa
1	CL3/126	126 mm	5.50 m [e]	5.50 m [e]	5.50 m [e]	5.50 m [e]	5.50 m [e]	5.50 m [e]
2	CL3/104	104 mm	4.80 m [e]	4.80 m [e]	4.80 m [e]	4.80 m [e]	4.80 m [e]	4.80 m [e]

a) Not designed for floor applications.
b) Designed for 0.25 and 1.50 kPa live load, 500 kg/m^3 weight for CLT, 0.25 kPa, 0.50 kPa, 1.0 kPa additional super imposed dead load.
c) Vibration calculation not considered for roof applications.
d) Roofs are designed for 500 kg/m^3 for CLT only (refer to *Table 4*).
e) Span limited by serviceability limit state deflection (Wind).
f) Span limited by serviceability limit state deflection (Gravity).
g) Red Stag design limits for roof are not constrained to this table. If specific floor designs are required, please contact Red Stag.
h) The maximum cantilever span is no less than 2.5 times of the cantilever length.
i) Refer to *Section 10* for Red Stag CLT roof design example.
j) Wind loads are considered with local pressure factor of 1.5.
k) Roofs are designed for 0.90 kPa snow loads.

Table 10: Cantilever Three (3) Layer CLT Roof Specification *[a, b, c, d, g, h, l, j, k]*

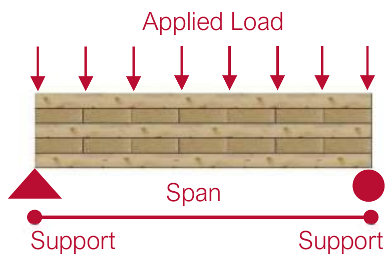
Recipe Priority [a]	Panel Title	Thickness	Applied Load (kPa)					
			Live Load (Imposed Load) 0.25 kPa			Live Load (Imposed Load) 1. 5 kPa		
			Super Imposed Dead Load			Super Imposed Dead Load		
			0.25 kPa	0.50 kPa	1.0 kPa	0.25 kPa	0.50 kPa	1.0 kPa
1	CL3/126	126 mm	1.10 m [e]	1.10 m [e]	1.10 m [e]	1.10 m [e]	1.10 m [e]	1.10 m [e]
2	CL3/104	104 mm	0.90 m [e]	0.90 m [e]	0.90 m [e]	0.90 m [e]	0.90 m [e]	0.90 m [e]

a) Not designed for floor applications.
b) Designed for 0.25 and 1.50 kPa live load, 500 kg/m^3 weight for CLT, 0.25 kPa, 0.50 kPa, 1.0 kPa additional super imposed dead load.
c) Vibration calculation not considered for roof applications.
d) Roofs are designed for 500 kg/m3 for CLT only (refer to *Table 4*).
e) Span limited by serviceability limit state deflection (Wind).
f) Span limited by serviceability limit state deflection (Gravity).
g) Red Stag design limits for roof are not constrained to this table. If specific floor designs are required, please contact Red Stag.
h) The maximum cantilever span is no less than 2.5 times of the cantilever length.
i) Refer to *Section 10* for Red Stag CLT roof design example.
j) Wind loads are considered with local pressure factor of 1.5.
k) Roofs are designed for 0.90 kPa snow loads.

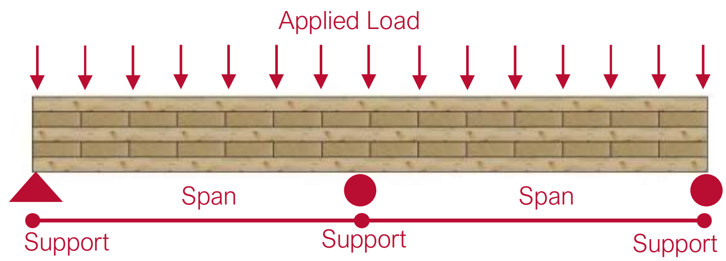
IMPORTANT: If a project is less than 200 m^3, Red Stag can only provide recipe priority 1 options unless agreed prior with the client. Recipe priority 2 or alternates are only available based on available feedstock and production capacity. If a project requires an alternate recipe to priority 1 options,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

9.3.2 Five (5) Layer CLT Roof Panel

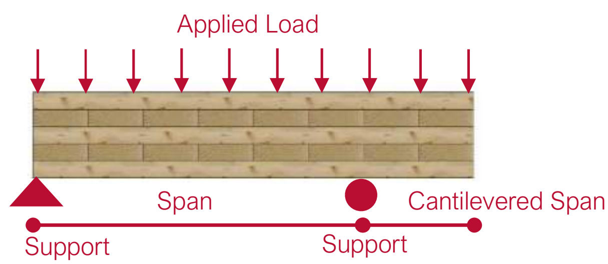
- Applied Loads: Imposed Load = 0.25 kPa, Snow Load = 0 kPa or 3 kPa, CLT Dead Load, Refer to *Table 5*.
- Vibration calculation not considered for roof applications.



Single span (Simply Supported) CLT panel



Double Span (Continuous Two Spans) CLT panel



Cantilevered CLT panel

Table 11: Single Span Five (5) Layer CLT Roof Specification [a, b, c, d, g, h, I, j, k].

Recipe Priority [a]	Panel Title	Thickness	Applied Load (kPa)					
			Live Load (Imposed Load) 0.25 kPa			Live Load (Imposed Load) 1. 5 kPa		
			Super Imposed Dead Load			Super Imposed Dead Load		
			0.25 kPa	0.50 kPa	1.0 kPa	0.25 kPa	0.50 kPa	1.0 kPa
1	CL5/210	210 mm	7.10 m [e]	6.80 m [f]	6.30 m [f]	7.10 m [e]	6.80 m [f]	6.30 m [f]
2	CL5/166	166 mm	6.10 m [e]	6.10 m [e]	5.60 m [f]	6.10 m [e]	6.10 m [e]	5.60 m [f]
3	CL5/188	188 mm	6.60 m [e]	6.40 m [f]	5.90 m [f]	6.60 m [e]	6.40 m [f]	5.90 m [f]
4	CL5/144	144 mm	5.60 m [e]	5.60 m [e]	5.00 m [f]	5.60 m [e]	5.60 m [e]	5.00 m [f]

a) Not designed for floor applications.
b) Designed for 0.25 and 1.50 kPa live load, 500 kg/m^3 weight for CLT, 0.25 kPa, 0.50 kPa, 1.0 kPa additional super imposed dead load.
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) Span limited by serviceability limit state deflection (Wind).
f) Span limited by serviceability limit state deflection (Gravity).
g) Red Stag design limits for roof are not constrained to this table. If specific floor designs are required, please contact Red Stag.
h) The maximum cantilever span is no less than 2.5 times of the cantilever length.
i) Refer to *Section 10* for Red Stag CLT roof design example.
j) Wind loads are considered with local pressure factor of 1.5.
k) Roofs are designed for 0.90 kPa snow loads.

Table 12: Doble Span Five (5) Layer CLT Roof Specification [a, b, c, d, g, h, I, j, k].

Recipe Priority [a]	Panel Title	Thickness	Applied Load (kPa)					
			Live Load (Imposed Load) 0.25 kPa			Live Load (Imposed Load) 1. 5 kPa		
			Super Imposed Dead Load			Super Imposed Dead Load		
			0.25 kPa	0.50 kPa	1.0 kPa	0.25 kPa	0.50 kPa	1.0 kPa
1	CL5/210	210 mm	7.70 m [e]	7.70 m [e]	7.70 m [e]	7.70 m [e]	7.70 m [e]	7.70 m [e]
2	CL5/166	166 mm	6.70 m [e]	6.70 m [e]	6.70 m [e]	6.70 m [e]	6.70 m [e]	6.70 m [e]
3	CL5/188	188 mm	7.10 m [e]	7.10 m [e]	7.10 m [e]	7.10 m [e]	7.10 m [e]	7.10 m [e]
4	CL5/144	144 mm	6.70 m [e]	6.70 m [e]	6.70 m [e]	6.70 m [e]	6.70 m [e]	6.70 m [e]

a) Not designed for floor applications.
b) Designed for 0.25 and 1.50 kPa live load, 500 kg/m^3 weight for CLT, 0.25 kPa, 0.50 kPa, 1.0 kPa additional super imposed dead load.
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) Span limited by serviceability limit state deflection (Wind).
f) Span limited by serviceability limit state deflection (Gravity).
g) Red Stag design limits for roof are not constrained to this table. If specific floor designs are required, please contact Red Stag.
h) The maximum cantilever span is no less than 2.5 times of the cantilever length.
i) Refer to Section 10 for Red Stag CLT roof design example.
j) Wind loads are considered with local pressure factor of 1.5.
k) Roofs are designed for 0.90 kPa snow loads.

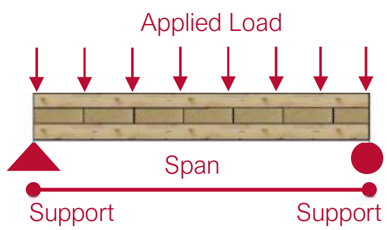
Table 13: Cantilever Five (5) Layer CLT Roof Specification [a, b, c, d, g, h, l, j, k].								
Recipe Priority [a]	Panel Title	Thickness	Applied Load (kPa)					
			Live Load (Imposed Load) 0.25 kPa			Live Load (Imposed Load) 1. 5 kPa		
			Super Imposed Dead Load			Super Imposed Dead Load		
			0.25 kPa	0.50 kPa	1.0 kPa	0.25 kPa	0.50 kPa	1.0 kPa
1	CL5/210	210 mm	1.80 m [e]	1.90 m [e]	1.90 m [e]	1.80 m [e]	1.90 m [e]	1.90 m [e]
2	CL5/166	166 mm	1.50 m [e]	1.50 m [e]	1.50 m [e]	1.50 m [e]	1.50 m [e]	1.50 m [e]
3	CL5/188	188 mm	1.60 m [e]	1.60 m [e]	1.60 m [e]	1.60 m [e]	1.60 m [e]	1.60 m [e]
4	CL5/144	144 mm	1.30 m [e]	1.30 m [e]	1.30 m [e]	1.30 m [e]	1.30 [e]	1.31 [e]

a) Not designed for floor applications.
b) Designed for 0.25 and 1.50 kPa live load, 500 kg/m^3 weight for CLT, 0.25 kPa, 0.50 kPa, 1.0 kPa additional super imposed dead load.
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) Span limited by serviceability limit state deflection (Wind).
f) Span limited by serviceability limit state deflection (Gravity).
g) Red Stag design limits for roof are not constrained to this table. If specific floor designs are required, please contact Red Stag.
h) The maximum cantilever span is no less than 2.5 times of the cantilever length.
i) Refer to *Section 10* for Red Stag CLT roof design example.
j) Wind loads are considered with local pressure factor of 1.5.
k) Roofs are designed for 0.90 kPa snow loads.

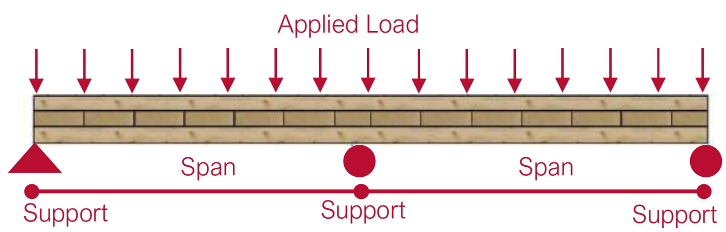
IMPORTANT: If a project is less than 200 m^3, Red Stag can only provide recipe priority 1 options unless agreed prior with the client. Recipe priority 2 or alternates are only available based on available feedstock and production capacity. If a project requires an alternate recipe to priority 1 options,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

9.3.4 Three (3) Layer CLT Floor Panel

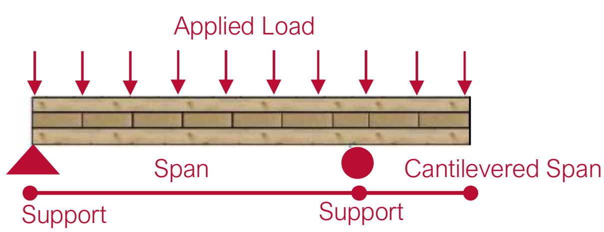
- Applied Loads: Imposed Load = 2 kPa, 3 kPa and 5 kPa,
  CLT Dead Load = Refer to *Table 4*.
- Vibration calculation considered in span performance.



Single span (Simply Supported) CLT panel



Double Span (Continuous Two Spans) CLT panel



Cantilevered CLT panel

Table 14: Three (3) Layer Simply Supported Single Span, Double Span and Cantilevered CLT Floor Specifications [a, b, c, d, h, I, j].

	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	CL3/126	126 mm	3.90 m [f]	3.90 m [e]	3.10 m [e]	3.80 m [f]	3.60 m [e]	3.00 m [e]	3.30 m [e]	3.20 m [e]	2.70 m [e]
	2	CL3/104	104 mm	3.40 m [f]	3.30 m [f]	2.70 m [e]	3.30 m [e]	3.10 m [e]	2.50 m [e]	2.80 m [e]	2.70 m [e]	2.30 m [e]
Double Span (Continuous Two Spans)	1	CL3/126	126 mm	3.90 m [f]	3.9 m [f]	3.60 m [e]	3.90 m [f]	3.90 m [f]	3.50 m [e]	3.803 m [g]	3.80 m [g]	3.20 m [e]
	2	CL3/104	104 mm	3.40 m [f]	3.40 m [f]	3.10 m [e]	3.40 m [f]	3.40 m [f]	3.00m [e]	3.40 m [f]	3.40 m [f]	2.80 m [e]
Cantilevered	1	CL3/126	126 mm	1.50 m [e]	1.30 m [e]	-	1.50 m [e]	1.30 m [e]	0.60 m [e]	1.40 m [e]	1.20 m [e]	0.80 m [e]
	2	CL3/104	104 mm	1.10 m [e]	0. 80 m [e]	-	1.10 m [e]	0.80 m [e]	-	1.00 m [e]	0. 80 m [e]	-

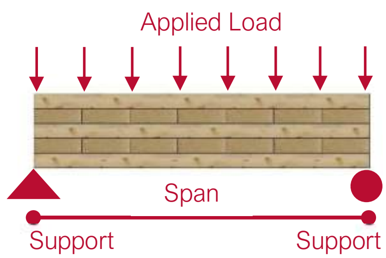
a) Recipe priority defines the most cost-effective Red Stag CLT recipe option.
b) Floors are designed for 2 kPa, 3 kPa or 5 kPa Live Load (Imposed Load).
c) Floors are designed for 0.5 kPa, 1 kPa or 1.5 kPa addition Dead Load (Super Imposed Dead Load).
d) Floors are designed for 500 kg/m^3 for CLT (refer to *Table 4*).
e) Span limited by serviceability limit state deflection.
f) Span controlled by vibration (exclude frequency limit).
g) Span controlled by vibration (frequency limit).
h) Red Stag design limits for floors are not constrained to this table. If specific floor designs are required, please contact Red Stag.
i) The maximum cantilever span is no less than 2.5 times of the cantilever length.
j) 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.

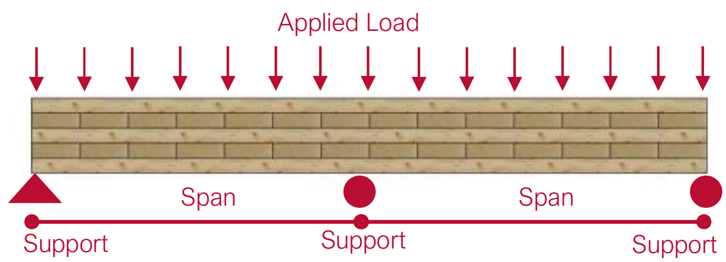
9.3.4 Five (5) Layer CLT Floor Panel

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

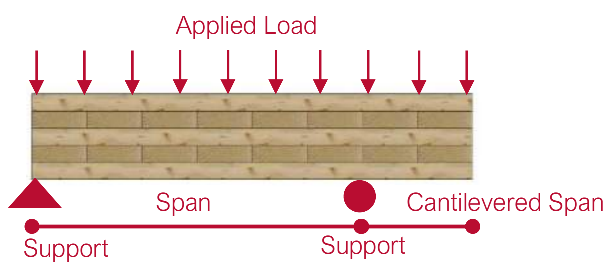
  CLT Dead Load = Refer to *Table 5*.
- Vibration calculation considered in span performance.



Single span (Simply Supported) CLT panel



Double Span (Continuous Two Spans) CLT panel



Cantilevered CLT panel

Table 15: 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	CL5/210	210 mm	5.50 m [f]	5.40 m [f]	4.80 m [e]	5.40 m [f]	5.40 m [f]	4.60 m [e]	5.10 m [e]	4.90 m [e]	4.30 m [e]
	2	CL5/166	166 mm	4.70 m [f]	4.70 m [f]	4.10 m [e]	4.70 m [f]	4.60 m [f]	3.90 m [e]	4.30 m [e]	4.20 m [e]	3.60 m [e]
	3	CL5/188	188 mm	5.10 m [f]	5.10 m [f]	4.30 m [e]	5.10 m [f]	5.00 m [e]	4.20 m [e]	4.60 m [e]	4.50 m [e]	3.90 m [e]
	4	CL5/144	144 mm	4.30 m [f]	4.30 m [f]	3.60 m [e]	4.30 m [f]	4.10 m [e]	3.40 m [e]	3.80 m [e]	3.70 m [e]	3.20 m [e]
Double Span (Continuous Two Spans)	1	CL5/210	210 mm	5.40 m [f]	5.40 m [f]	5.40 m [f]	5.40 m [f]	5.40 m [f]	5.40 m [f]	5.10 m [g]	5.10 m [g]	5.10 m [g]
	2	CL5/166	166 mm	4.70 m [f]	4.70 m [f]	4.70 m [f]	4.70 m [f]	4.70 m [f]	4.60 m [e]	5.60 m [f]	4.60 m [e]	4.40 m [g]
	3	CL5/188	188 mm	5.10 m [f]	5.10 m [f]	5.10 m [f]	5.10 m [f]	5.10 m [f]	4.90 m [e]	4.80 m [g]	4.80 m [g]	4.60 m [e]
	4	CL5/144	144 mm	4.30 m [f]	4.30 m [f]	4.10 m	4.30 m [f]	4.30 m [f]	4.00 m [e]	4.20 m [g]	4.20 m [g]	3.80 m [e]
Cantilevered	1	CL5/210	210 mm [e]	2.60 m [e]	2.30 m [e]	1.80 m [e]	2.50 m [e]	2.30 m [e]	1.80 m [e]	2.30 m [e]	1.90 m [e]	1.50 m [e]
	2	CL5/166	166 mm [e]	2.10 m [e]	1.90 m [e]	1.40 m [e]	2.10 m [e]	1.80 m [e]	1.40 m [e]	1.90 m [e]	1.80 m [e]	1.40 m [e]
	3	CL5/188	188 mm [f]	2.30 m [e]	2.10 m [e]	1.60 m [e]	2.30 m [e]	2.00 m [e]	1.60 m [e]	2.10 m [e]	1.90 m [e]	1.50 m [e]
	4	CL5/144	144 mm [e]	1.80 m [e]	1.50 m [e]	1.10 m [e]	1.80 m [e]	1.50 m [e]	1.10 m [e]	1.60 m [e]	1.50 m [e]	1.10 m [e]

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 *Error! Reference source not found.*).
e) Span limited by serviceability limit state deflection.
f) Span controlled by vibration (exclude frequency limit).
g) Span controlled by vibration (frequency limit).
h) Red Stag design limits for floors are not constrained to this table. If specific floor designs are required, please contact Red Stag.
i) The maximum cantilever span is no less than 2.5 times of the cantilever length.
j) 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.

9.4. Recesses and Penetrations in CLT Floor Panels

Although the cross-layer configuration of CLT panels reduces the risk of splitting at penetrations, Red Stag strongly recommends that the designing engineer consider the design calculations based on the reduced width of the continuous (uninterrupted by processing) sections of the remaining CLT element not interrupted by penetrations to ensure suitable load transfer. In a conservative design, all design loads should be transferred to the continuous uninterrupted sections of the panel (sections of the panel that have the uninterrupted longitudinal lamellas across the span) (refer to *Figure 61*).

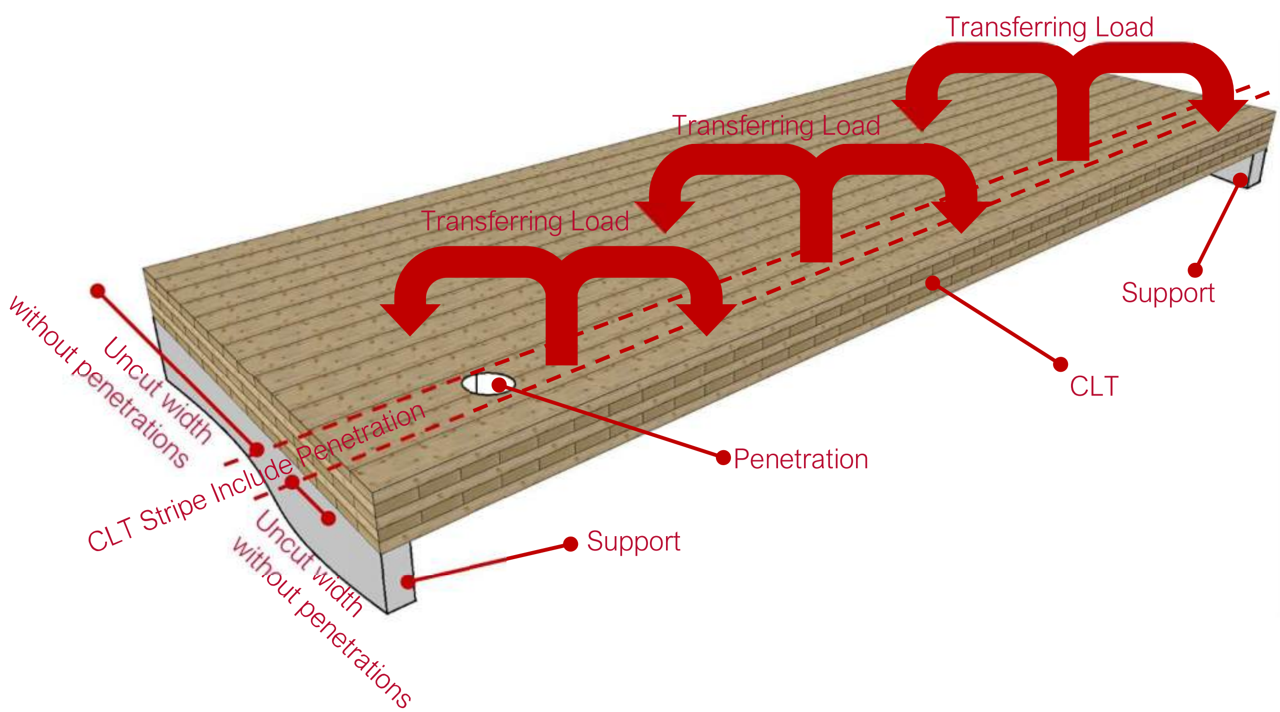


Figure 61: Design basis for load transfer due to penetrations in CLT panels.

When a large volume of fibre is removed from CLT elements, such as shower recesses or similar, it is strongly recommended that the structural designer reconsider the load-carrying capacity of the panel under applied loads based on the new thickness of the spanning lamellas after fibre removal. Refer to *Figure 62*.

Deep recesses and larger recess areas remove a large proportion of the fibre in the spanning (longitudinal) lamella of the CLT panel, which significantly contributes to the panel's load-carrying capacity. This becomes even more critical when a full depth penetration is added to the recessed area (e.g. shower waste).

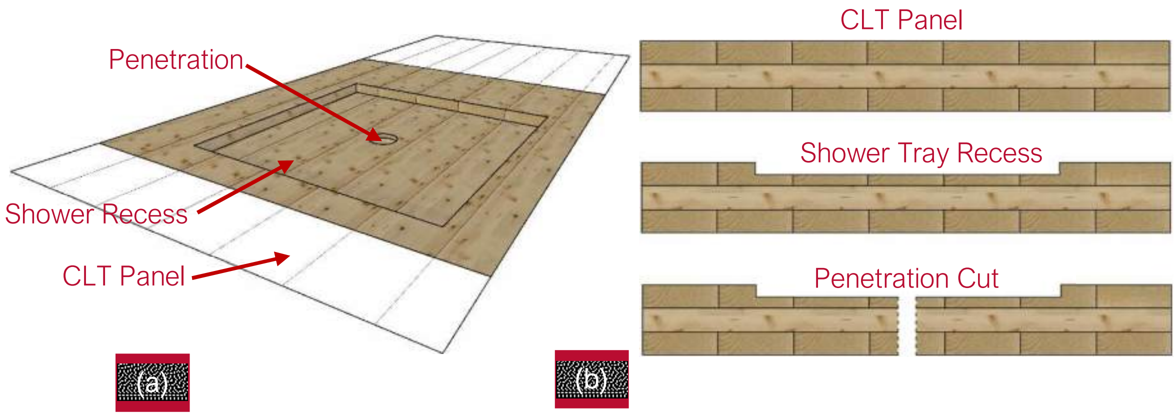


Figure 62: Shower tray and chasing through the Red Stag CLT panel; a) Shower recess in the CLT panel and penetration cut through CLT panel; b) Step by step shower tray CNC process.

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 *and* . 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].

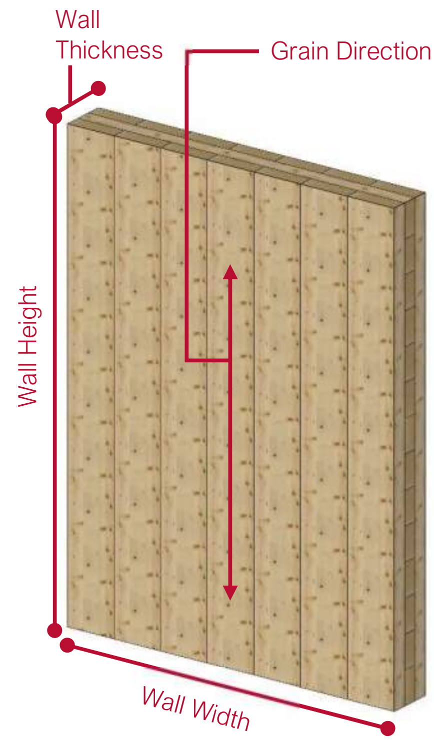


Table 16: Wall Load Carrying of the Three (3) Layer CLT Panel Under Uniformly Distributed Vertical Load.

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	CL3/126	126 mm	280[1,4] 370[2,4] 440[3,5] kN/m	280[1,4] 370[2,5] 400[3,5] kN/m	270[1,5] 320[2,4] 340[3,5] kN/m	240[1,5] 280[2,5] 290[3,5] kN/m	-100 kg/m^3	151 kg/m^3
2	CL3/104	104 mm	230[1,4] 310[2,5] 330[3,5] kN/m	230[1,4] 280[2,5] 290[3,5] kN/m	200[1,5] 230[2,5] 230[3,5] kN/m	170[1,5] 190[2,5] 180[3,5] kN/m	- 83 kg/m^3	126 kg/m^3

a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.
[1]. k_1 =0.6 for load combination 1.35 G.
[2]. k_1 =0.8 for load combination 1.2 G + 0.4 Q.
[3]. k_1 =1.0 for load combination 1.2 G + 0.4 Q +Wu.
[4]. Governed by perpendicular to grain bearing.
[5]. Governed by Euler Buckling.

Table 17: 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	CL5/210	210 mm	470[1,4] 630[2,4] 780[3,4] kN/m	470[1,4] 630[2,4] 770[3,5] kN/m	470[1,4] 620[2,5] 720[3,5] kN/m	460[1,5] 580[2,5] 660[3,5] kN/m	-161 kg/m³	242 kg/m³
2	CL5/166	166 mm	370[1,4] 490[2,4] 620[3,4] kN/m	370[1,4] 490[2,4] 620[3,4] kN/m	370[1,4] 490[2,4] 570[3,5] kN/m	370[1,4] 470[2,5] 510[3,5] kN/m	-127 kg/m³	191 kg/m³
3	CL5/188	188 mm	420[3,4] 560[3,4] 690[3,5] kN/m	420[3,4] 560[3,4] 660[3,5] kN/m	420[3,4] 530[3,5] 610[3,5] kN/m	400[3,5] 500[3,5] 550[3,5] kN/m	-143 kg/m³	216 kg/m³
4	CL5/144	144 mm	320[3, 4] 430[3,4] 540[3,4] kN/m	320[3,4] 430[3,4] 510[3,5] kN/m	320[3, 4] 410[3,5] 450[3,5] kN/m	300[3, 5] 370[3,5] 380[3,5] kN/m	-110 kg/m³	165 kg/m³

a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.
[1]. k_1 =0.6 for load combination 1.35 G.
[2]. k_1 =0.8 for load combination 1.2 G + 0.4 Q.
[3]. k_1 =1.0 for load combination 1.2 G + 0.4 Q +Wu.
[4]. Governed by perpendicular to grain bearing.
[5]. Governed by Euler Buckling.

10.1 Recess and Penetrations in CLT Floor Panel

For wide openings such as large windows and doors, Red Stag strongly recommend the charted engineer reconsider the calculations for the load carrying capacity of the CLT wall for the extra load which is transferred from the lintels and ensure that the lintel depth and performance is sufficient to transfer the loads(refer to *Figure 63*).

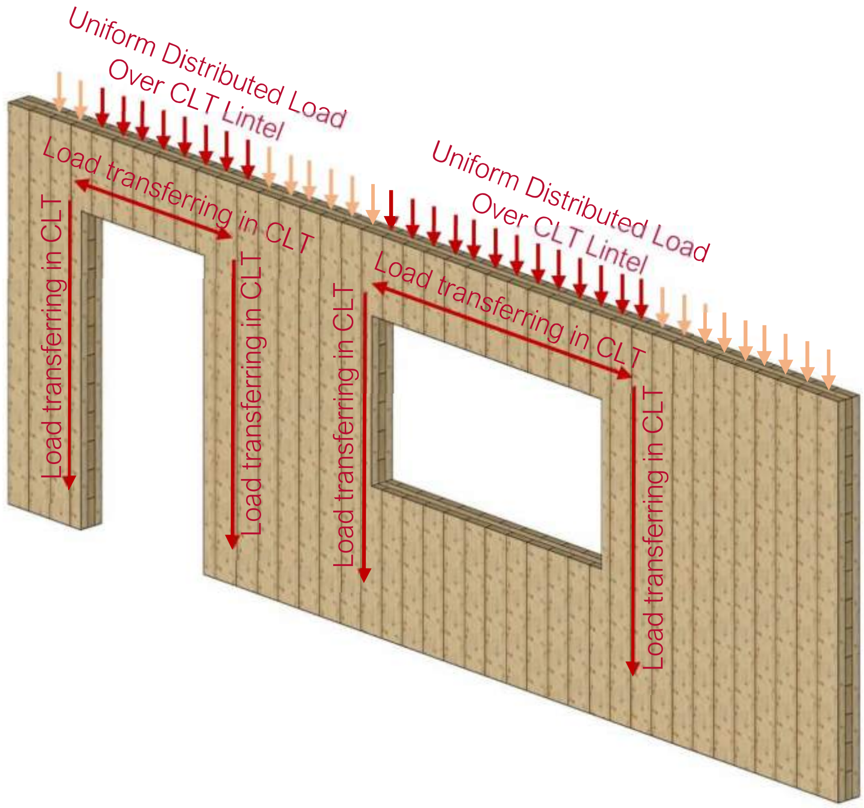


Figure 63: Load transferring over a CLT wall.

Red Stag can supply various types of lintels based the client's request for different structural and architectural purposes. When openings (windows or doors) are cut from a single solid CLT billet, the final product is architecturally appealing and simplifies the installation (refer to *Figure 64b*); however, separated assemblies with several components can improve the structural performance due to the management of grain orientation (refer to *Figure 64a* and *Figure 64c*). This method will reduce wastage and potentially transportation costs based on efficient panel optimisation during nesting (refer to *Figure 64d and Figure 64e*).

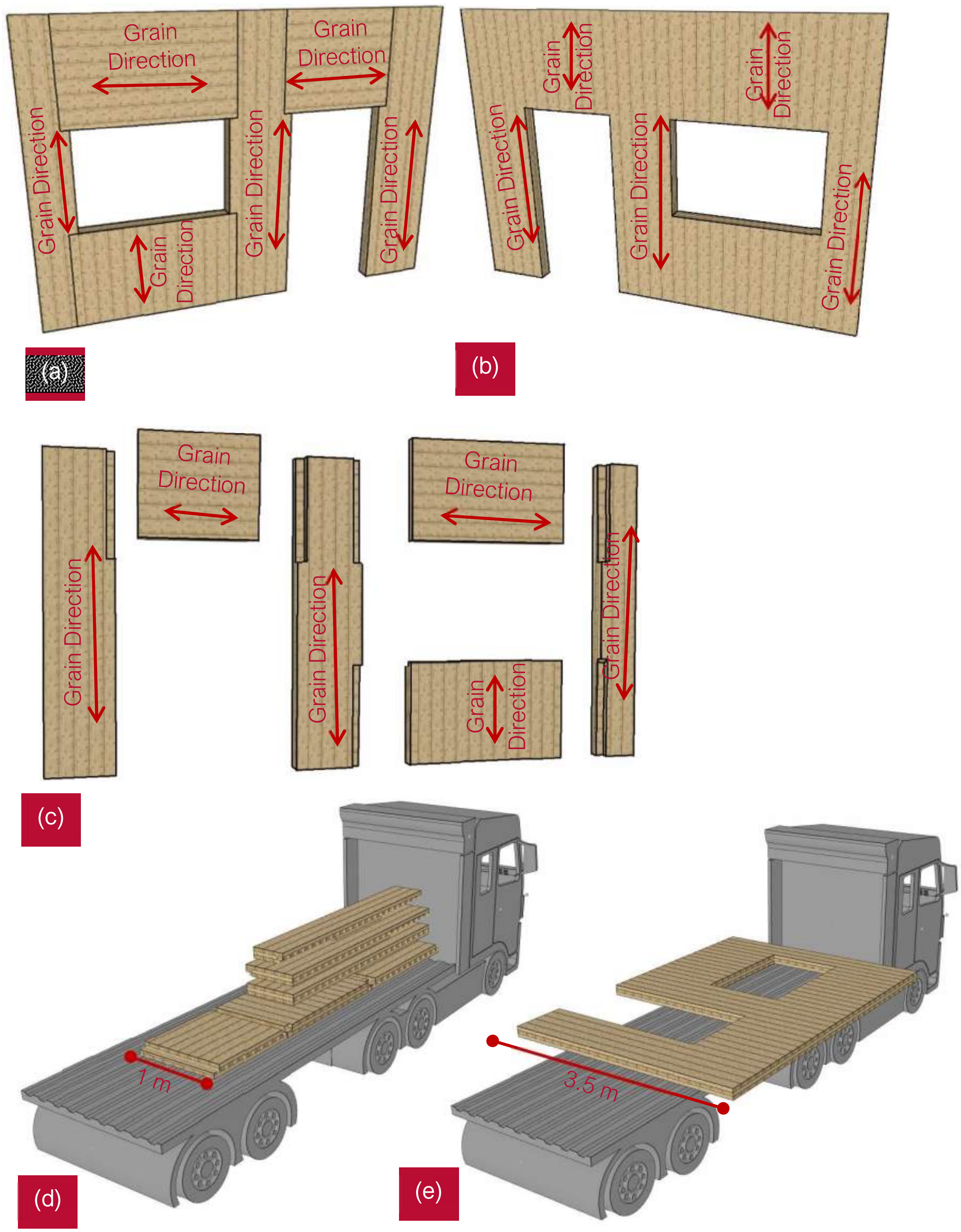


Figure 64: Variation in two methods of constructions for CLT structures; a) Single solid wall including window and door openings; b) Multi piece CLT elements to form CLT wall which is including window and door opening; d) cost efficient transportation which has less than 3 m width; e) costly transportation wider than 3 m which is requiring pilot.

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 65*). 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 18* - *Table 20*. 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 66* and *Figure 67*.

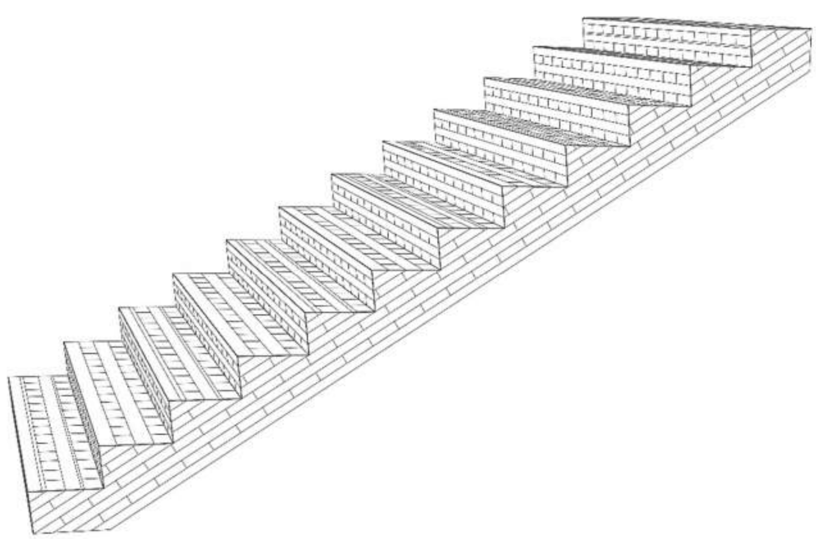


Figure 65: Example of the Red Stag CLT stairs.

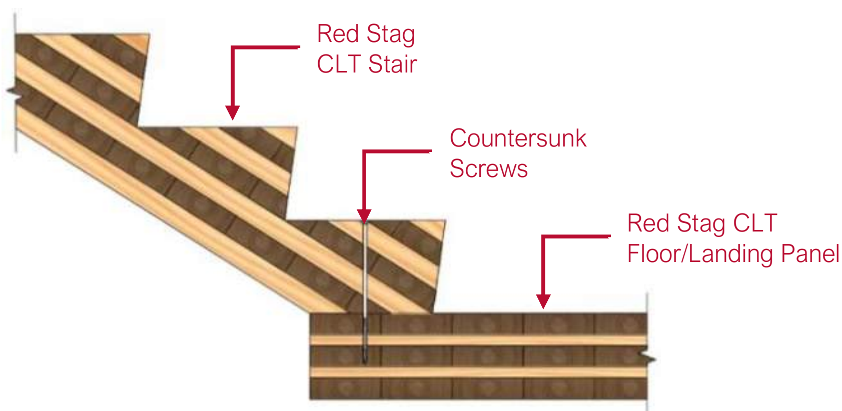


Figure 66: Example of Red Stag CLT stair panel base connection to CLT landing/floor panel.

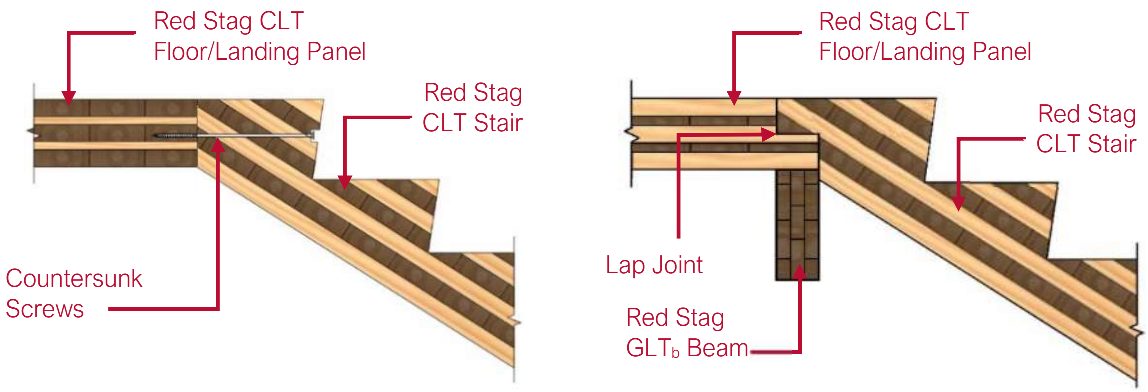


Figure 67: Example of Red Stag CLT stair panel upper connection to CLT landing/floor panel.

Table 18: Red Stag CLT Stair Spans [a, b, c, d, e, f, g]

Panel Title	CLT Panel Stringer	Stringer Thickness	Super Imposed Dead Load 0.25 kPa / Live Load (Imposed Load)			Removed CO_2 from Atmosphere	CLT Stairs CO_2 Benefit Compare to Concrete Stairs
			2 kPa [b]	4 kPa [b]	5 kPa [b]		
CLT7/126/294 [a]	CLT 3/126	126 mm	3.80 m[e]	3.20 m[f]	3.00 m[f]	- 161 kg/m^3	242 kg/m^3
CLT9/210/378[a]	CLT 5/210	210 mm	5.40 m[e]	4.80 m[f]	4.60 m[f]	- 224 kg/m^3	338 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, 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 controlled by vibration (exclude frequency limit).
f) Span limited by serviceability limit state deflection.
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 68*. All other tread/riser combinations reduce the dead loads incorporated in *Figure 68*.
h) Refer to *Section 10* for Red Stag CLT Stair design example.

Table 19 : Red Stag CLT Stair Spans [a, b, c, d, e, f, g]							
Panel Title	CLT Panel Stringer	Stringer Thickness	Super Imposed Dead Load 0.5 kPa Live Load (Imposed Load)			Removed CO_2 from Atmosphere	CLT Stairs CO_2 Benefit Compare to Concrete Stairs
			2 kPa [b]	4 kPa [b]	5 kPa [b]		
CLT7/126/294 [a]	CLT 3/126	126 mm	3.70 m [f]	3.10 m [f]	2.90 m [f]	-161 kg/m³	242 kg/m³
CLT9/210/378 [a]	CLT 5/210	210 mm	5.40 m [e]	4.70 m [f]	4.50 m [f]	- 224 kg/m³	338 kg/m³

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, 4 kPa and 5 kPa Live Load (Imposed Load).
c) Red Stag CLT Stairs are designed based on 500 kg/m³ for the CLT (CLT stringer & CLT Tread & Riser).
d) Red Stag CLT Stairs are designed for vibration based on the FPInnovation method.
e) Span controlled by vibration (exclude frequency limit).
f) Span limited by serviceability limit state deflection.
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 68*. All other tread/riser combinations reduce the dead loads incorporated in *Figure 68*.
h) Refer to *Section 10* for Red Stag CLT Stair design example.

Table 20: Red Stag CLT Stair Spans [a, b, c, d, e, f, g]							
Panel Title	CLT Panel Stringer	Stringer Thickness	Super Imposed Dead Load 1.0 kPa Live Load (Imposed Load)			Removed CO_2 from Atmosphere	CLT Stairs CO_2 Benefit Compare to Concrete Stairs
			2 kPa [b]	4 kPa [b]	5 kPa [b]		
CLT7/126/294 [a]	CLT 3/126	126 mm	3.40 m [f]	2.90 m [f]	2.80 m [f]	-161 kg/m³	242 kg/m³
CLT9/210/378 [a]	CLT 5/210	210 mm	5.10 m [f]	4.50 m [f]	4.30 m [f]	- 224 kg/m³	339 kg/m³

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, 4 kPa and 5 kPa Live Load (Imposed Load).
c) Red Stag CLT Stairs are designed based on 500 kg/m³ for the CLT (CLT stringer & CLT Tread & Riser).
d) Red Stag CLT Stairs are designed for vibration based on the FPInnovation method.
e) Span controlled by vibration (exclude frequency limit).
f) Span limited by serviceability limit state deflection.
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 68*. All other tread/riser combinations reduce the dead loads incorporated in *Figure 68*.
h) Refer to *Section 10* for Red Stag CLT Stair design example.

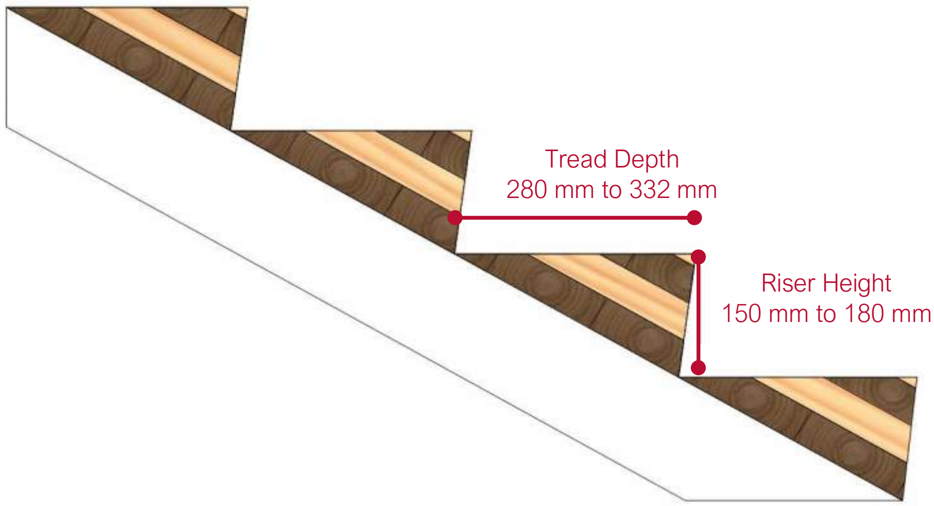


Figure 68: Pitch line, tread, and riser dimensions for common and main private stair ways.

Various examples of Red Stag CLT stairs and landings are presented in *Figure 69*. The examples are for client's guidance only and an accurate architectural and structural design are required for each project. Examples of potential stair to landing connections are presented in *Figure 66* and *Figure 67*.

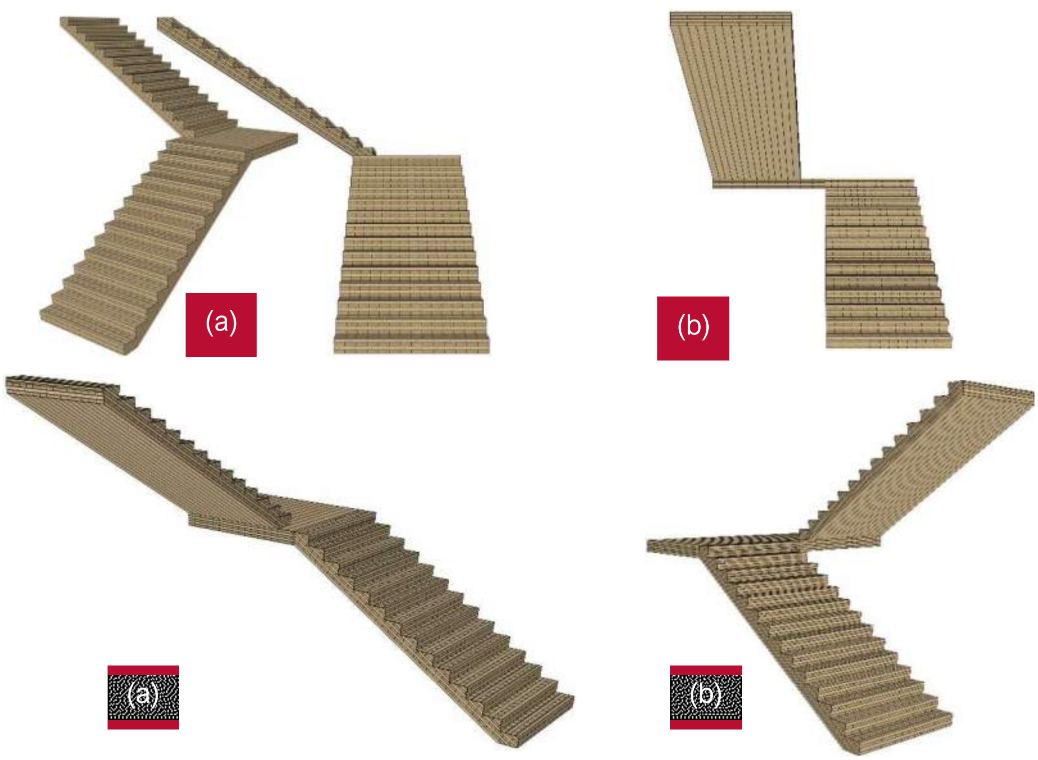


Figure 69: Examples of Red Stag CLT stair and landing designs; (a) L-shaped Red Stag CLT stairs; (b) U-shaped Red Stag CLT stairs.

Red Stag CLT stairs can be installed with the balance of the CLT to remove the need for temporary staircase, providing immediate, safe access to the next floor in multi storey buildings (refer to *Figure 70*). This can save time, eliminates the need for temporary scaffolding and ladders and improves site construction safety. Red Stag CLT stairs can be designed by the structural engineer to safely accommodate heavy loads during construction.

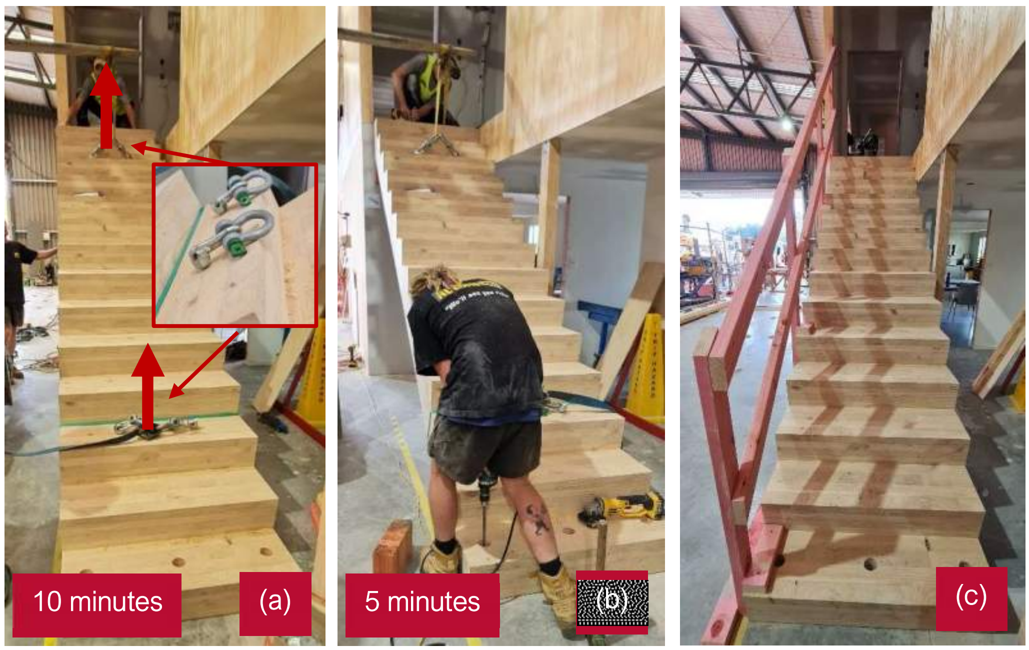
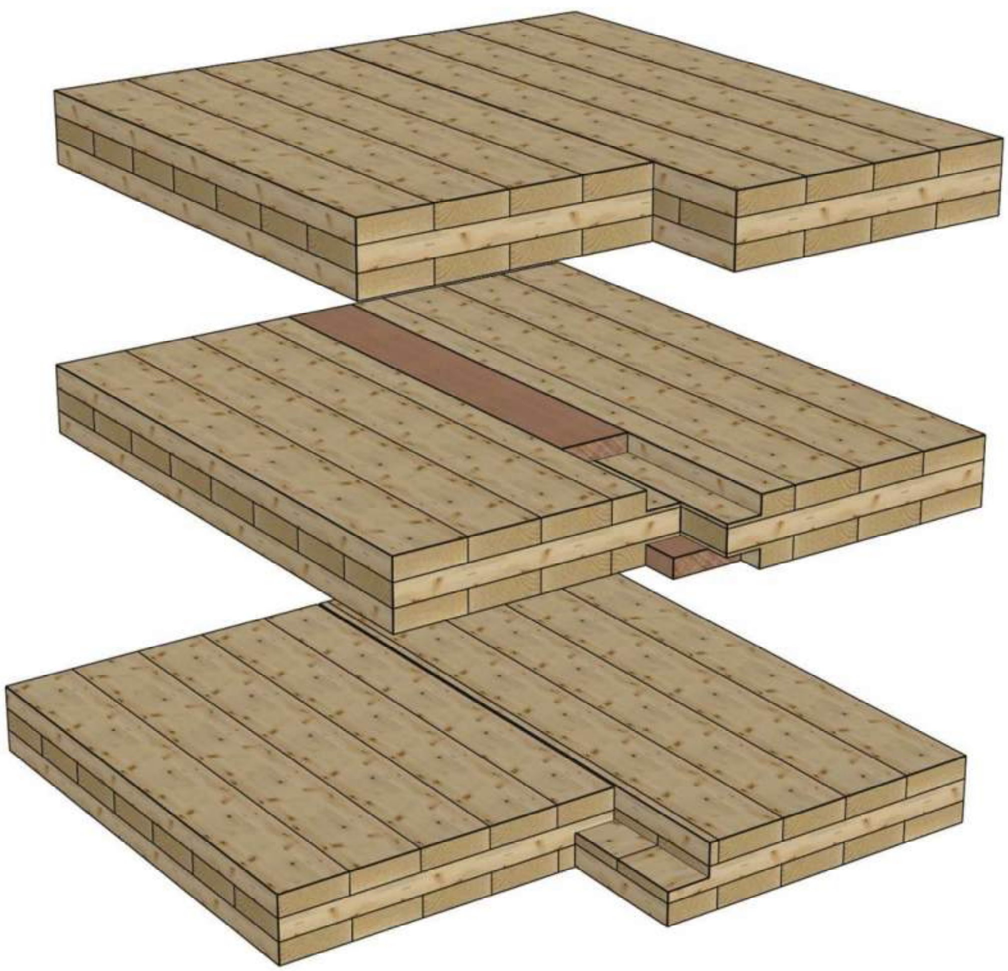


Figure 70: Red Stag CLT stairs being installed quickly on site; a) Lift and position; b) Fix to foundation and landing; c) Add temporary balustrade.

Section 3

Cross Laminated Timber Connections



RED STAG®

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 Red Stag (Red Stag has one of the most cost effective and largest stock holding of fixings and installation aids in Oceania) from fixing providers (refer to *Figure 71*). 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 72 and Figure 73*). There are other types of traditional and innovative fasteners and fastening systems that can also be used in CLT assemblies.

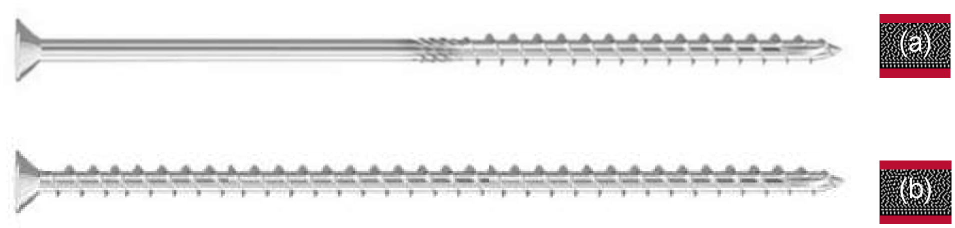


Figure 71: A partially threaded screw versus a fully threaded screw;
a) Partially threaded screw, b) Fully threaded screw.

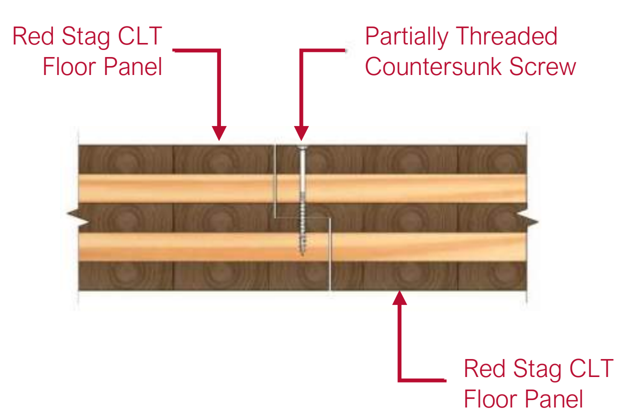


Figure 72: Red Stag CLT floor panel to Red Stag CLT floor panel connection.

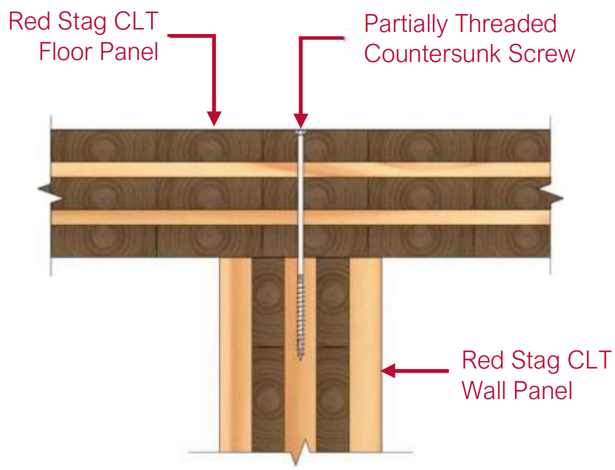


Figure 73: Red Stag CLT floor panel to Red Stag CLT wall panel connection.

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. Butt joints are typically connected via angled self-tapping screws, installed at controlled angles. The screws typically penetrate the shear plane at half of the panel thickness, typically at a 45° angle. Intersecting the joint at half the panel thickness, the screws are loaded perpendicular to their longitudinal axis (Refer to *Figure 74 - Figure 75*).

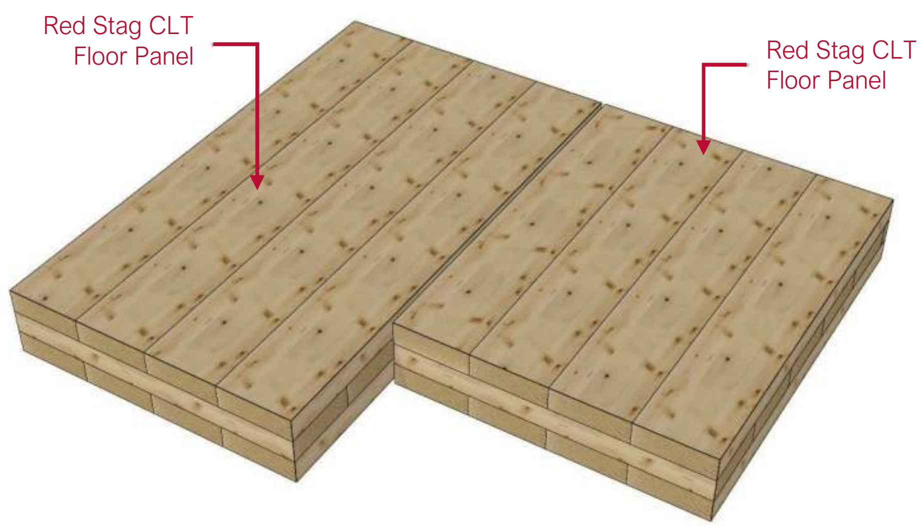


Figure 74: 3D view of butt joint connection.

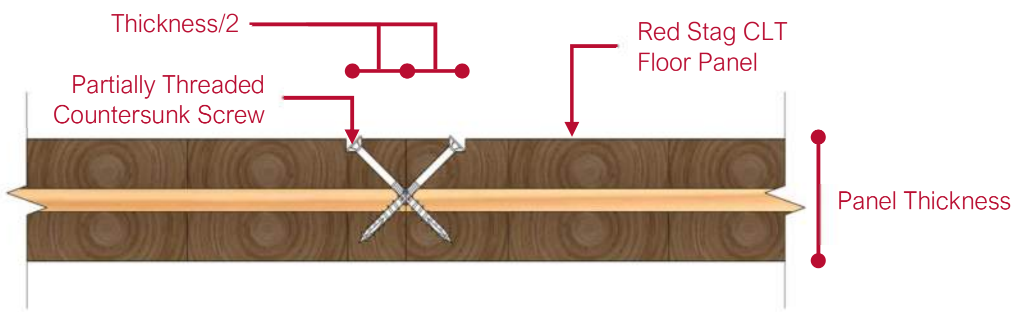


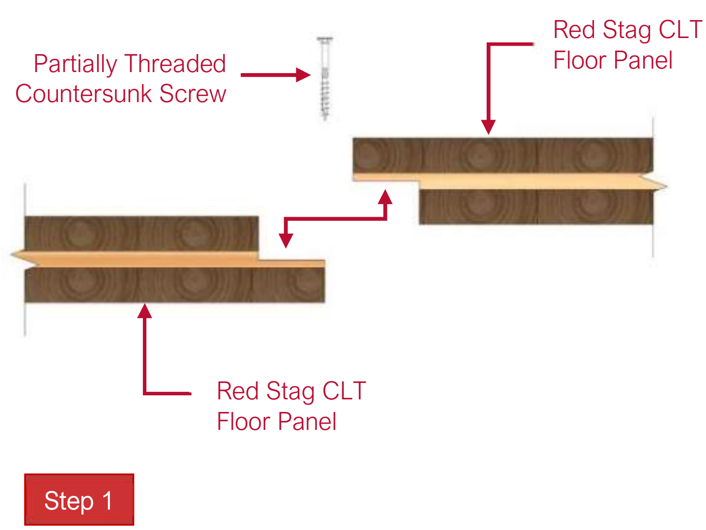
Figure 75: Cross-section detail of butt joint connection.

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 to the surface, and act in pure shear at half the panel thickness. Assembly details of the half-lap joint are presented in *Figure 76*. Half-lap joints offer the balance between connection performance and ease of assembly. 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 77*).

While the half-lap joint is a 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 in higher load conditions, reinforcing screws should be considered (refer to *Figure 78*). 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 79*).



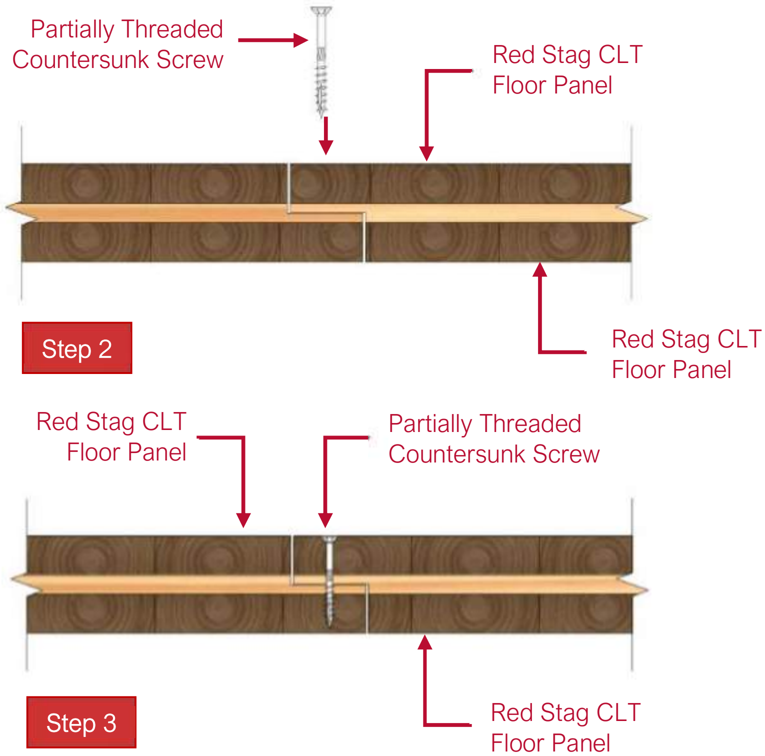


Figure 76: Assembly details of the half-lap joint.

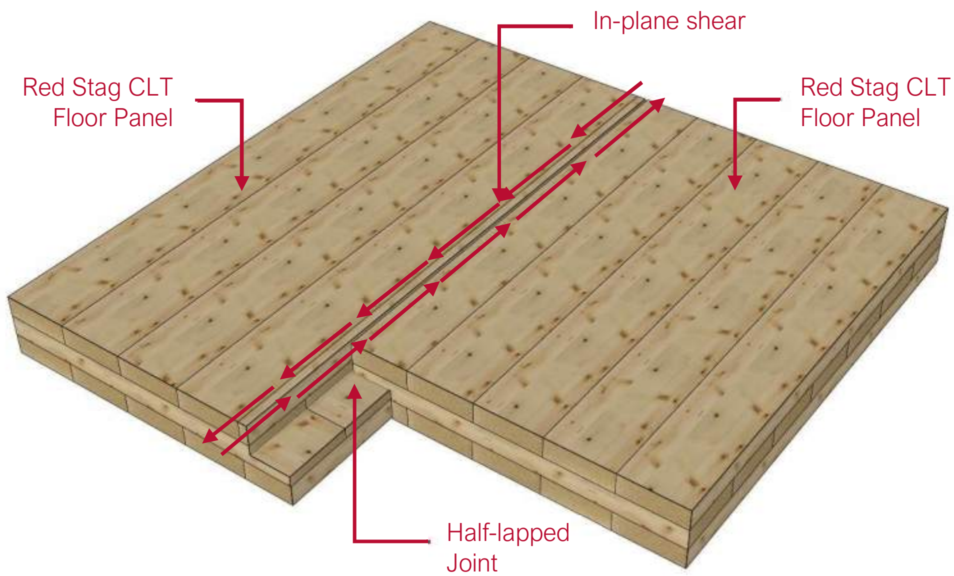


Figure 77: In-plane shear along the half-lap joint between two Red Stag CLT panels.

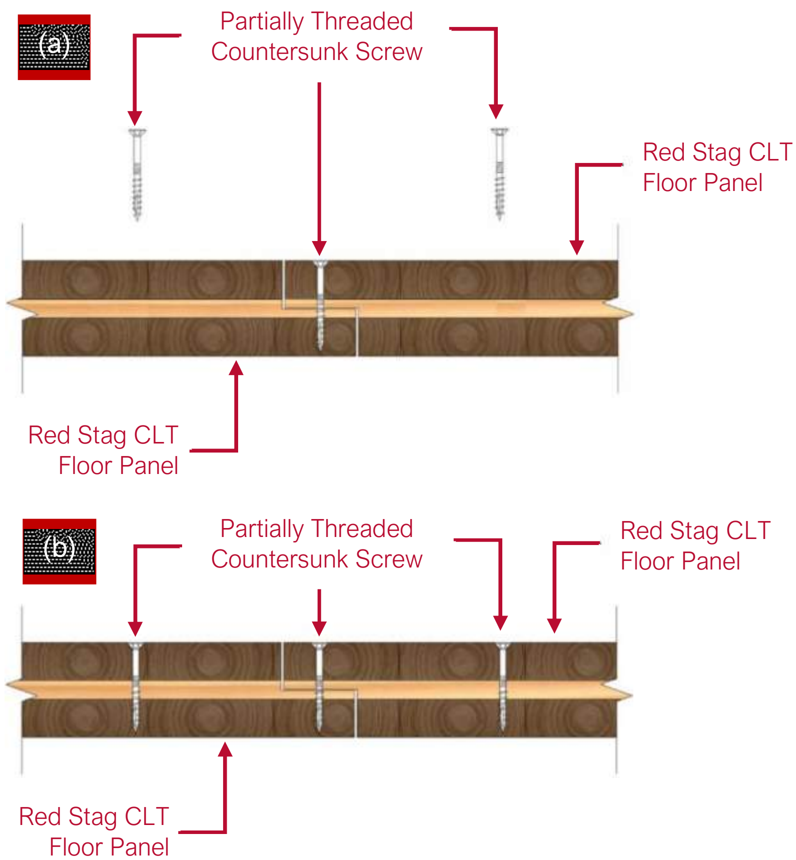


Figure 78: Reinforcing screws to reduce the risk of splitting.

a) Before Reinforcement; b) After Reinforcement.

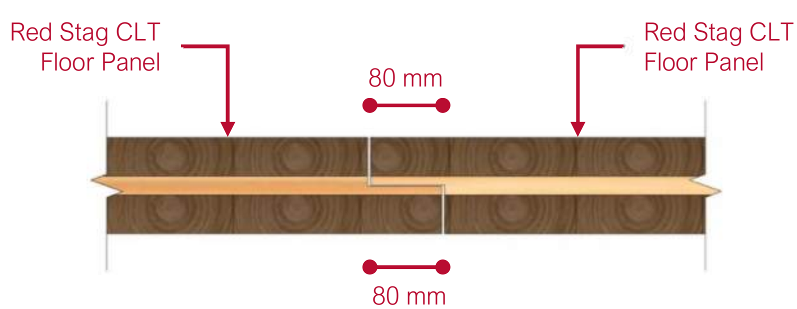


Figure 79: Optimum size half-lap joint (80 mm).

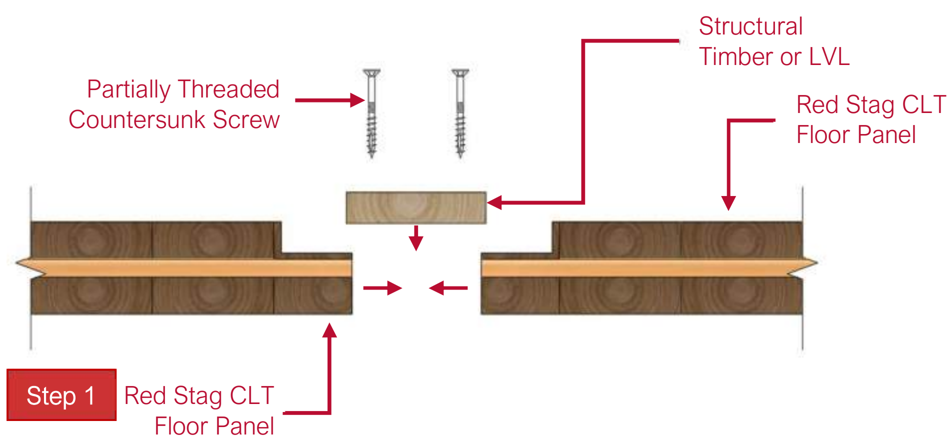
15. Spline Joint Connections

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 on each side of the spline, creating a pure shear connection. Assembly details of a single spline joint is presented in *Figure 80*.

If the longitudinal shear along the connection line is very high, a double spline joint connection (a spline on the bottom and top faces of the panel) is recommended to increase the strength and stiffness of the connection (Refer to *Figure 81*). The four rows of fasteners support in doubling the shear plane resistance (refer to *Figure 82 and Figure 83*). It is recommended to position screw lines on the diagonal so that underside screw lines are in between the screws for the upper spline (refer to *Figure 83*).

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 84*.

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 complex machining and a labour-intensive connection detail.



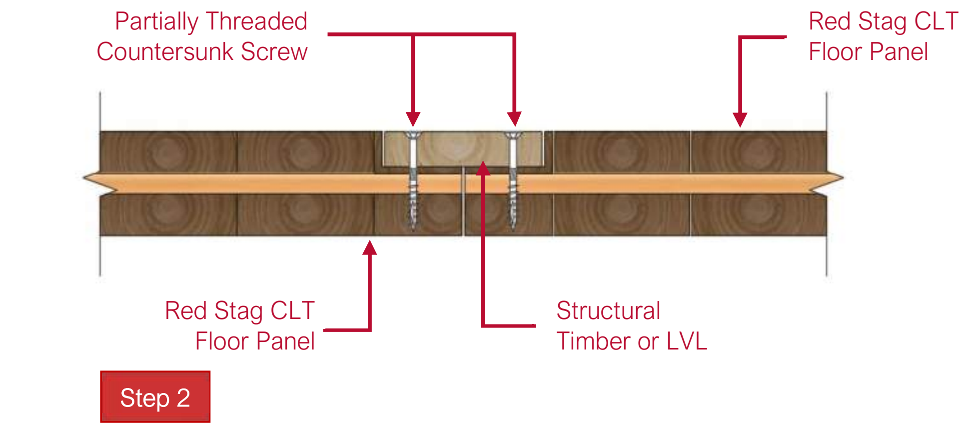


Figure 80: Assembly details of the single surface spline joint.

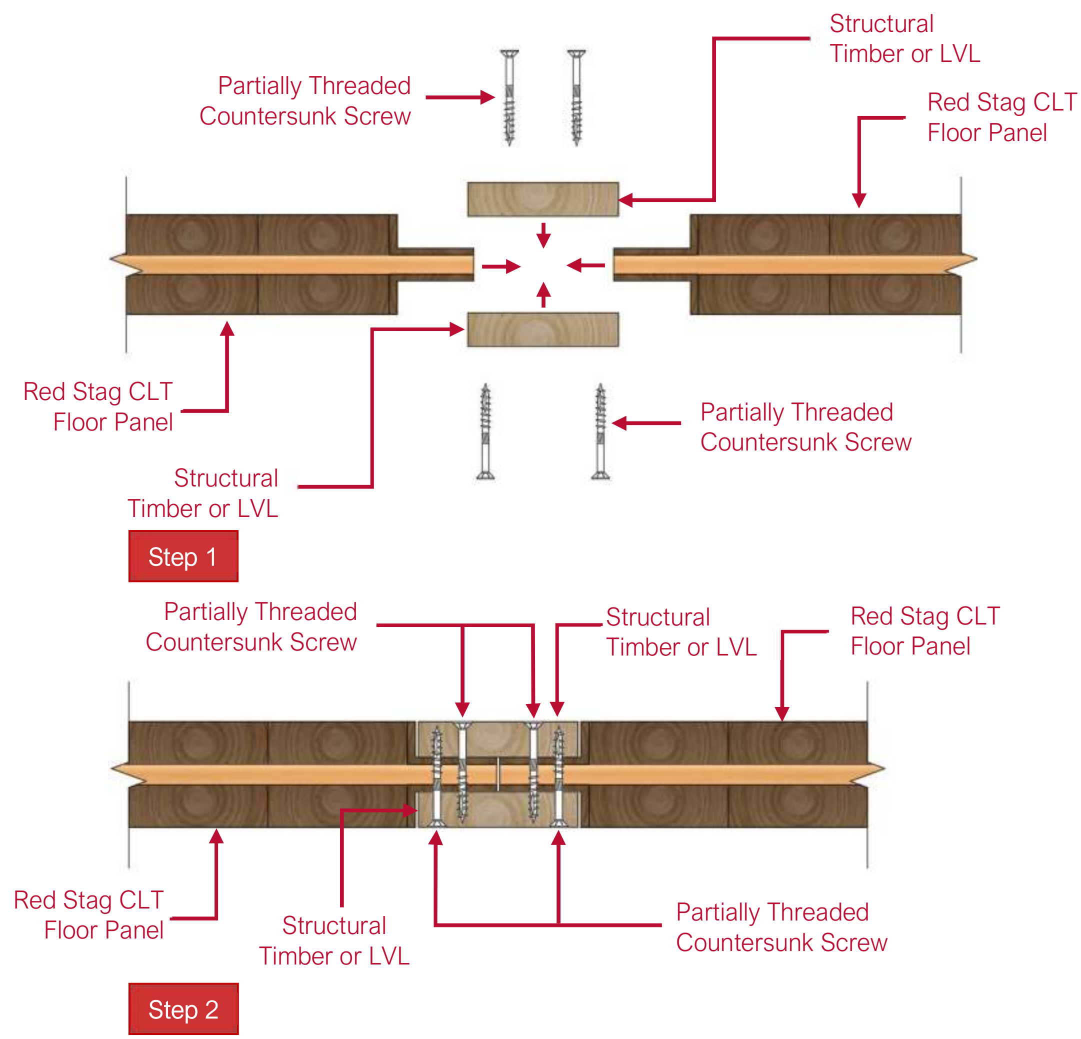


Figure 81: Assembly details of the double surface spline joint.

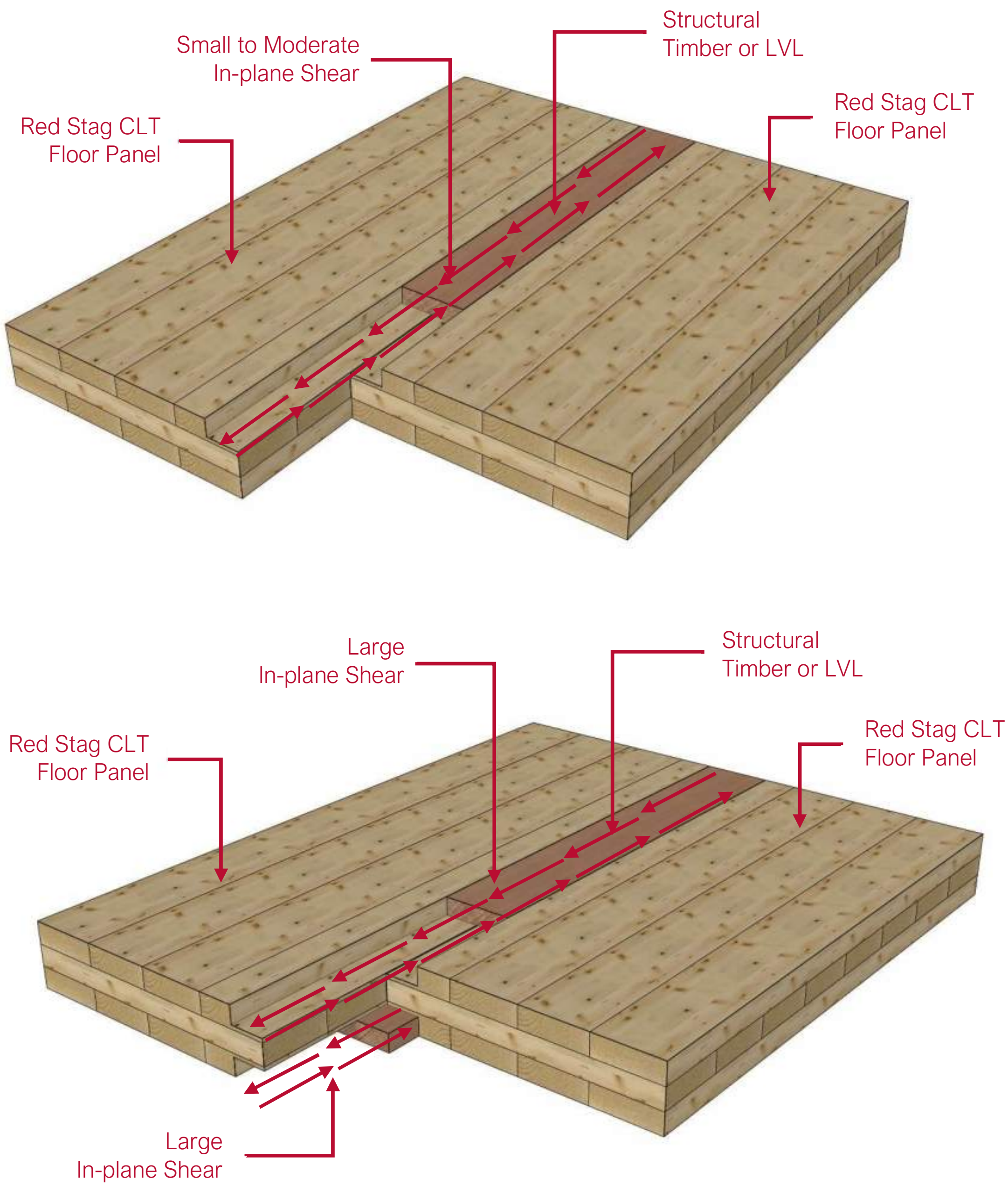


Figure 82: Longitudinal shear along the connection line in single and double surface spline joints.

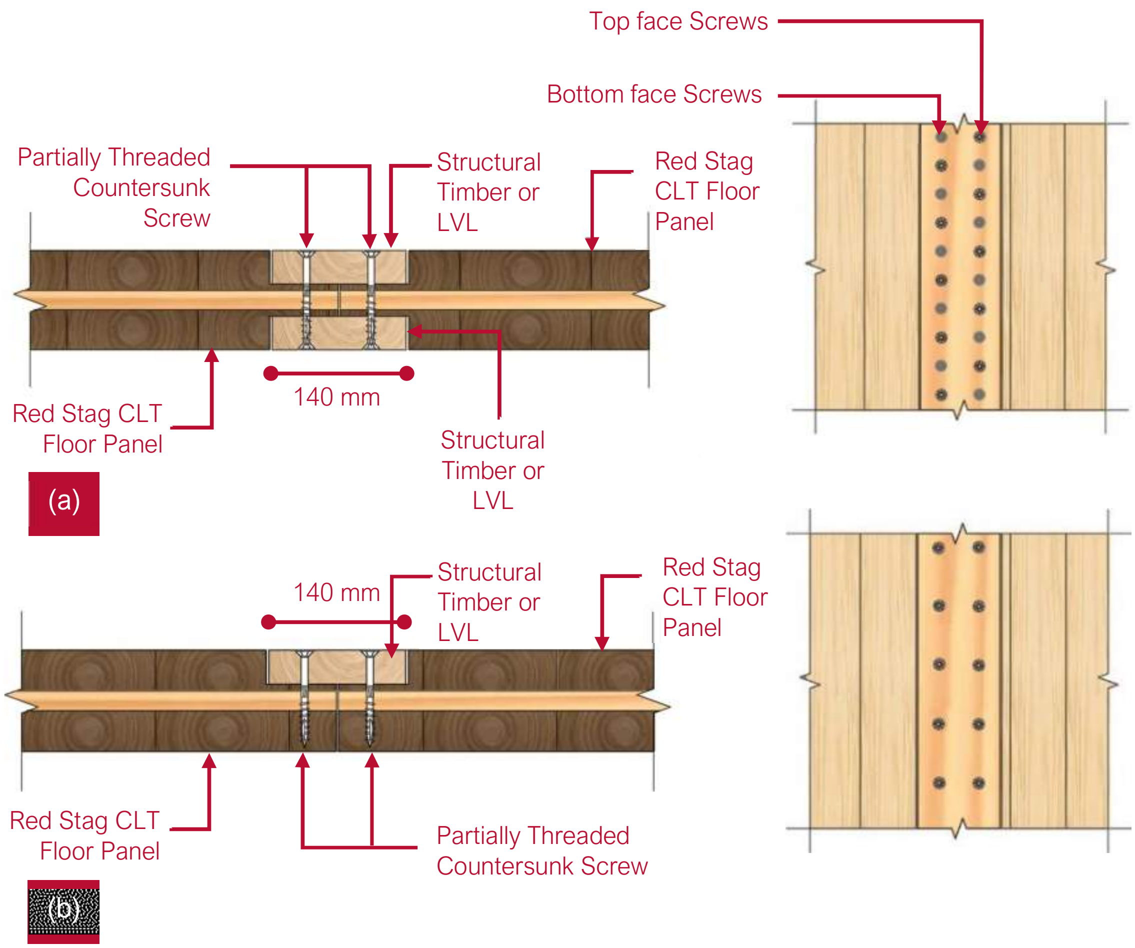


Figure 83: Screw spacing in a single surface spline joint versus a double surface spline joint. Double surface spline joints require sufficient space for double the number of fasteners. a) Double surface spline joint; b) Single surface spline joint.

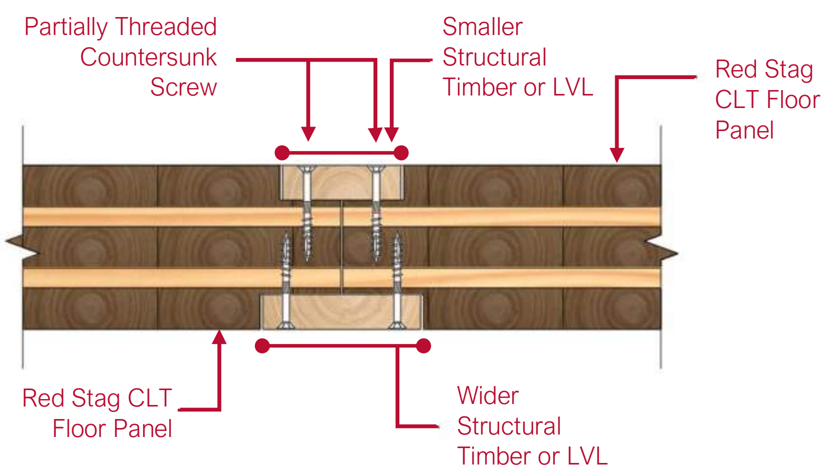


Figure 84: Screw layout for a double surface spline joint with an asymmetric timber spline plate.

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 85* to *Figure 97*.

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

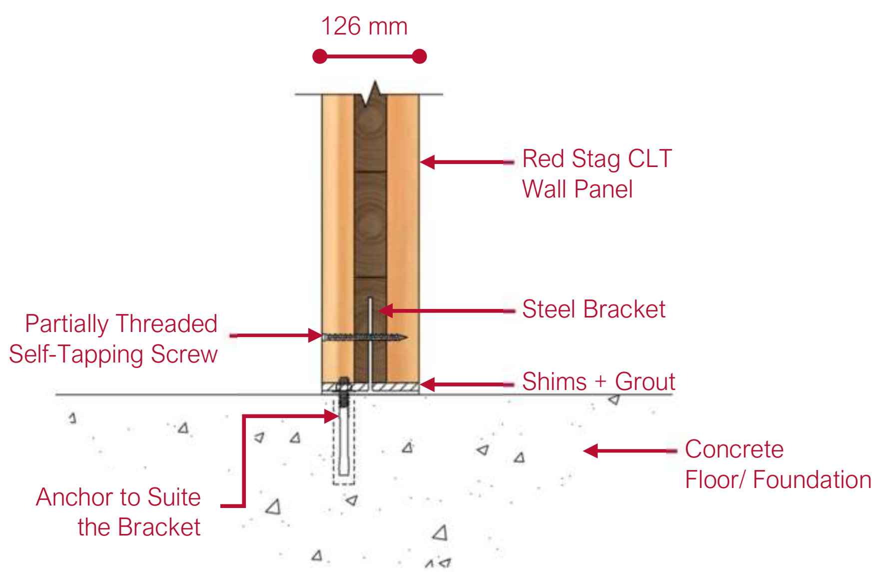


Figure 85: Internal Red Stag CLT wall to the concrete foundation/floor connection.

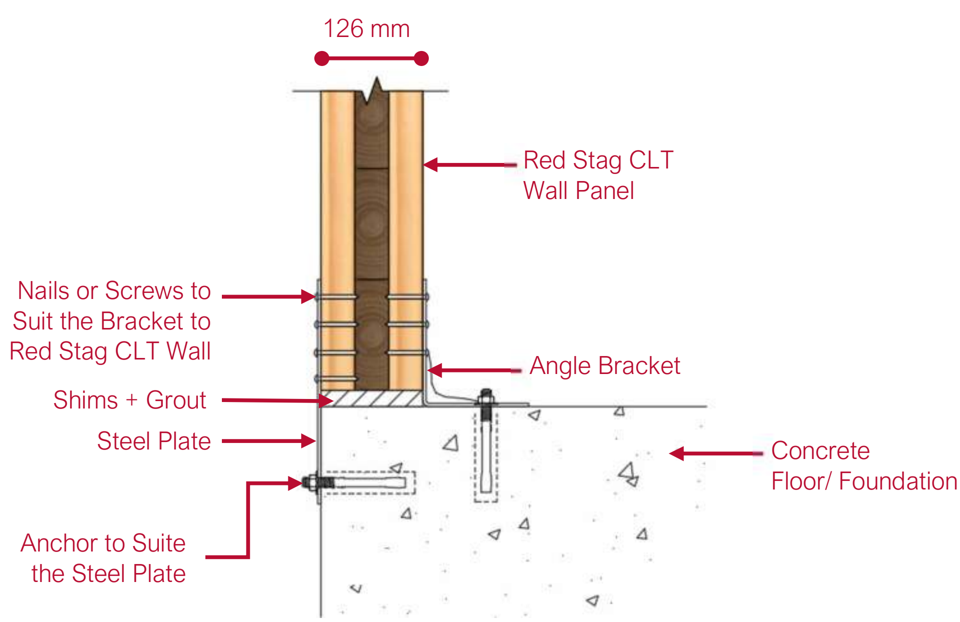


Figure 86: Red Stag CLT wall panel to the concrete foundation/floor (On edge of external walls of the building).

16.2 Red Stag CLT Wall Panel Connection

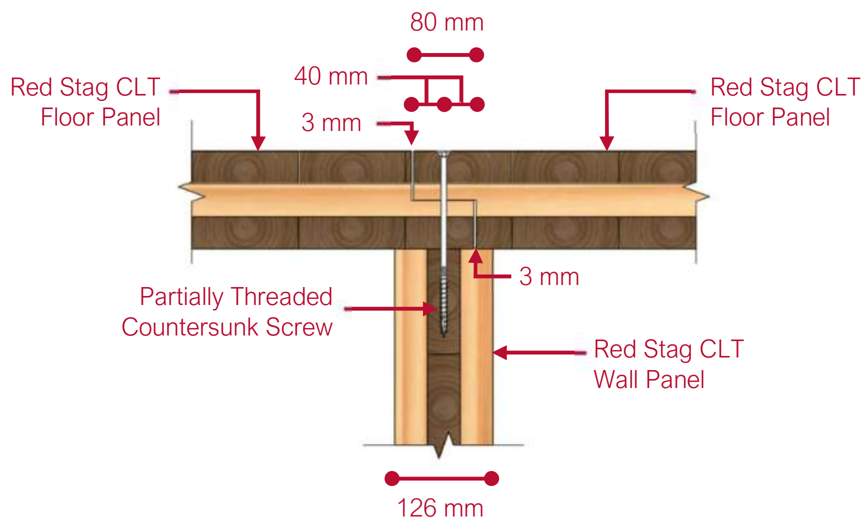


Figure 87: Red Stag three (3) Layer CLT wall panel to CLT floor panel half joint connection.

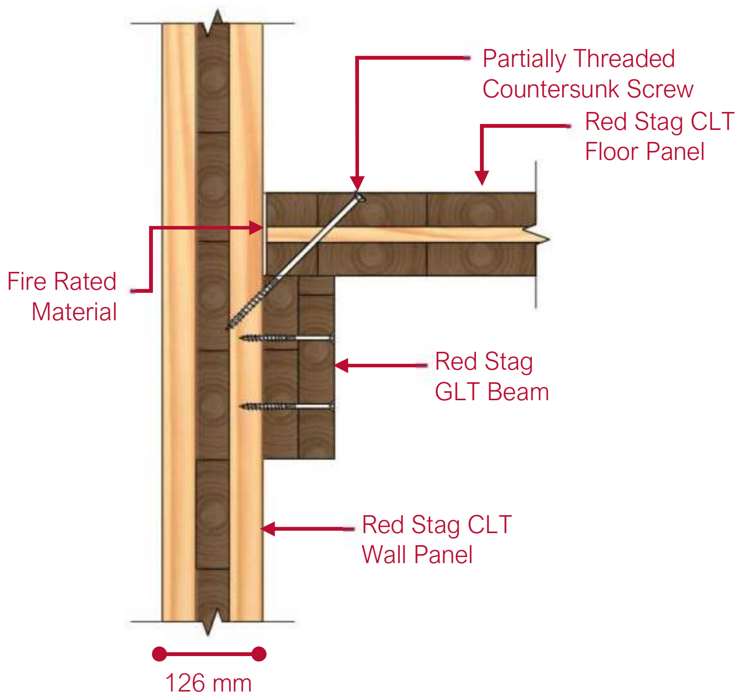


Figure 88: Red Stag CLT wall panel to CLT floor panel (On edge of external walls of building).

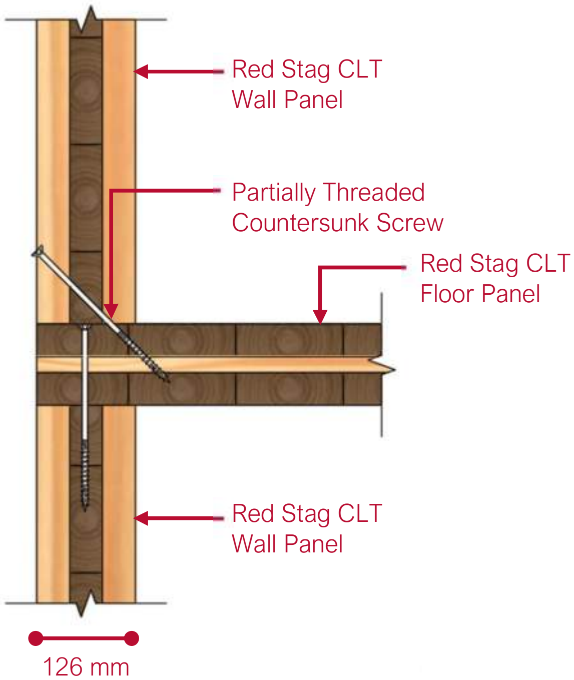


Figure 89: Red Stag CLT wall panel to CLT floor panel.

16.3 Red Stag CLT Roof Panel Connection

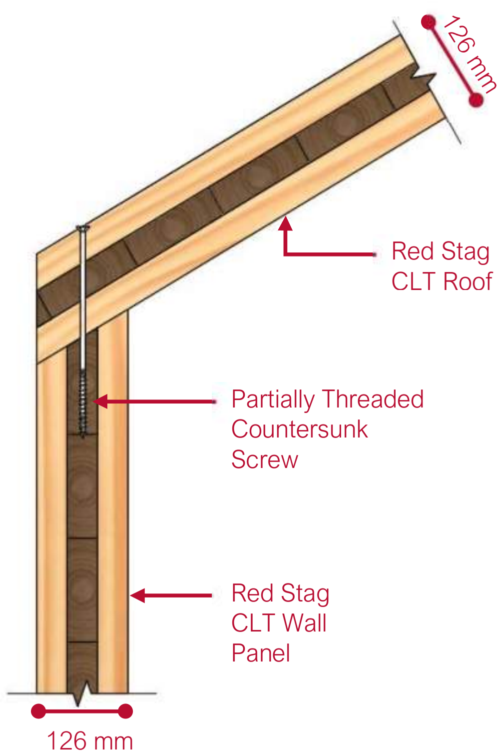


Figure 90: Red Stag three (3) layer CLT roof panel to CLT wall panel connection.

16.4 Mixed Timber Connection to Red Stag CLT Connections

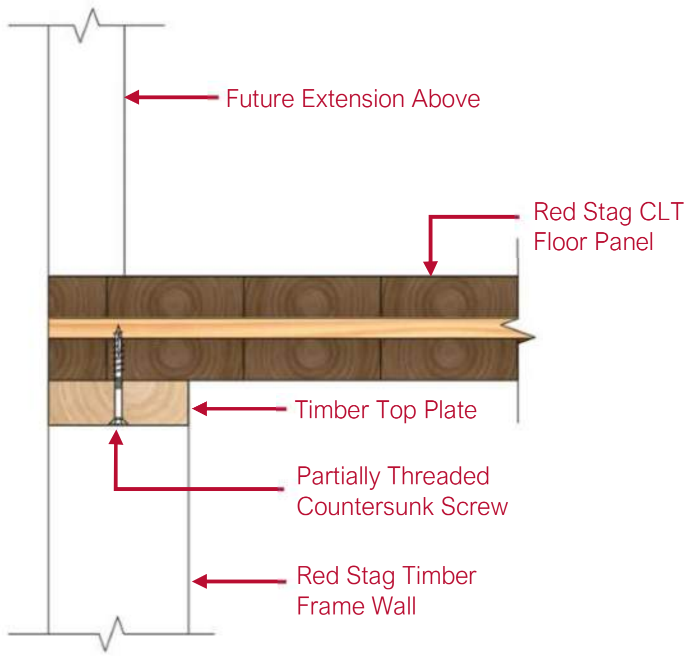


Figure 91: Timber frame wall to Red Stag CLT floor panel connection.

16.5 Red Stag CLT Floor Connection

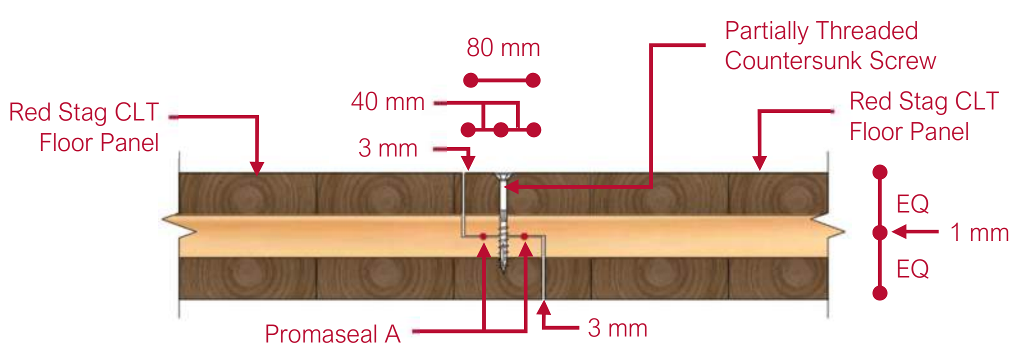


Figure 92: Red Stag three (3) layer CLT floor to floor half-lap joint connection.

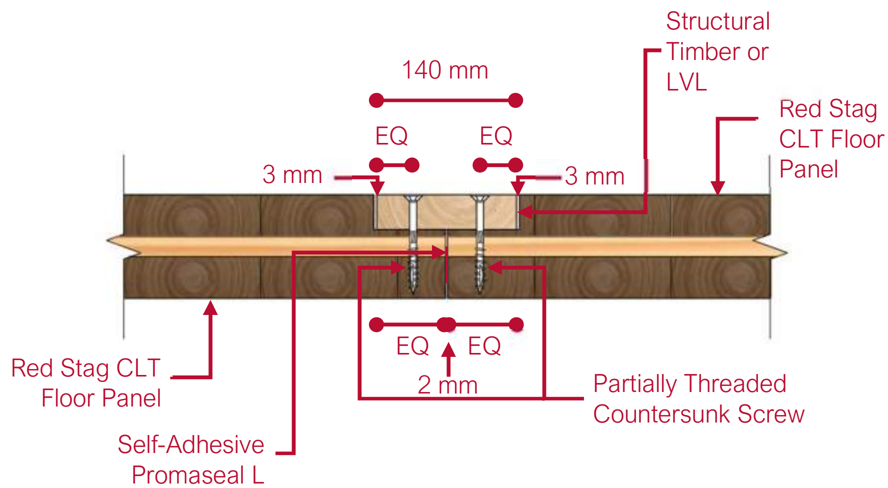


Figure 93: Red Stag three (3) layer CLT floor to floor with spline plate connection.

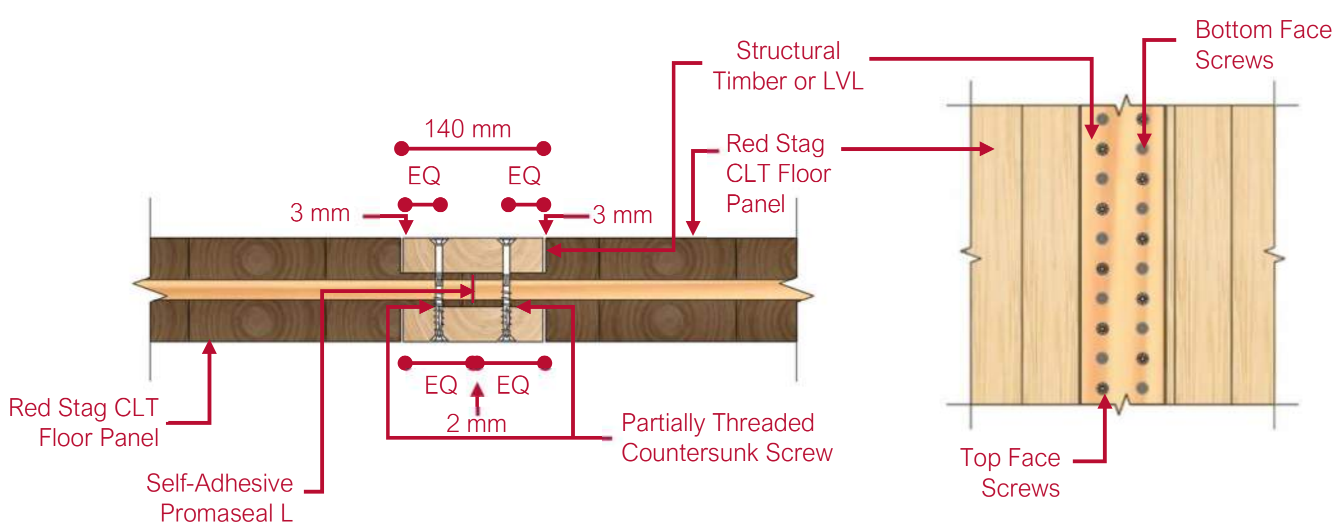


Figure 94: Red Stag three (3) layer CLT floor panel to floor panel with double spline plate connection.

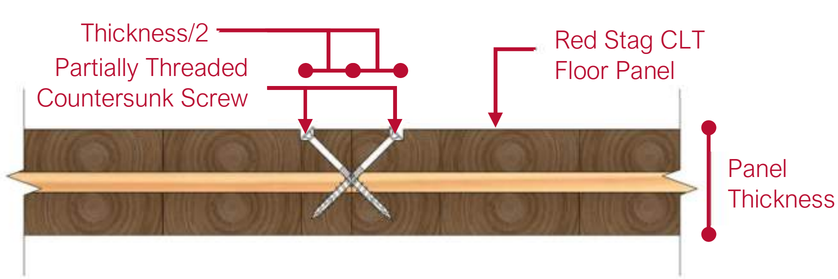


Figure 95: Red Stag three (3) layer CLT floor to floor butt joint connection.

16.6 Red Stag CLT Stair Connection Details

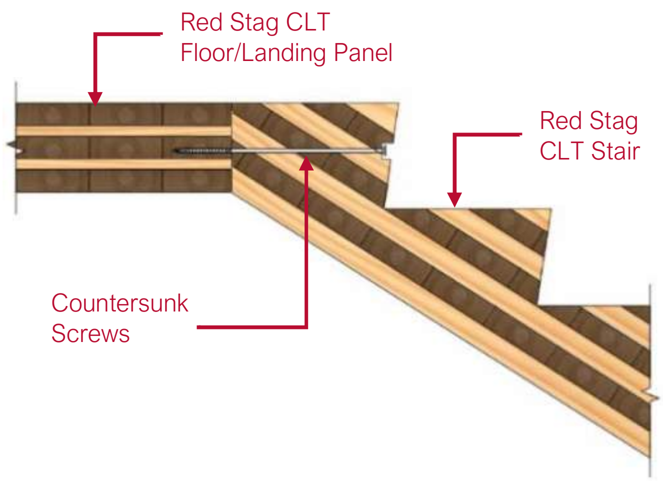


Figure 96: Red Stag CLT stair panel to CLT landing/floor panel connection.

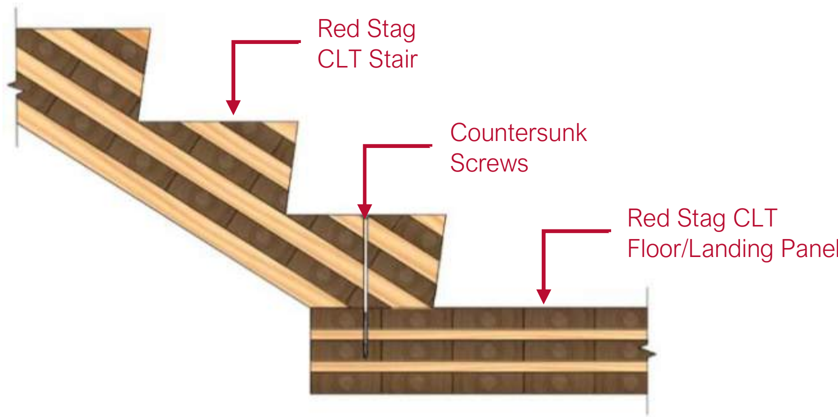


Figure 97: Red Stag CLT stair panel to CLT landing/floor panel connection.

16.7 Red Stag CLT Connection Details for Timber Hybrid Systems

Mixing Red Stag CLT with other types of timber systems such as trusses and Light Timber Framing (LTF) allow for designs to optimise and capitalise on the attributes of the various solutions.

Balloon construction system presented in *Figure 98 and Figure 99* illustrate some common methods for connecting timber floor trusses or solid timber joists to Red Stag CLT walls.

In balloon-type construction, Red Stag CLT wall panels are continuous, and the other floor systems attach to the side of the wall. The solid timber joist or timber floor truss systems can be attached to the CLT walls using traditional metal hangers commonly used in light frame and heavy post-and-beam timber construction. Alternatively, EWP ledgers, girders, beams, or metal brackets supporting the joists could be attached to the CLT walls. Self-tapping screws and traditional fasteners are used to attach the hardware to the wall.

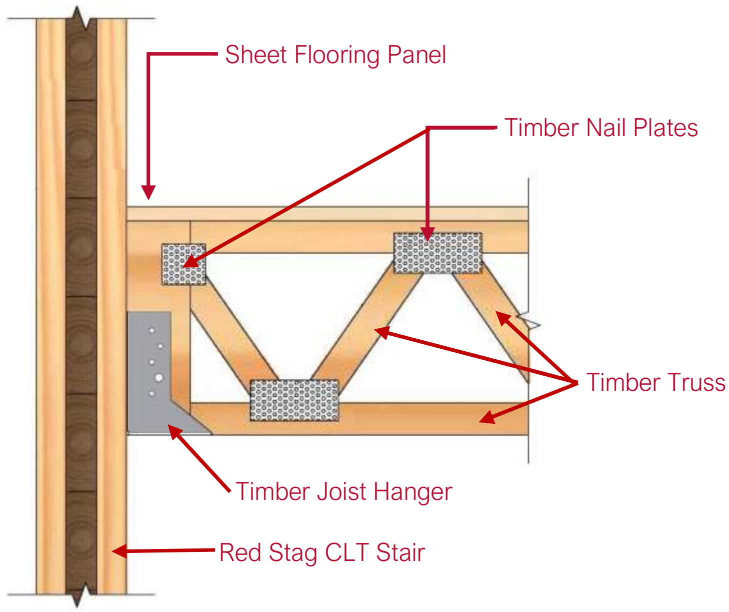


Figure 98: Timber floor truss to Red Stag CLT wall panel connection detail.

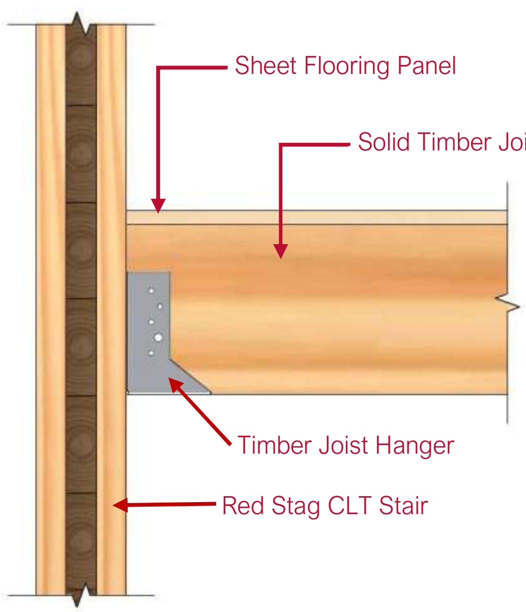


Figure 99: Solid timber joist to Red Stag CLT wall panel connection detail.

17. Fastener Placement in CLT Panels

New recommendations have been introduced into the Canadian CLT standard to specify the minimum spacing of fasteners installed into panel edges 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 21*and *Figure 100* for three layer panels and *Table 22*, *Table 23* and *Figure 101* for five layer panels.

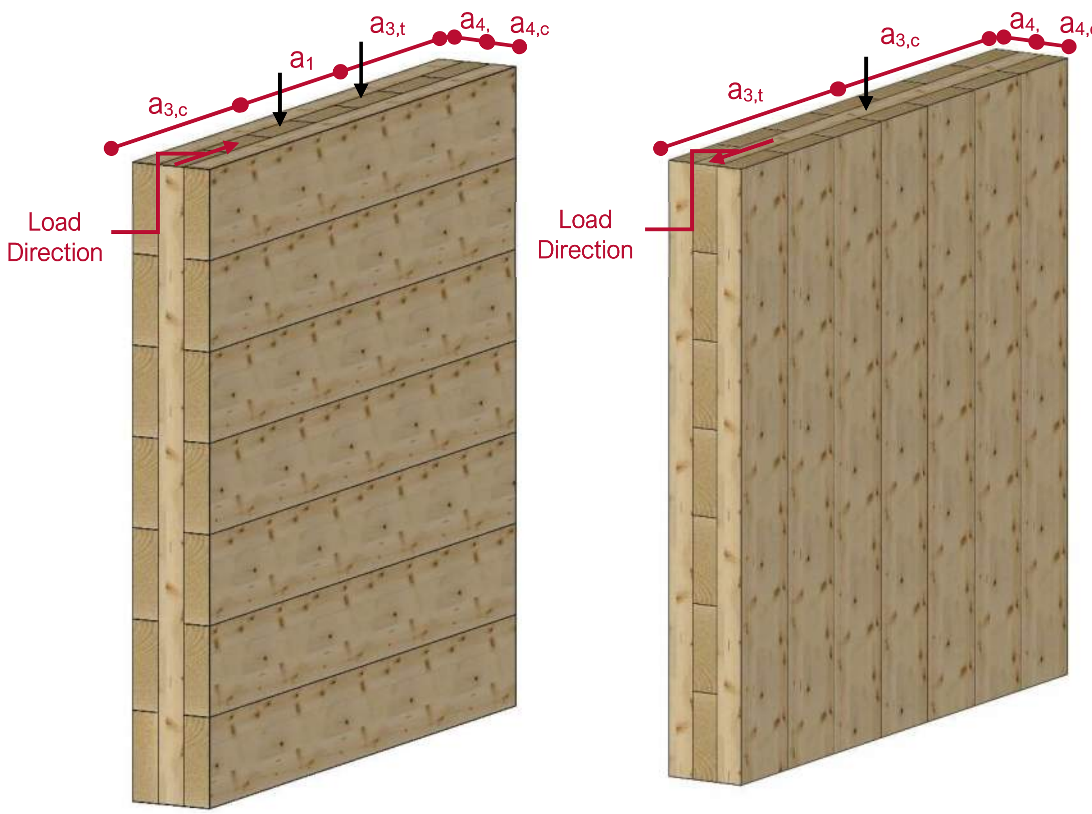


Figure 100: Spacing placement of fasteners on the edge of CLT panels.

Table 21: 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

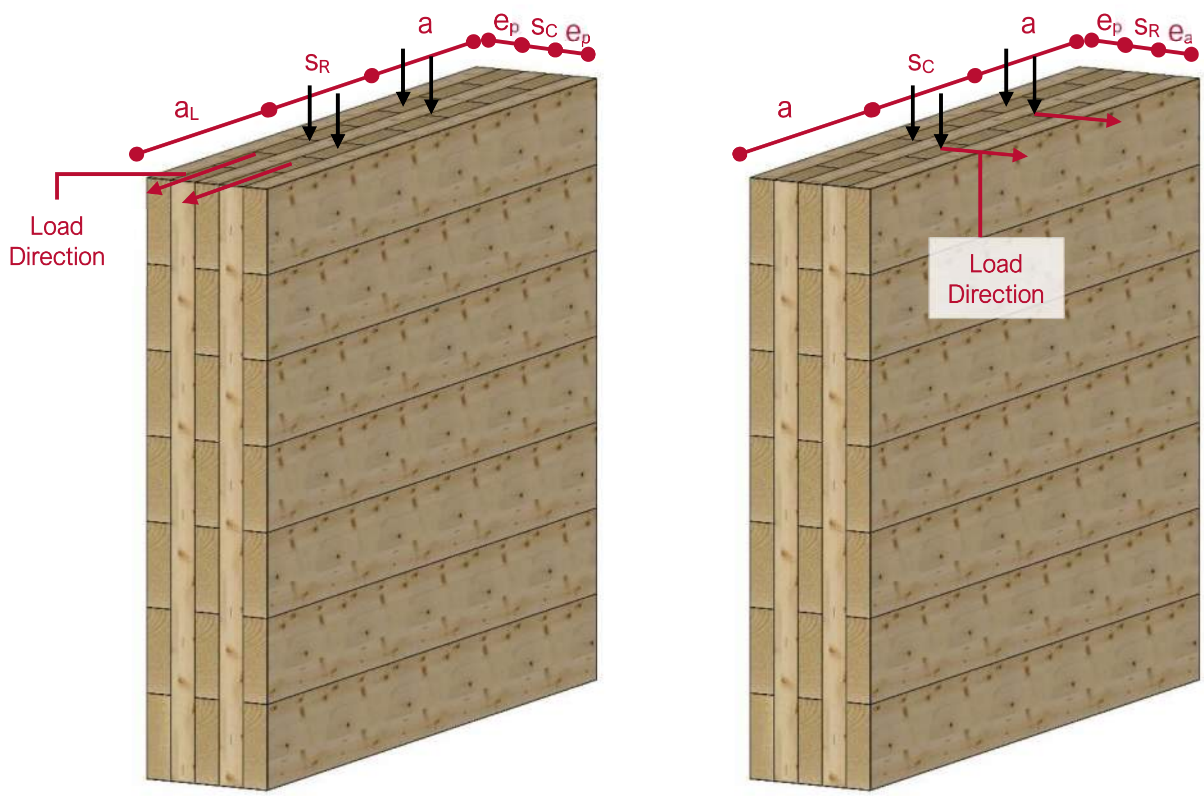


Figure 101: Spacing placement of the fasteners on the edge of CLT panels.

Table 22: 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 23: 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

It is generally recommended to use a monolithic substrate or underlay between CLT and flooring to mitigate the risk of the CLT panel configurations adversely impacting floor coverings. Moisture management is critical in CLT construction, as excessive moisture can lead to dimensional changes, and connectors performance varying.

A suitable floor covering underlay can act as a barrier against moisture ingress, but its primary function is to create a monolithic substrate to reduce the influence of CLT or structural joints (including control joints) on the floor coverings. It is essential to select an underlay that is compatible with the specific requirements of the flooring system and the expected environmental conditions. The underlay should provide adequate protection from potential moisture sources and manage any joint movement with the CLT joints. Proper installation and sealing of the underlay are crucial to reduce any movement and moisture-related problems created during the construction phase and exposure of the CLT to the environment (this includes the difference in relative humidity of the building materials prior to and post HVAC system activation) and to ensure the longevity and performance of the CLT structure. Typically, underlay jointing should not align with joints in the CLT. Prior to installing any underlay or floor covering, it is recommended to confirm the moisture content of the CLT (moisture levels can lift reasonably due to exposure to the elements during the construction phase) and ensure that all CLT elements are equalised and stable at the relative humidity and temperature intended for the standard operation of the building before installing (HVAC set point stabilisation).

It is recommended that all specifiers and installers confirm the appropriate underlay and installation process on CLT with the floor covering manufacturer, distributor/agent and the applicable floor covering association (e.g. floornz.org.nz) prior to specifying and installing.

A CLT floor build-up, particularly with Red Stag CLT panels, offers a visually striking and structurally sound option for interior design. The exposed underside of these panels can contribute to a warm and inviting aesthetic while maintaining an open and spacious feel without secondary linings or a traditional ceiling.

Below are examples of lining build-ups on top of Red Stag CLT panels (Refer to *Figure 102* and *Figure 103*).

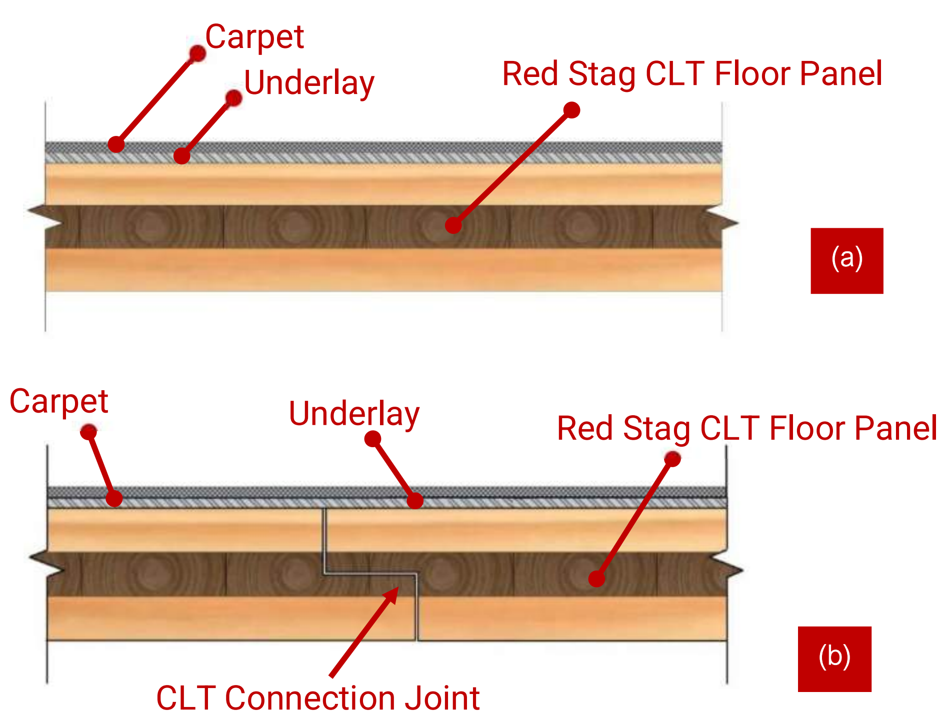


Figure 102: Red Stag CLT with carpet overlay; (a) single solid CLT floor panel; (b) Two CLT panel connect at by lap joint. Note that the underlay joints should be sufficiently far away from the CLT connection joints to ensure a monolithic substrate (refer to flooring providers specifications).

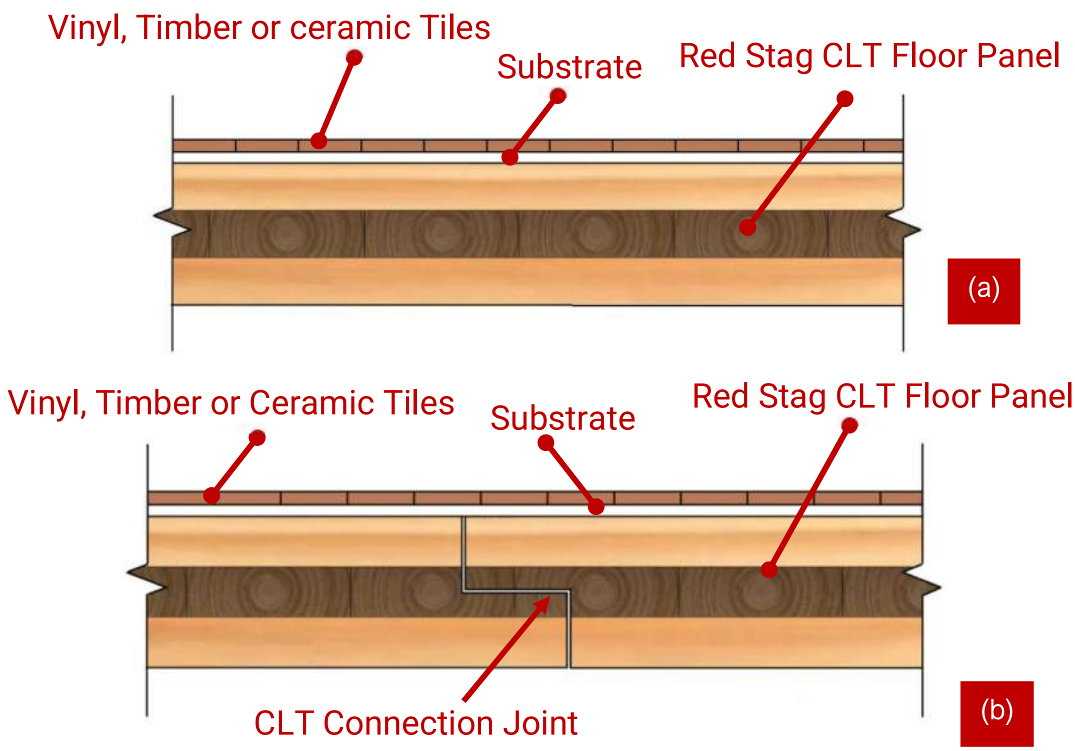
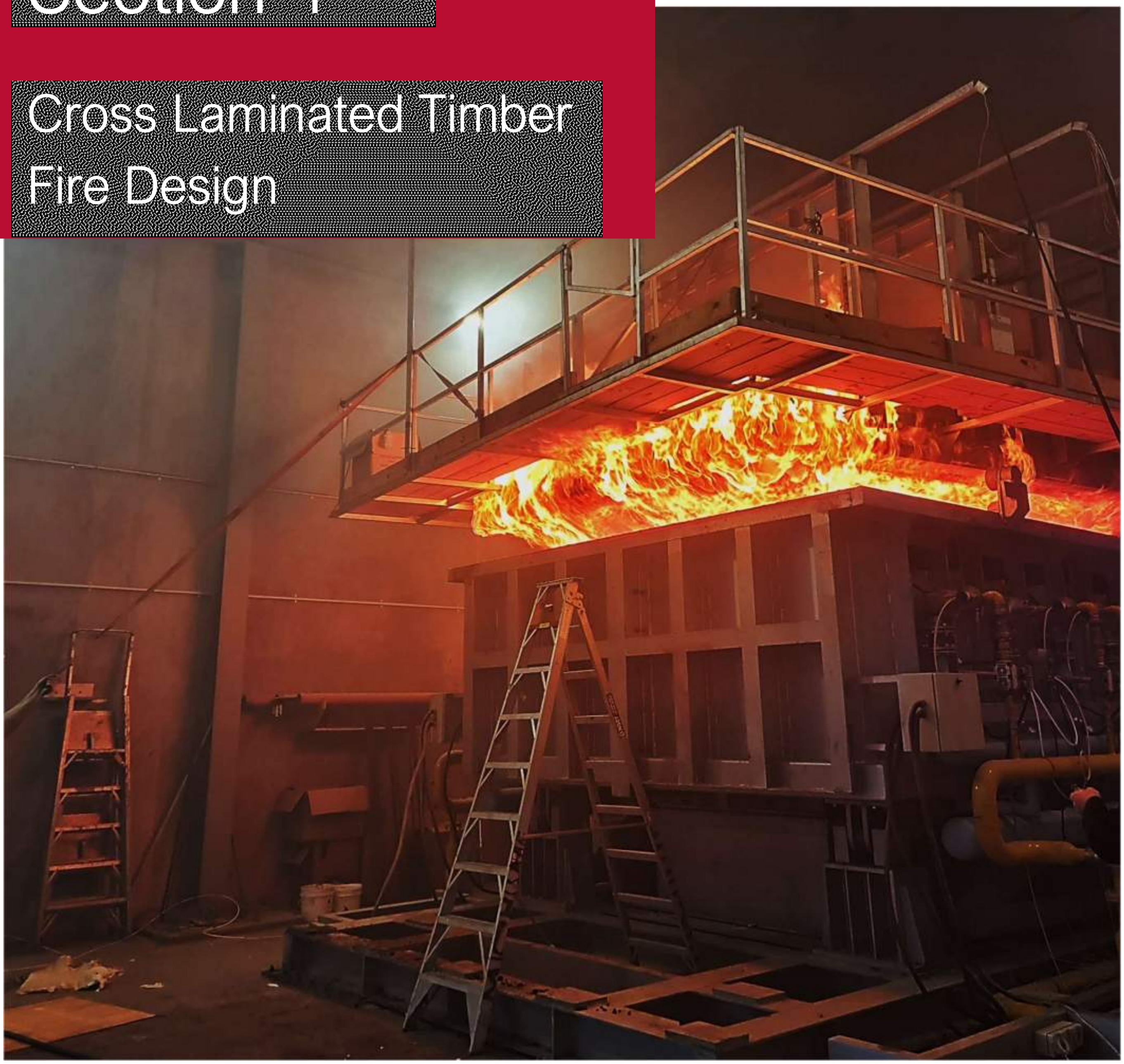


Figure 103: Red Stag CLT with timber or ceramic tile; (a) single solid CLT floor panel; (b) Two CLT panel connect at by lap joint. Note that the underlay joints should be sufficiently far away from the CLT connection joints.

Section 4

Cross Laminated Timber Fire Design



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.

20. 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 104a* to *Figure 104c*).

Common representations of FRR ratings are as follows:

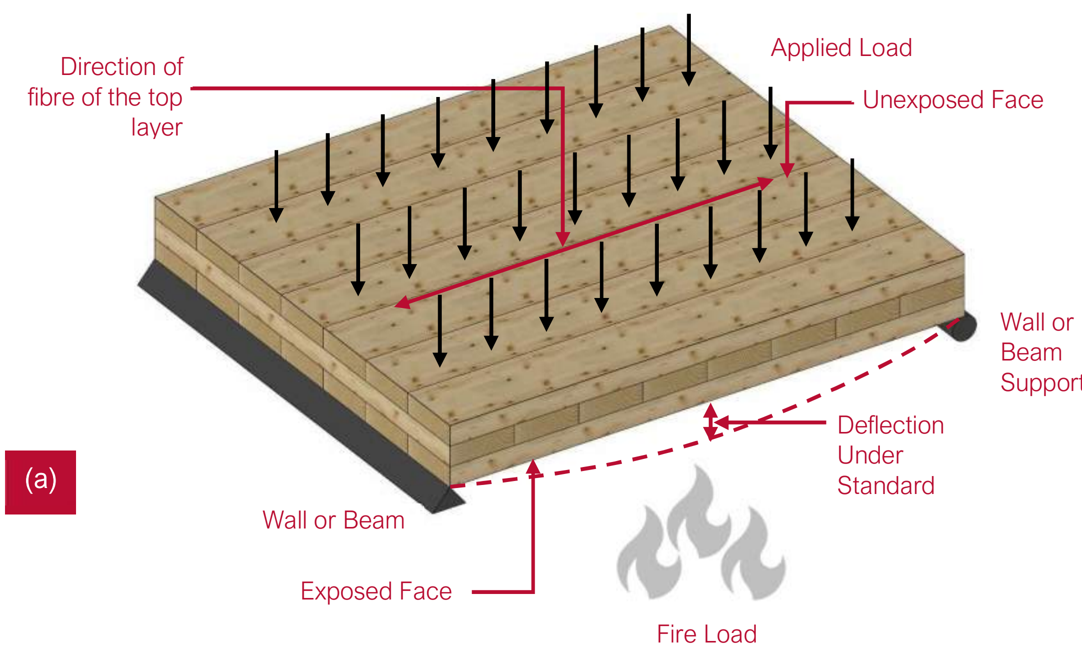
- 30/30/30: 30 minute Structural Resistance; 30 minutes Integrity; 30 minute Insulation rating.
- 60/60/60: 60 minute Structural Resistance; 60 minutes Integrity; 60 minute Insulation rating.
- -/30/60: Structural Resistance rating not applicable; 30 minutes Integrity; 60 minute Insulation rating.
-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

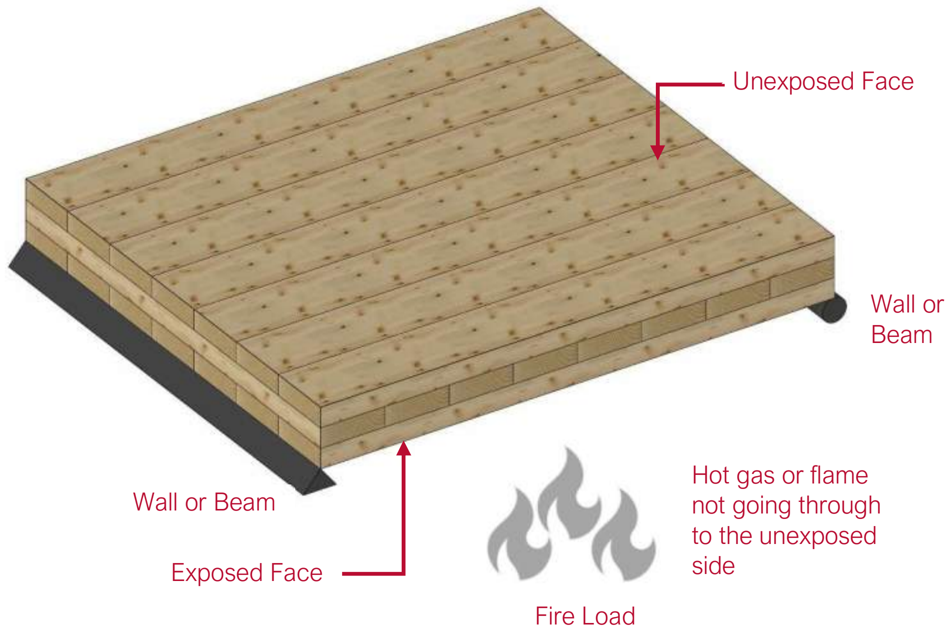
Figure 104a describes the structural adequacy of CLT. This is the ability to support a specified applied load and only applies to loadbearing elements in a structure. The assembly must support the applied load for the duration of the test (relates to the loadbearing function).

Figure 104b 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 104c 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)

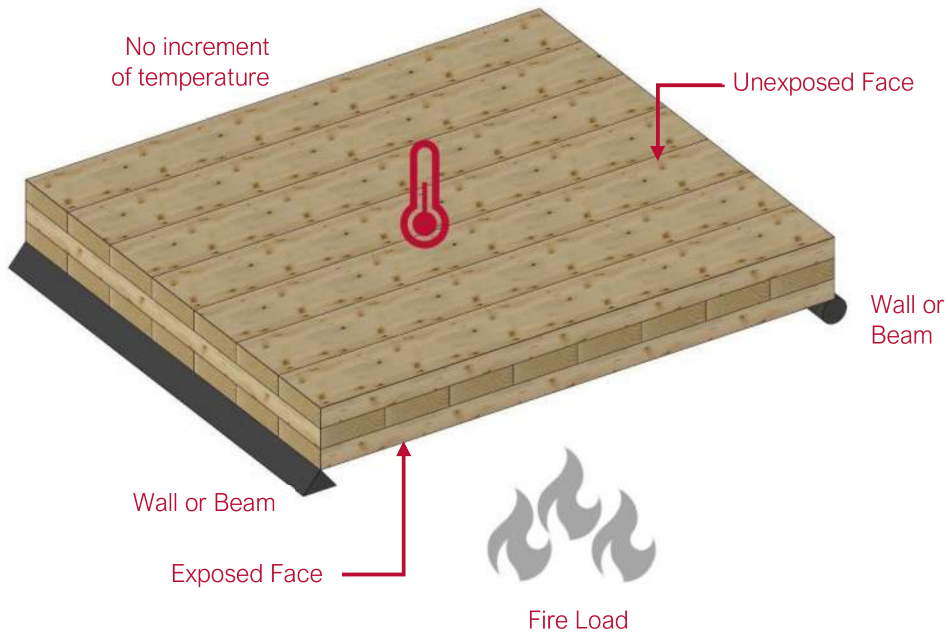


Figure 104: (a) Fire testing confirmed that a 103.5 mm thick Red Stag CLT panel satisfied the structural adequacy for 60 minutes during fire testing, (b) Fire testing confirmed that a 103.5 mm thick Red Stag CLT panel satisfied the integrity requirements for 60 minutes during fire testing, (c) Fire testing 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. Generally, 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.

21. 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 105*).

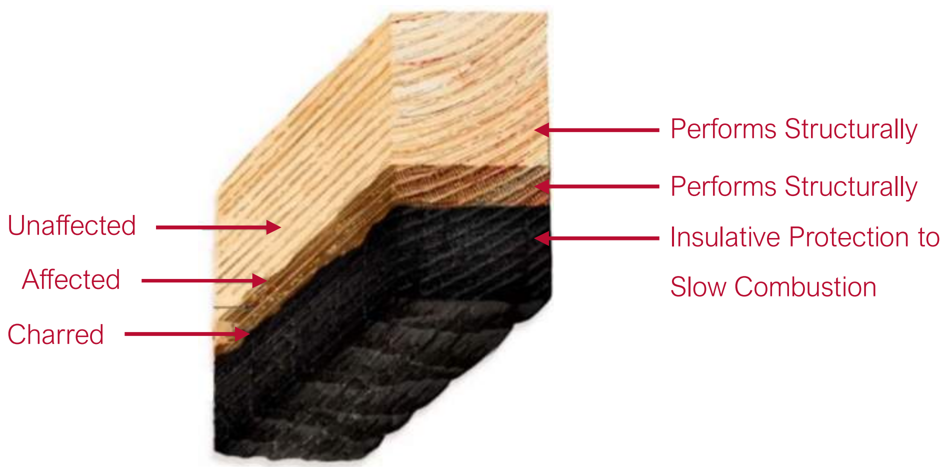


Figure 105: Different phases of degradation of timber in Red Stag CLT panel.

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 106*).

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 106a and Figure 106b*). The third-party fire test report confirmed no structural, integrity or instability failure after more than 60 minutes.

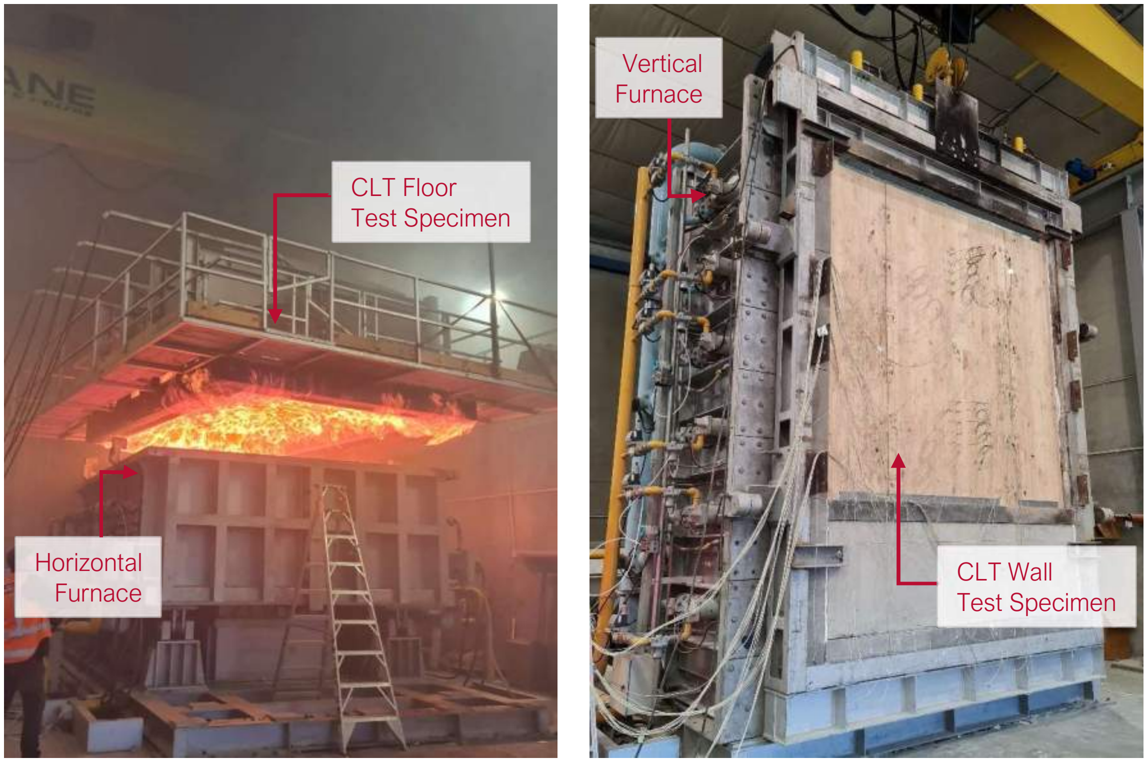
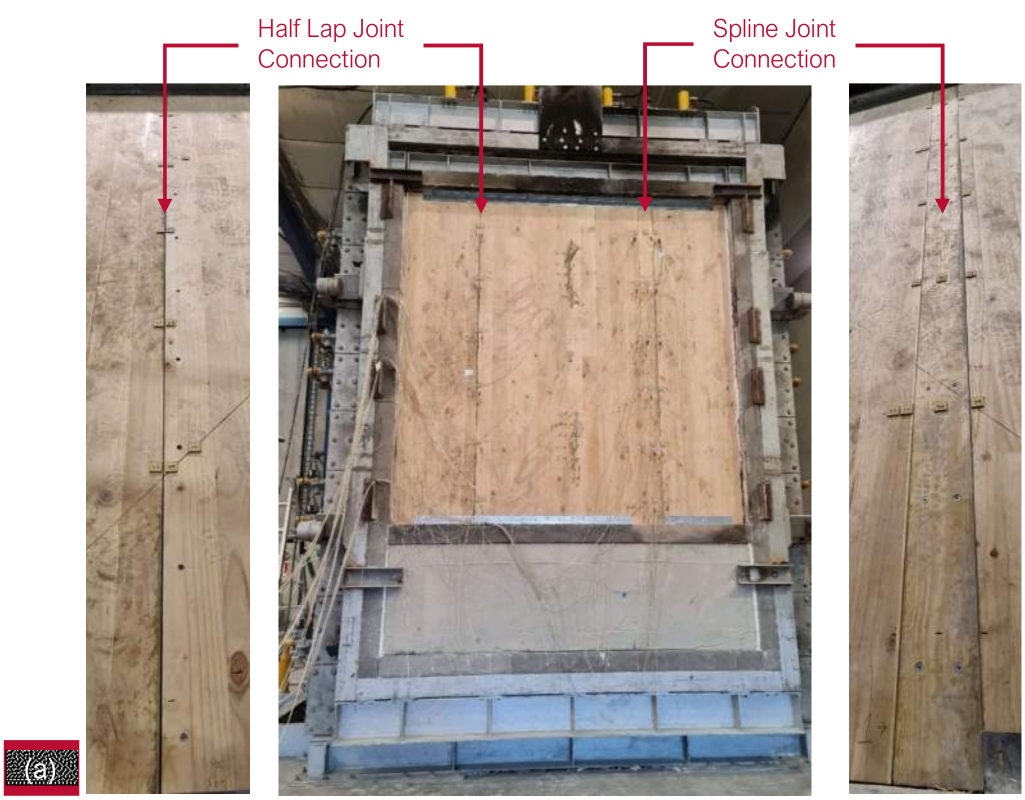


Figure 106: A general view of the large-scale fire test set-up and associated test specimen after the fire test on Red Stag CLT. a) Red Stag CLT floor test specimen after the fire test, b) Red Stag CLT wall test specimen before the fire test.

22. 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 107* 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 108* to *Figure 109*.



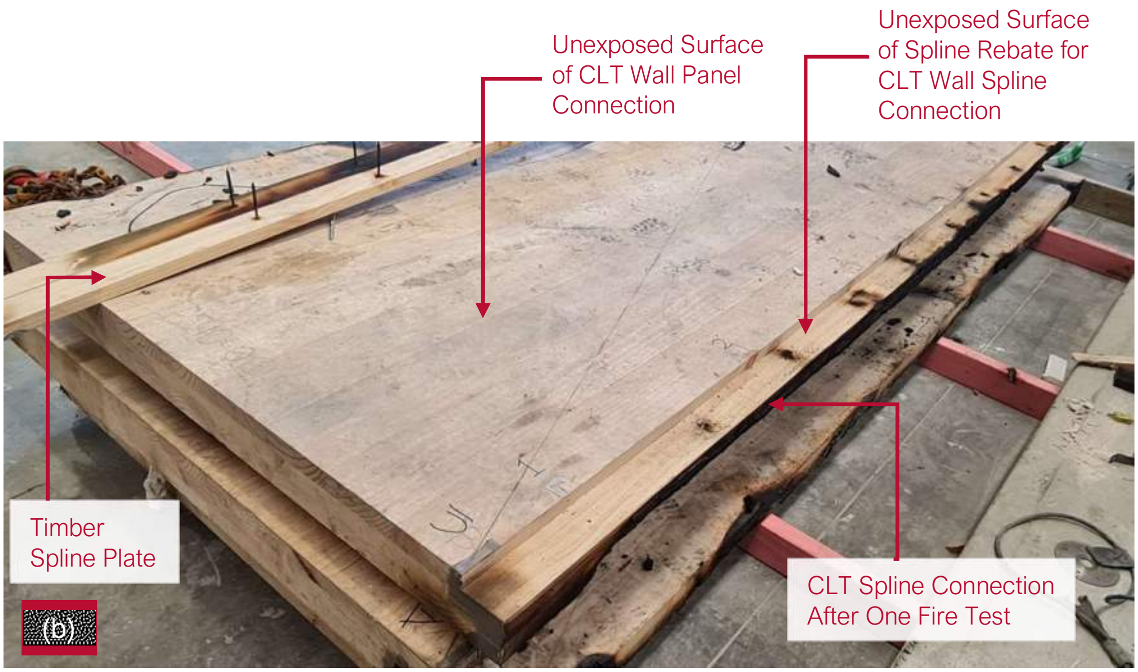


Figure 107: Large-scale Red Stag CLT wall fire test set-up after testing under structural loading to test CLT connection.

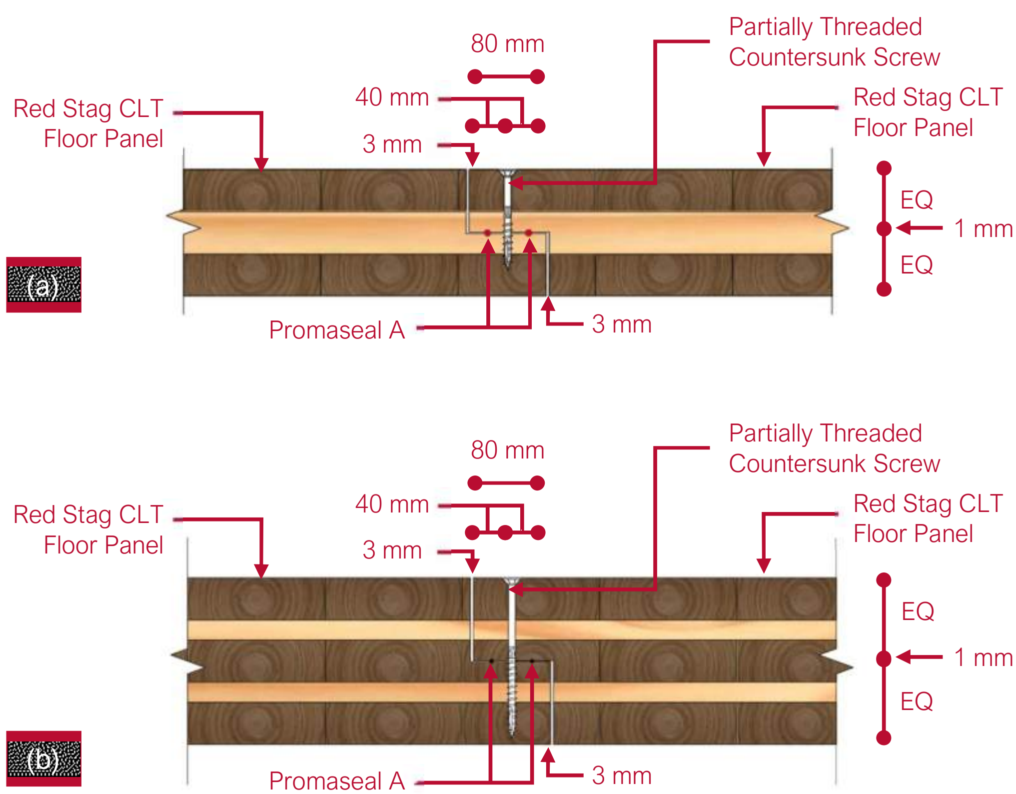


Figure 108: Red Stag CLT Panel to CLT Panel Half Lap Joint Connection [24], [25].

a) Three (3) Layer Red Stag CLT Panel, b) Five (5) Layer Red Stag CLT Panel.

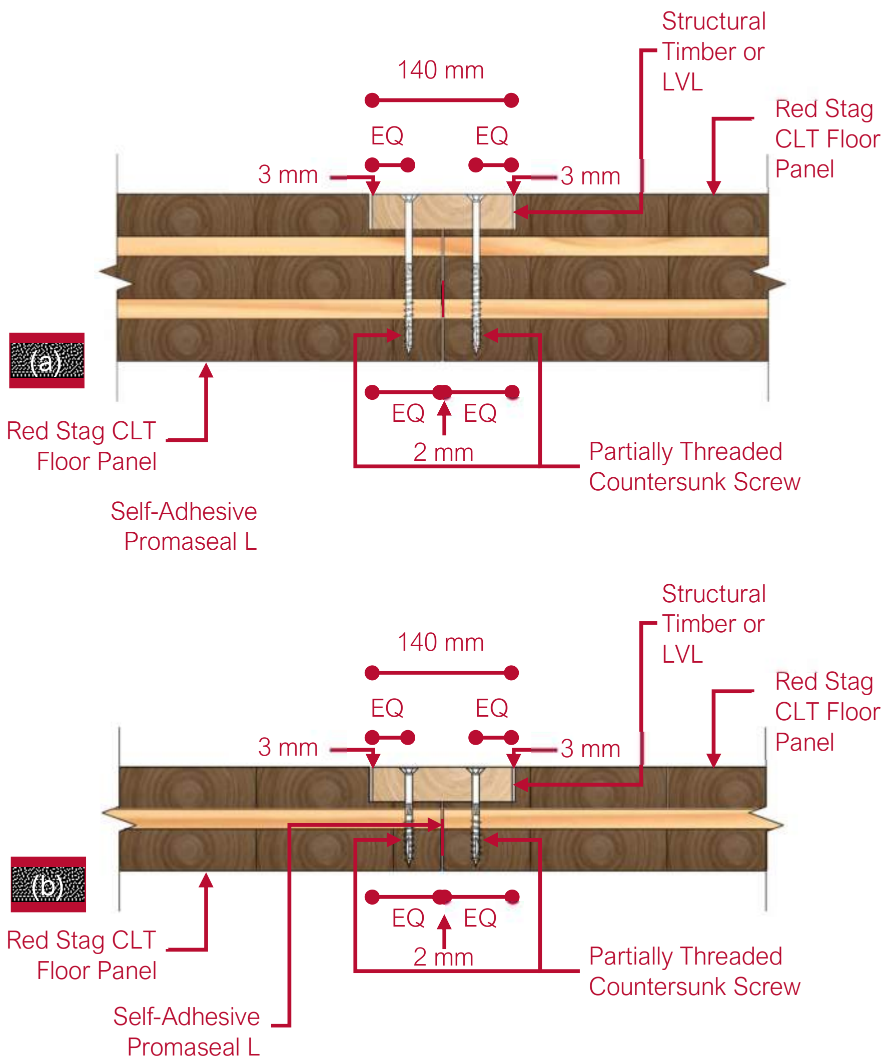


Figure 109: Red Stag CLT Panel to CLT Panel Spline Connection [24], [25].

a) Three (3) Layer Red Stag CLT Panel, b) Five (5) Layer Red Stag CLT Panel.

23. Fire Penetrations

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 110* and *Figure 111* illustrate fire penetration test configurations (pipes and cables) on Red Stag CLT floor and wall panels.

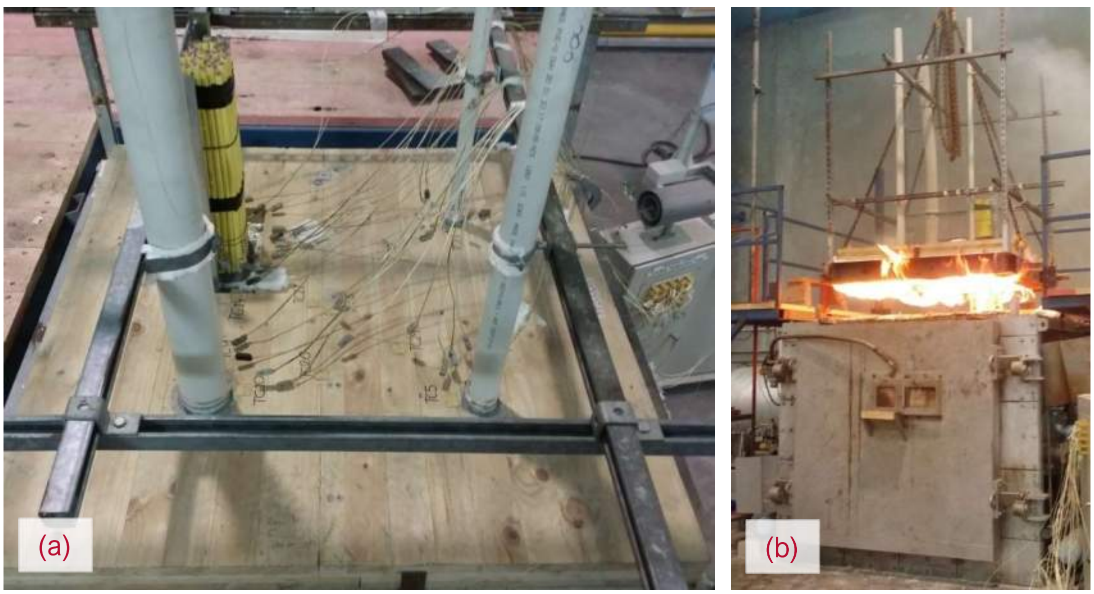


Figure 110: Various service (pipes and cables) fire tests on Red Stag CLT floor panels [26]. a) Specimen before the fire test, b) Specimen after the fire test.

Figure 111: 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.

Red Stag CLT has been successfully tested with door sets for a 60-minute fire event. *Figure 112* shows testing of multiple door sets with Red Stag CLT in the BRANZ fire laboratory. Deflection and temperature results confirmed that Red Stag CLT achieved a 60 minutes fire resistance with door sets as a system.

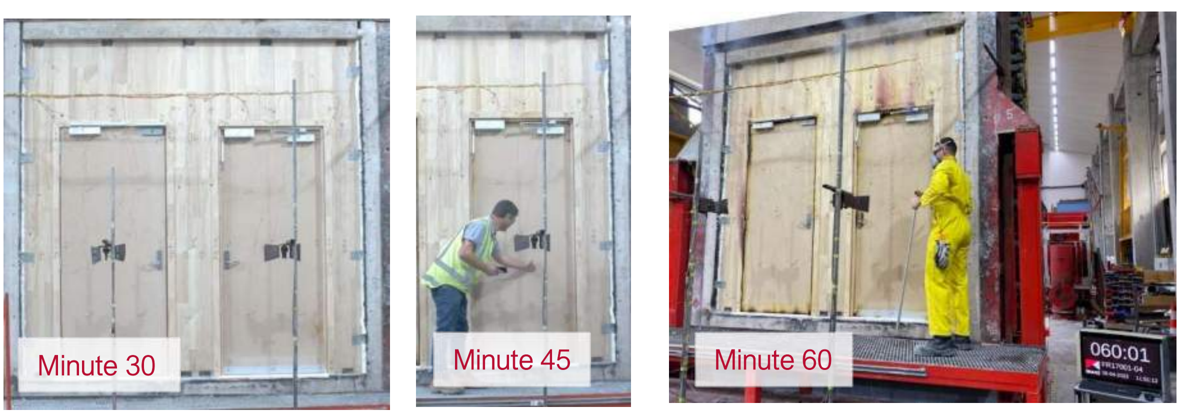


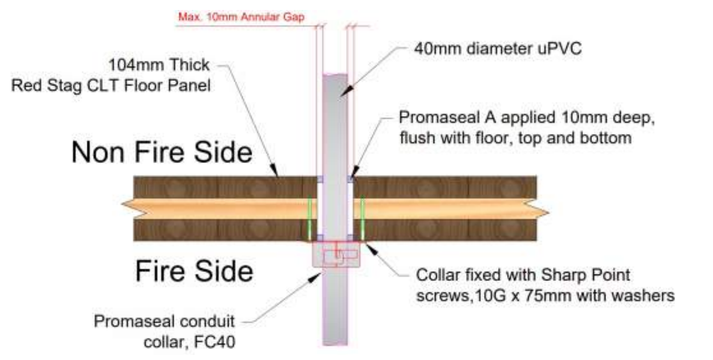
Figure 112: 60 minute fire test of Red Stag CLT and door sets as system.

The fire test results on Red Stag CLT are summarised in *Table 24*. 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 24: Red Stag Panel Fire Rated Penetration Details [24],[26]

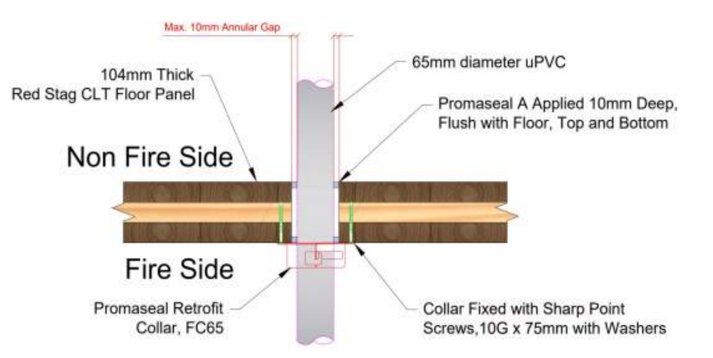
Red Stag Fire Rated Penetration Detail for Ø40 mm uPVC Pipe

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



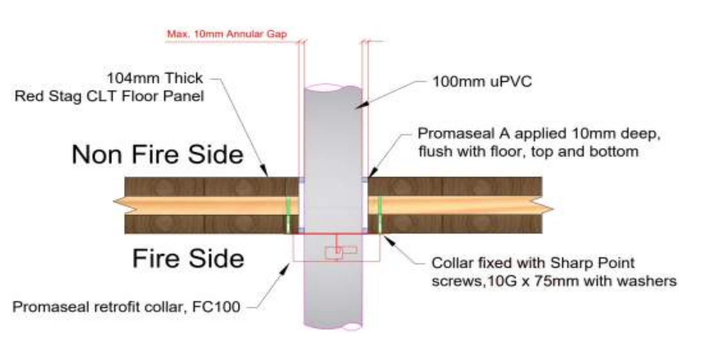
Red Stag Fire Rated Penetration Detail for Ø65 mm uPVC Pipe

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



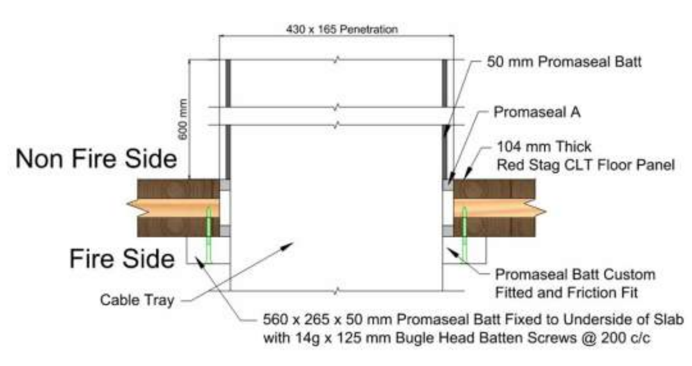
Red Stag Fire Rated Penetration Detail for Ø100 mm uPVC Pipe

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



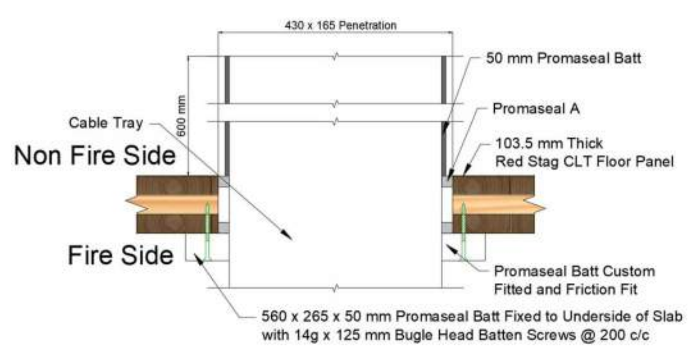
Fire Rated Penetration Detail for Comms Cable – D1 Configuration

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



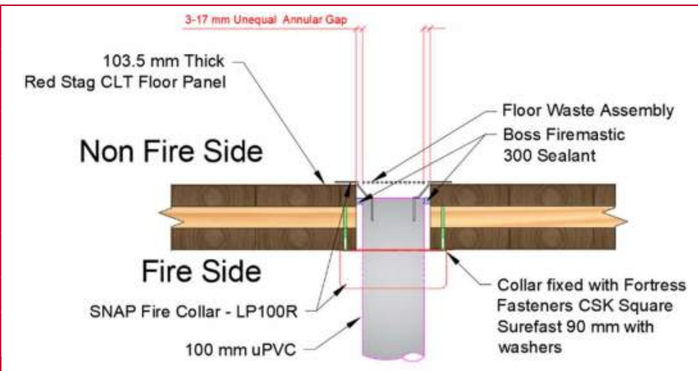
Fire Rated Penetration Detail for Comms Cable – D2 Configuration

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



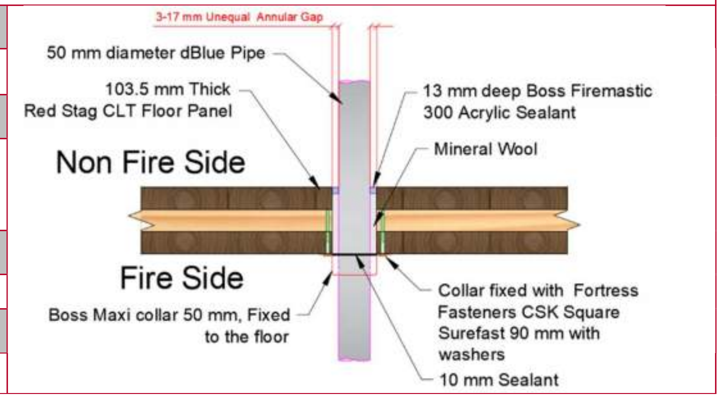
Red Stag Fire Rated Penetration Detail for Ø100 mm uPVC Pipe with Floor Waste Assembly

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



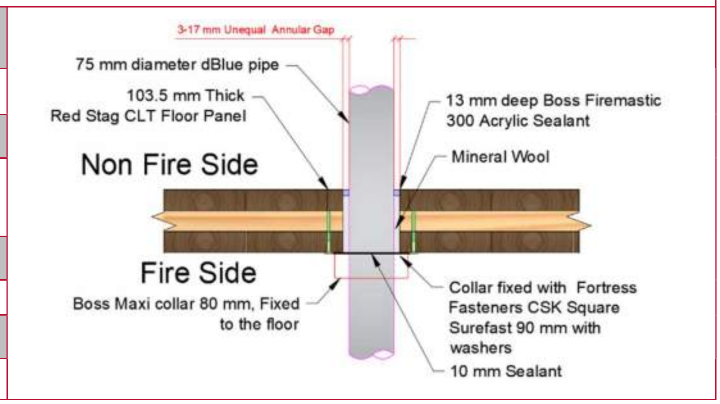
Red Stag Fire Rated Penetration Detail for Ø50 mm dBlue Pipe

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



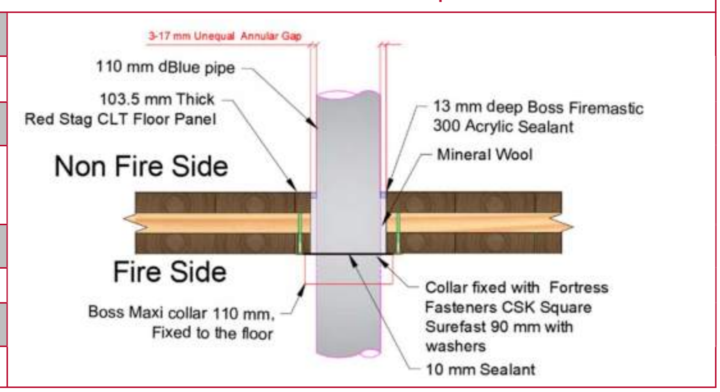
Red Stag Fire Rated Penetration Detail for Ø75 mm dBlue Pipe

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



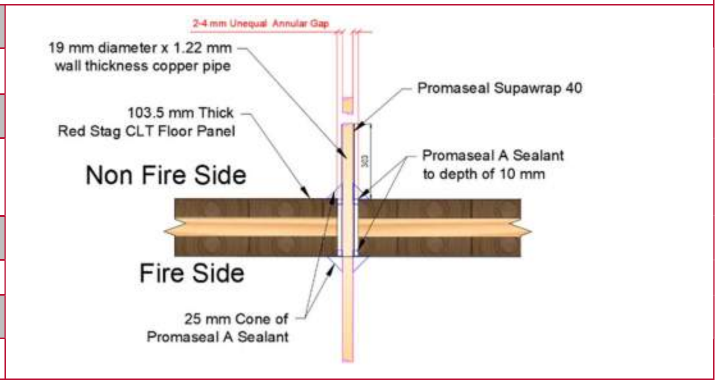
Red Stag Fire Rated Penetration Detail for Ø110 mm dBlue Pipe

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



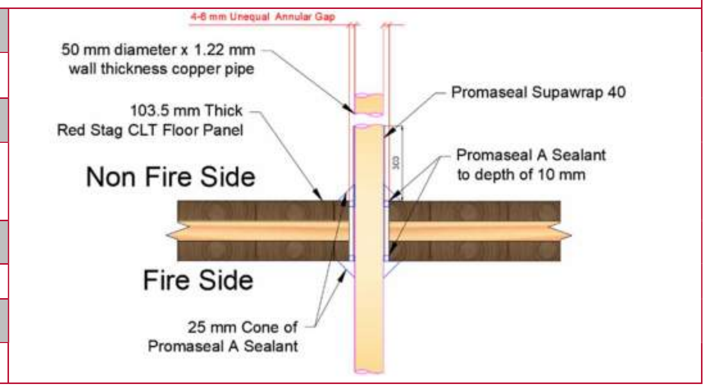
Red Stag Fire Rated Penetration Detail for Ø19 mm Copper Pipe

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



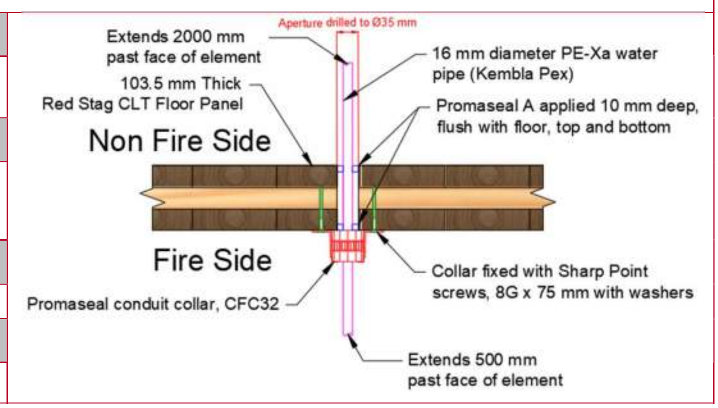
Red Stag Fire Rated Penetration Detail for Ø50 mm Copper Pipe

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



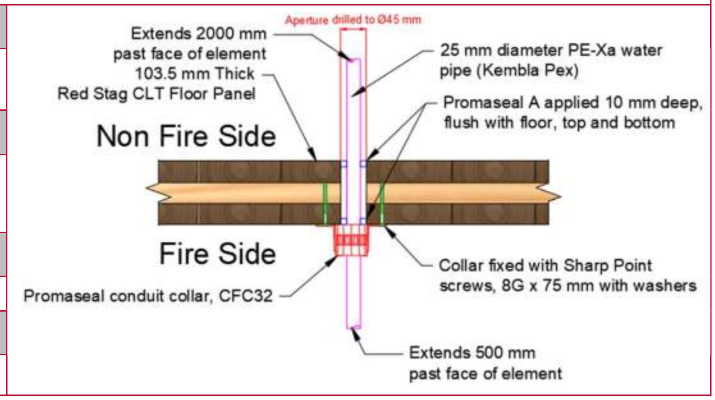
Red Stag Fire Rated Penetration Detail for Ø16 mm PE-Xa Water Pipe (Kembla Pex)

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



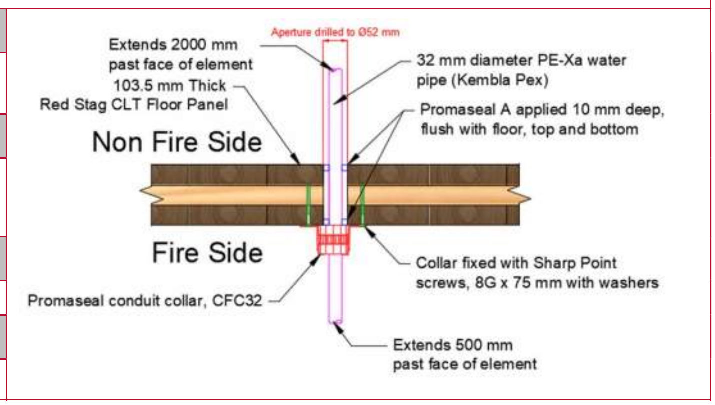
Red Stag Fire Rated Penetration Detail for Ø25 mm PE-Xa Water Pipe (Kembla Pex)

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



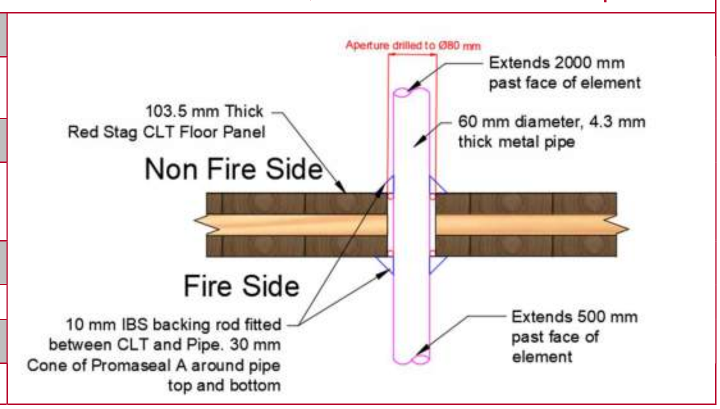
Red Stag Fire Rated Penetration Detail for Ø32 mm PE-Xa Water Pipe (Kembla Pex)

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



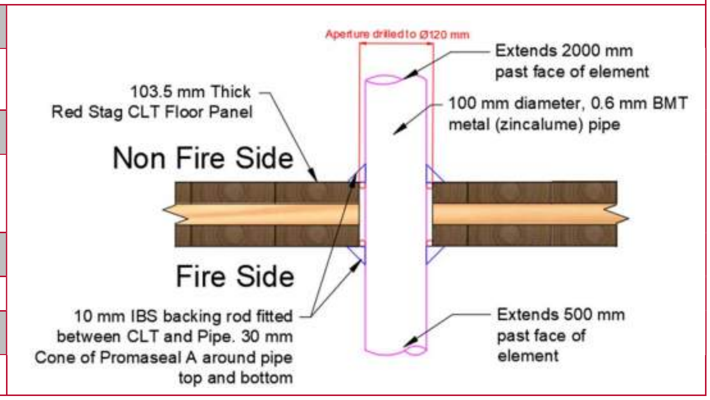
Red Stag Fire Rated Penetration Detail for Ø60 mm, 4.3 mm thick Metal Pipe

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



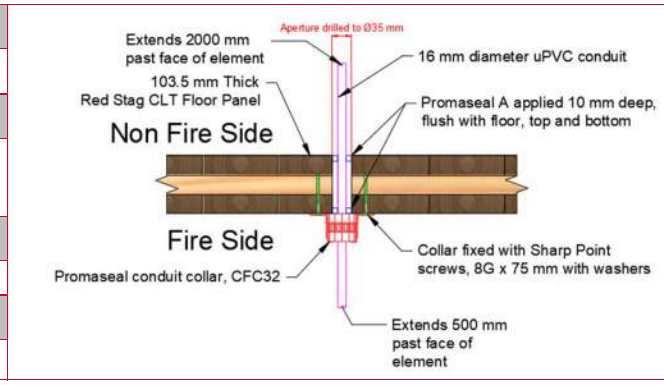
Red Stag Fire Rated Penetration Detail for Ø100 mm, 0.6 BMT Metal (Zincalume) Pipe

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/-



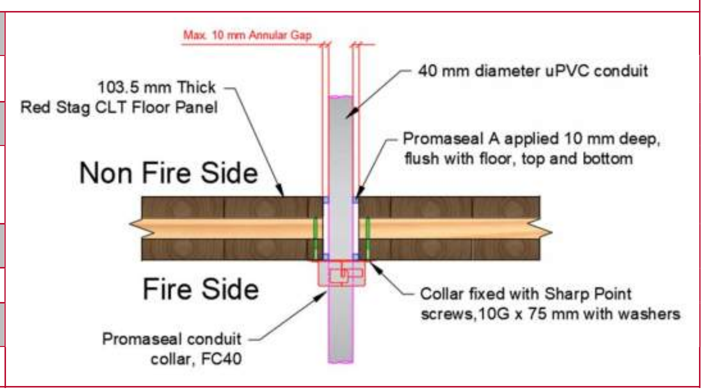
Red Stag Fire Rated Penetration Detail for Ø16 mm uPVC Conduit filled with 3-core TPS Cables

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



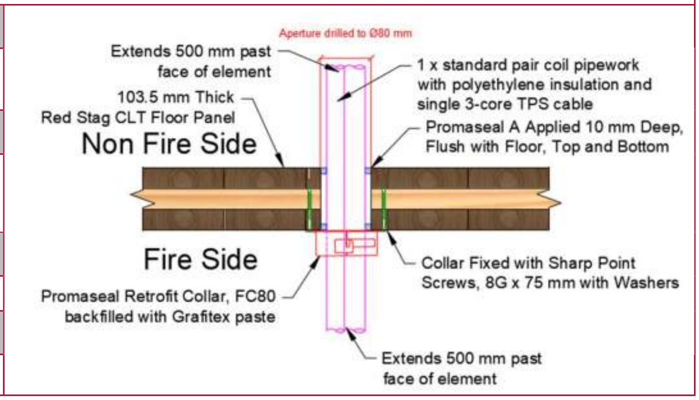
Red Stag Fire Rated Penetration Detail for Ø40 mm uPVC Conduit filled with 3-core TPS Cables

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



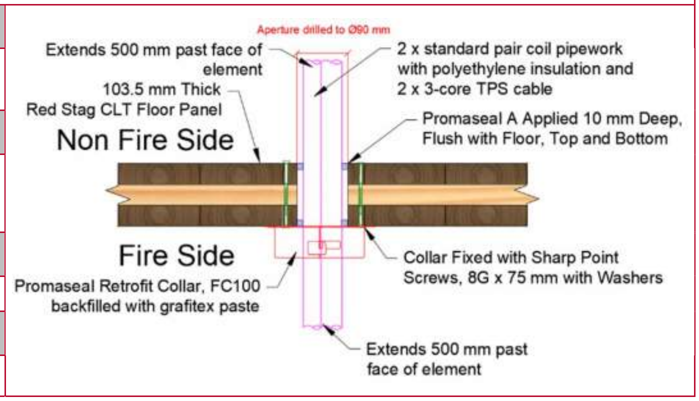
Red Stag Fire Rated Penetration Detail for Single STD Pair Coil & 2.5 mm 3C TPS

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



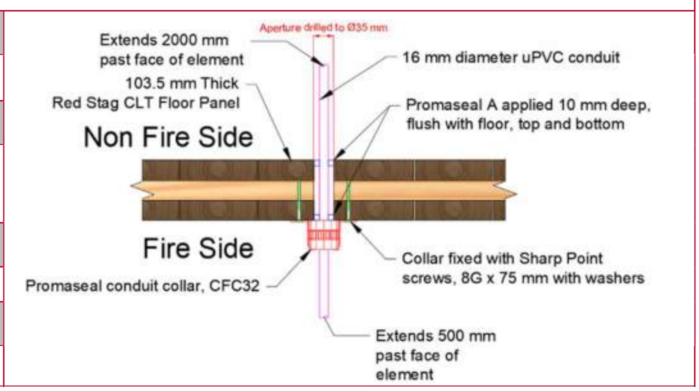
Red Stag Fire Rated Penetration Detail for Double STD Pair Coil & 2.5 mm 3C TPS

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



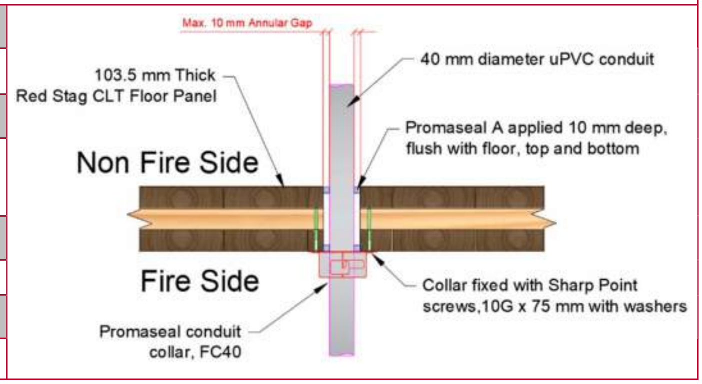
Red Stag Fire Rated Penetration Detail for Ø16 mm uPVC Conduit

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



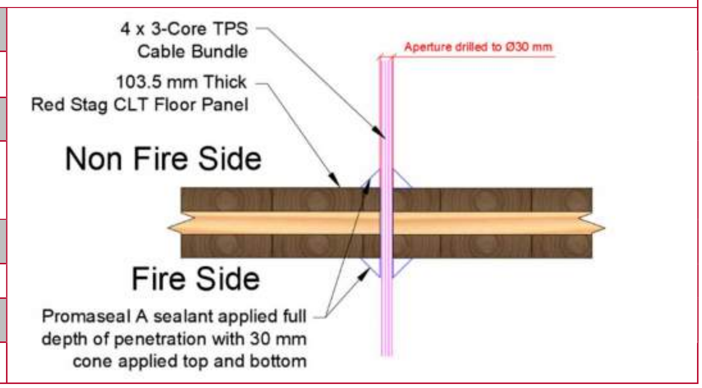
Red Stag Fire Rated Penetration Detail for Ø40 uPVC Conduit

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



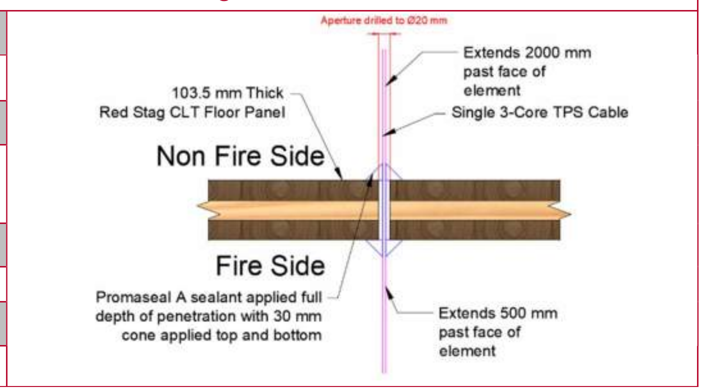
Red Stag Fire Rated Penetration Detail for 4 x 3-core TPS Cable Bundle

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



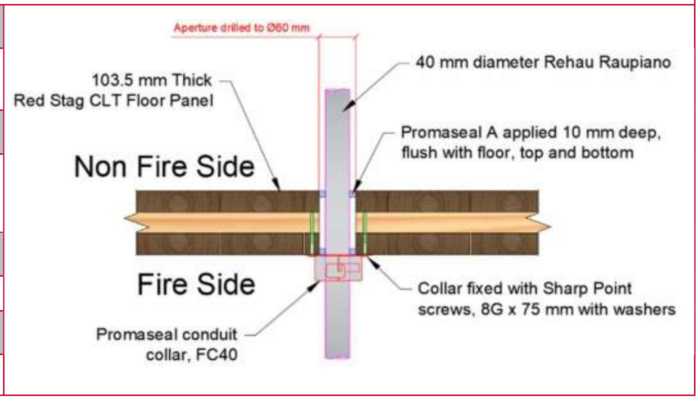
Red Stag Fire Rated Penetration Detail for Single 3-core TPS Cable

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



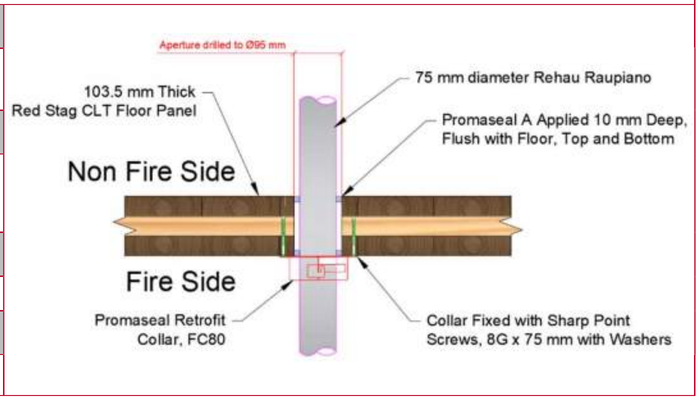
Red Stag Fire Rated Penetration Detail for Ø40 mm Rehau Raupiano Pipe

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



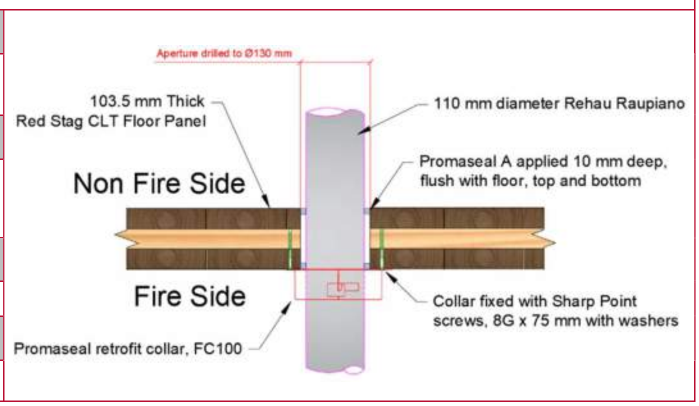
Red Stag Fire Rated Penetration Detail for Ø75 mm Rehau Raupiano Pipe

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

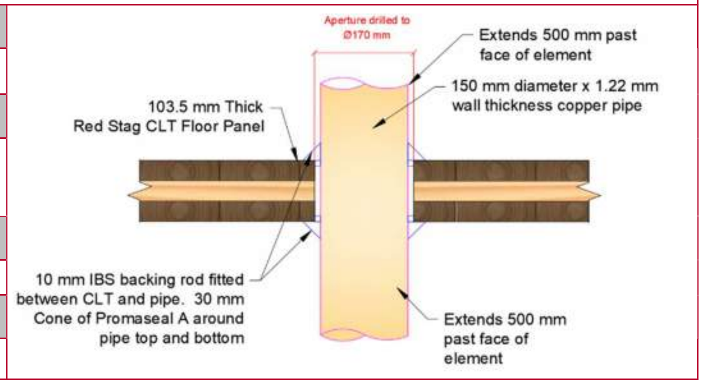


Red Stag Fire Rated Penetration Detail for Ø110 mm Rehau Raupiano Pipe

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



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 25* and *Table 26*). 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 25: 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 26: 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	8 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	8 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	8 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].

Table 27 to *Table 29* 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 27: 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 28: 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 29: 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.

24.1. Determining Group Number for Varius Surface Finishes

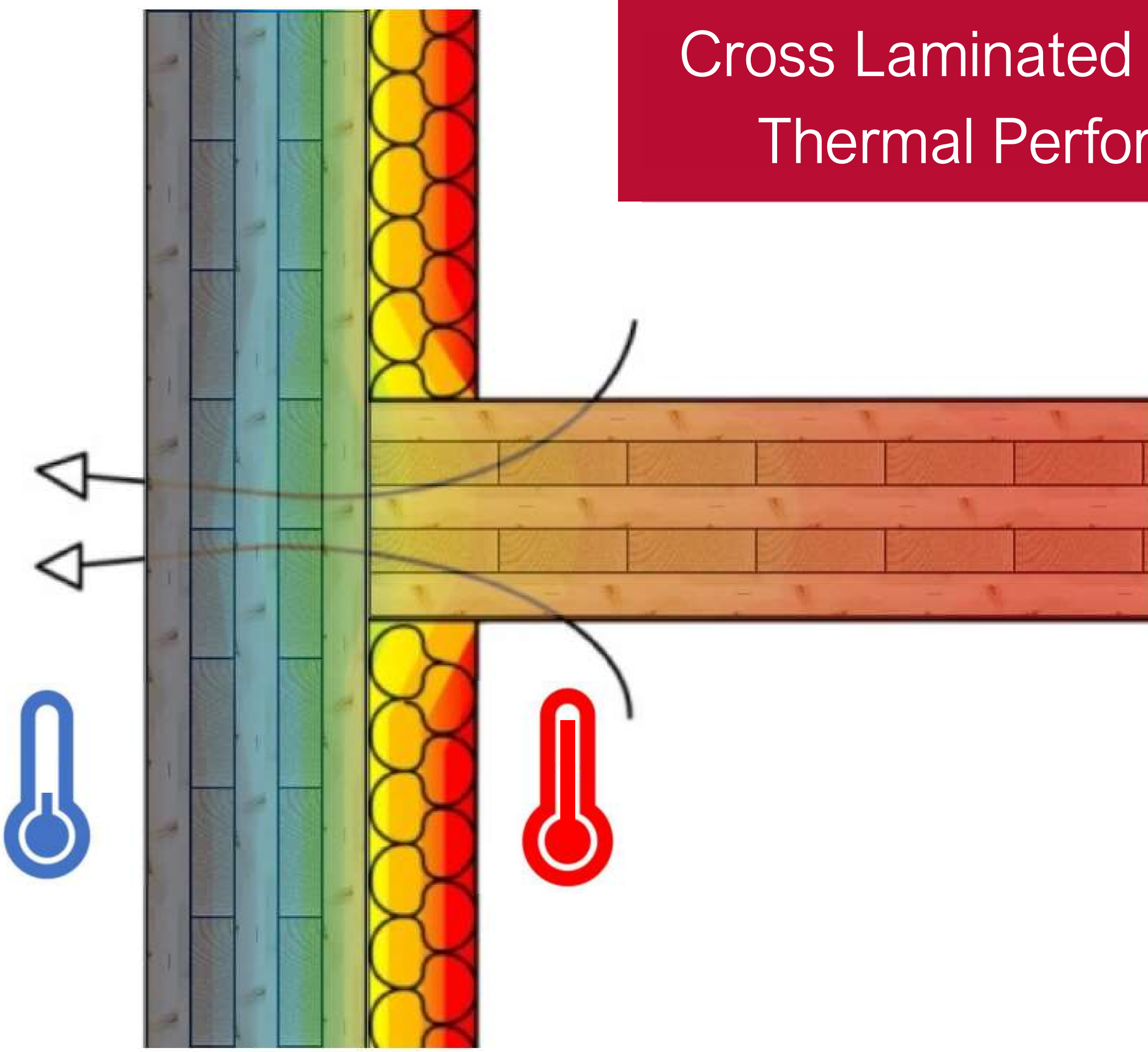
For the purposes of compliance with the surface finish requirements, the specified combinations of substrate and coating in *Table 30* show the required performance without the need for further evaluation using A1.2 or A1.3 in C/VM2 Verification Method: Framework for fire safety design.

Table 30: Specified performance for substrate and coating combinations.

Coating (coating in good condition and well adhered to substrate)	Substrate	Group Number
Waterborne or solvent borne paint coatings ≤ 0.4 mm thick Polymeric films ≤ 0.2 mm thick	Concrete and masonry ≥ 15 mm thick Sheet metal ≥ 0.4 mm thick Fibber-cement board ≥ 6 mm thick Porcelain, ceramic, glass, solid stone, or similar tiles	1-S
Waterborne or solvent borne paint coatings ≤ 0.4 mm thick	Gypsum plasterboard with or without paper facing ≥ 9.5 mm thick	2-S
Waterborne or solvent borne paint coatings, varnish or stain ≤ 0.4 mm thick ≤ 100 g/m^2	Solid wood or wood product ≥ 9.0 mm thick ≥ 600 kg/m^3 for particle boards, or ≥ 400 kg/m^3 for all other wood and wood products	3
Note: The requirements of this table do not apply to metal faced panels with polymeric substrate.		

Section 5

Cross Laminated Timber Thermal Performance



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 113* and *Figure 8* to *Figure 10* in Section 1).

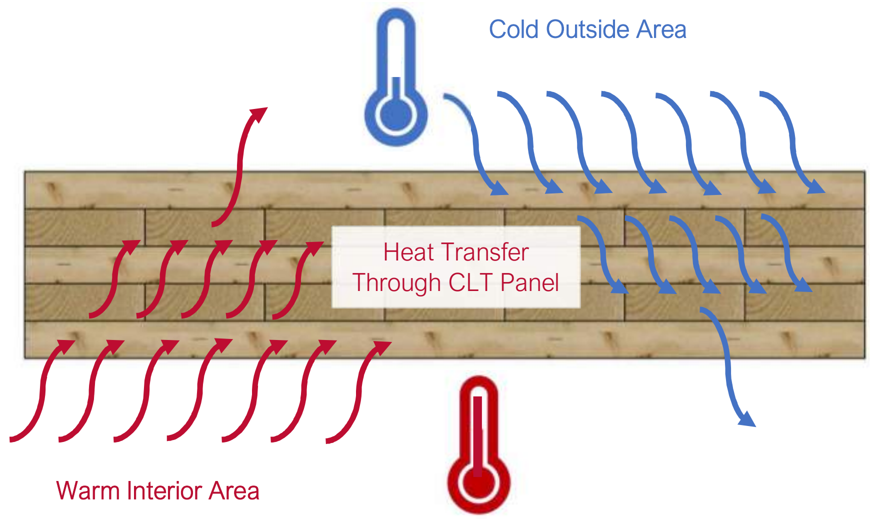


Figure 113: Thermal performance of the CLT building

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 114* and *Figure 115*).

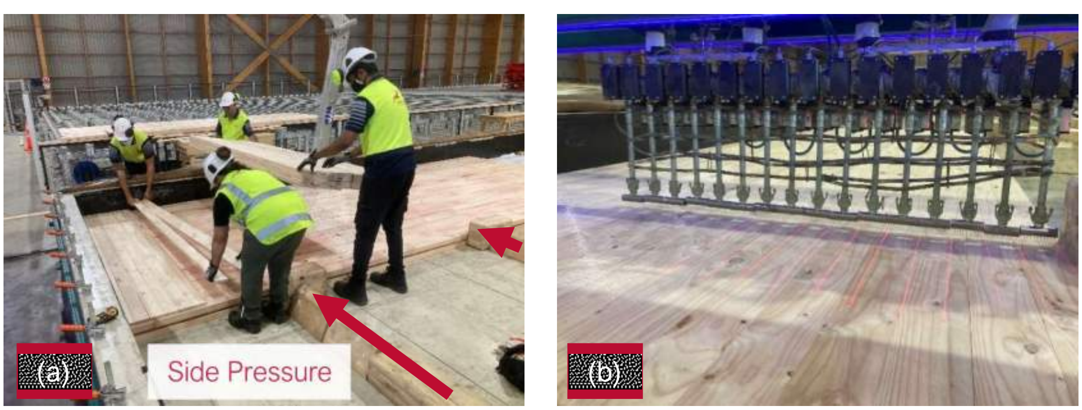


Figure 114: Red Stag Manufacturing line; (a) Layer arrangement with side pressure, (b) Adhesive distribution, (c) Hydraulic side pressure and Vacuum Membrane, (d) Final Red Stag CLT Product.

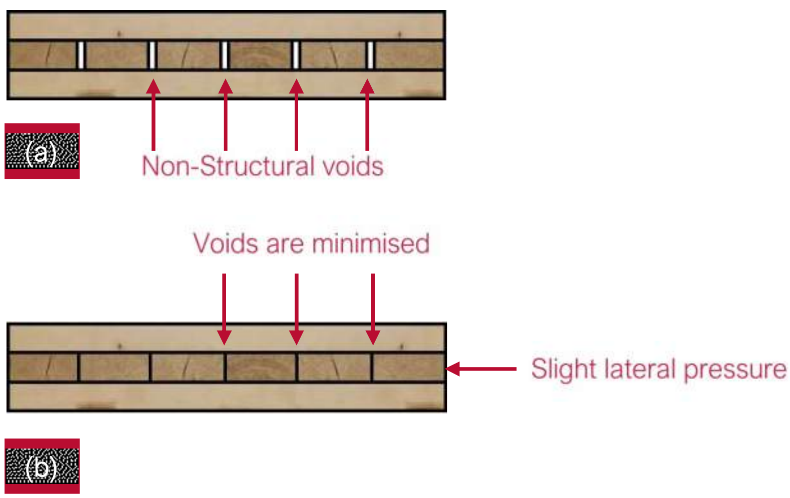


Figure 115: CLT panel manufacturing with and without lateral pressure.
a) CLT panel with non-structural voids, b) CLT panel with lateral pressure to minimise voids.

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 (refer to *Figure 116*). 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 116: 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.

25.1. 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 $m^2 \cdot °C/W$. 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 31 to *Table 33* detail the thermal resistance (R-value) of CLT for various thicknesses of Red Stag CLT [35].

Table 31: 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 $m^2 \cdot °C/W$	0.86 $m^2 \cdot °C/W$
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 $m^2 \cdot °C/W$ 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 32: 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

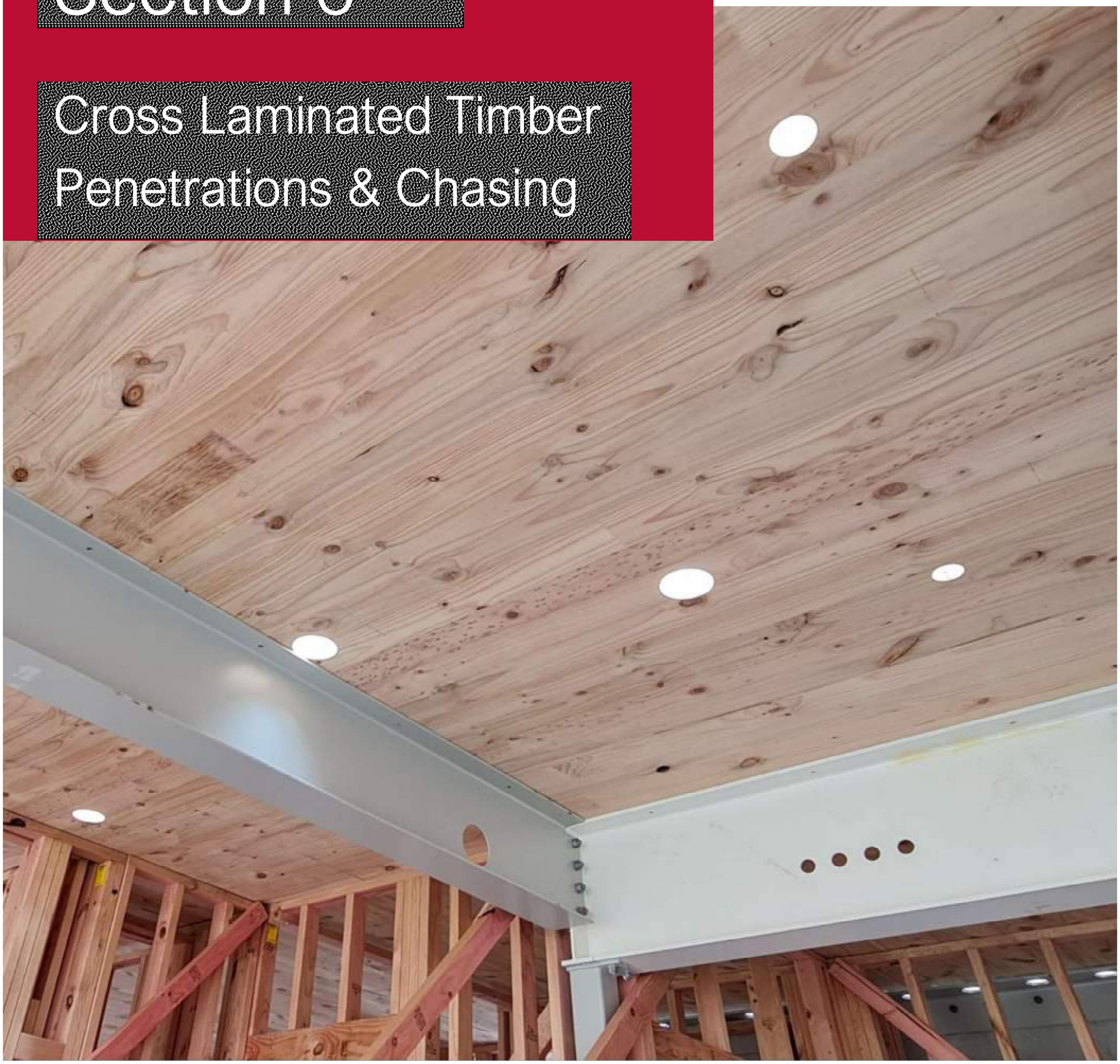
a. Recipe priority defines the most cost-effective Red Stag CLT recipe option.
b. Based on the NZS4214, Table E, softwoods (e.g. pine) at 12% moisture content, density of 450 kg/m^3, thickness of 18 mm, conductivity of 0.120 W/mK. The unit of measure is $m^2 \cdot °C/W$ and assumes a single solid wood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

Table 33: 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



Red Stag CLT Design Guide V1.5
September 2024

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 117*).

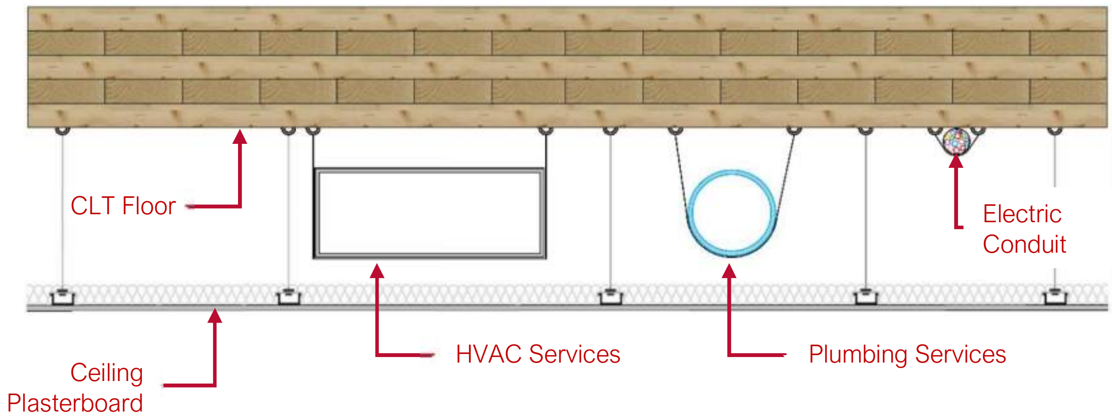
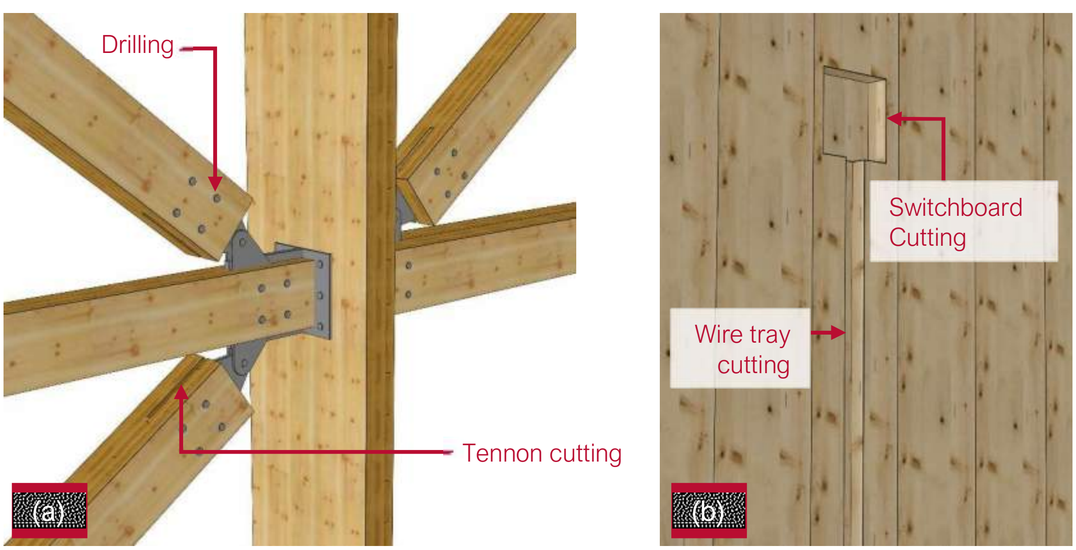


Figure 117: Cross-section view of suspended or direct fix utilities under CLT floor systems.

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 118*.



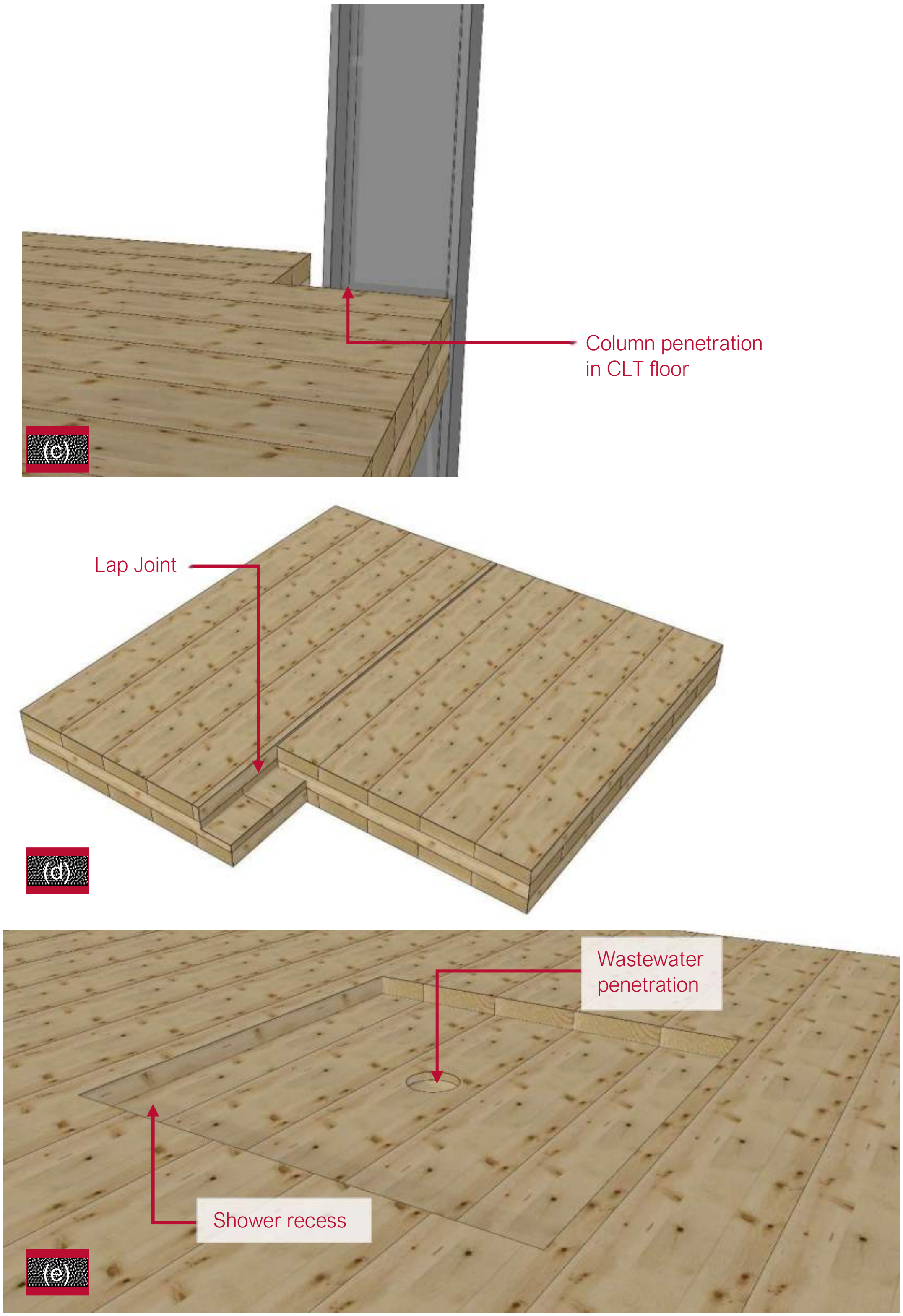


Figure 118: Penetrations and chasing through the Red Stag CLT panels. a) Slots and drilling for CLT members (beam, column and bracings, b) Electrical penetrations for walls, c) Column penetrations in floors, d) Lap joint, e) Shower tray.

Section 7

Cross Laminated Timber Quality Assurance

Make it better

Red Stag CLT Design Guide V1.5
September 2024

27. 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.

27.1 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 119).*

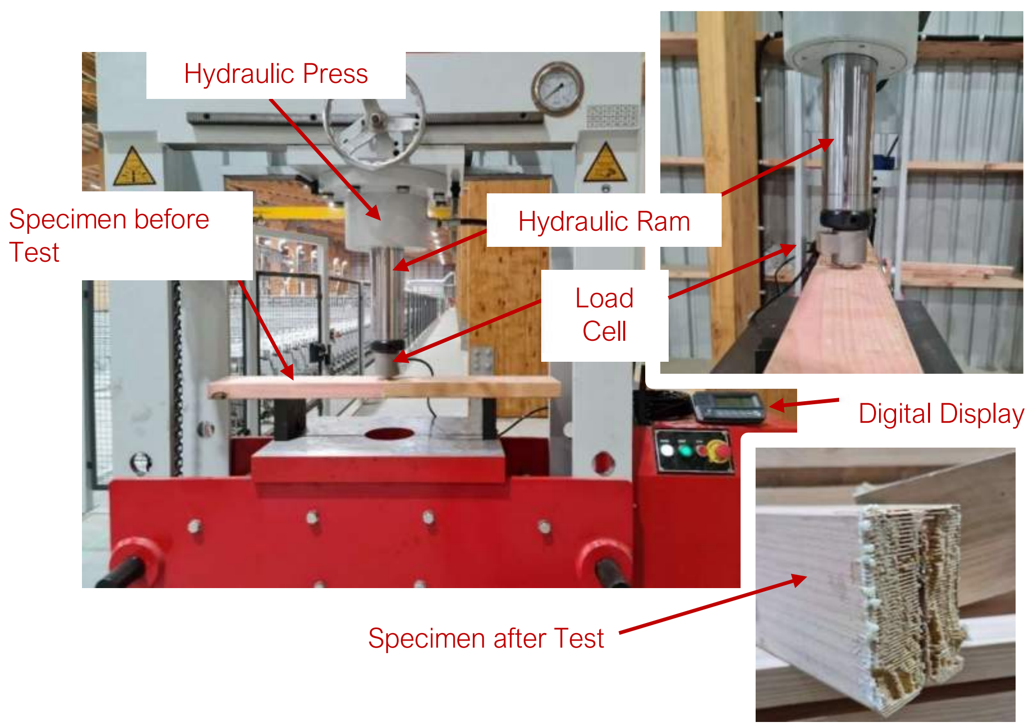
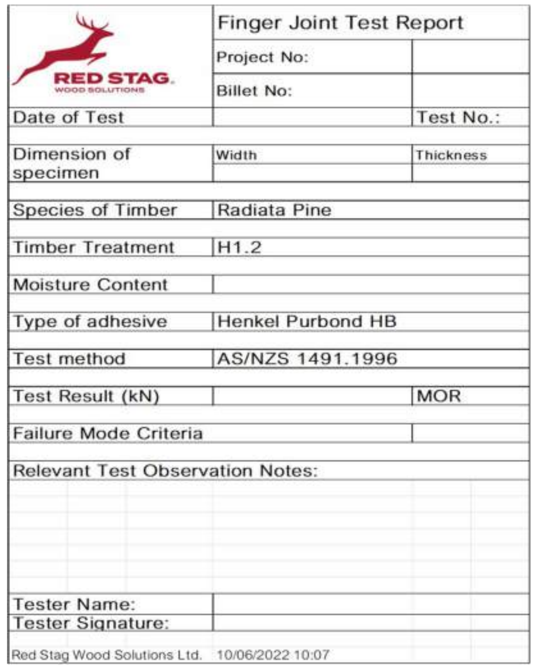


Figure 119: FJ test set-up.

27.1.1 Red Stag Finger Joint Test Report

Red Stag will maintain a documented QA programme to ensure conformance with the AS 5068:2006 and AS/NZS 1491:1996 standard. An example of the Red Stag test report for FJ testing is shown in *Figure 120*.



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 120: Example of the Red Stag FJ test report.

27.2 Delamination Test

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

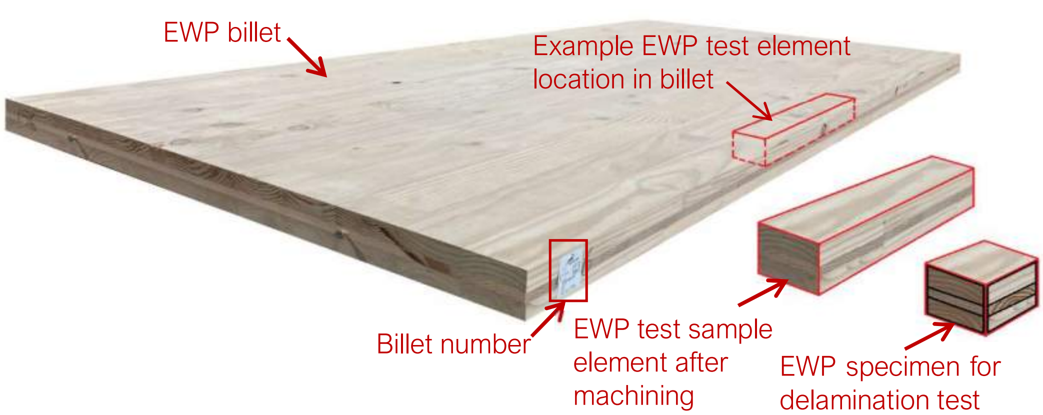


Figure 121: EWP delamination test specimen preparation.

Red Stag has invested in highly advanced automated delamination testing technology. This fully automated system can perform delamination test to demonstrate the integrity of the adhesive bond by long term weathering simulation through a short-term watering and drying process for EWP samples.

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 122*).

The test equipment has the capability to be programmed automatically for wide range of testing standards including AS/NZS 1328.1 and BS EN 16351:2021.

Figure 122: Delamination testing equipment.

27.2.1 Red Stag Delamination Test Report

Red Stag maintain a documented QA programme to ensure conformance with AS/NZS 1328.1 and the Annex A of BS EN 16351:2021 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.

28. Red Stag Third Part EWP Quality Testing

28.1 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 123* and *Figure 124*).

Figure 123: 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 124: 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.

29.1 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 125* to *Figure 127,* 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 125*). Testing on short, intermediate, and long-span CLT panels show exceptional structural performance under shear force, bending moment, and combination of the two.

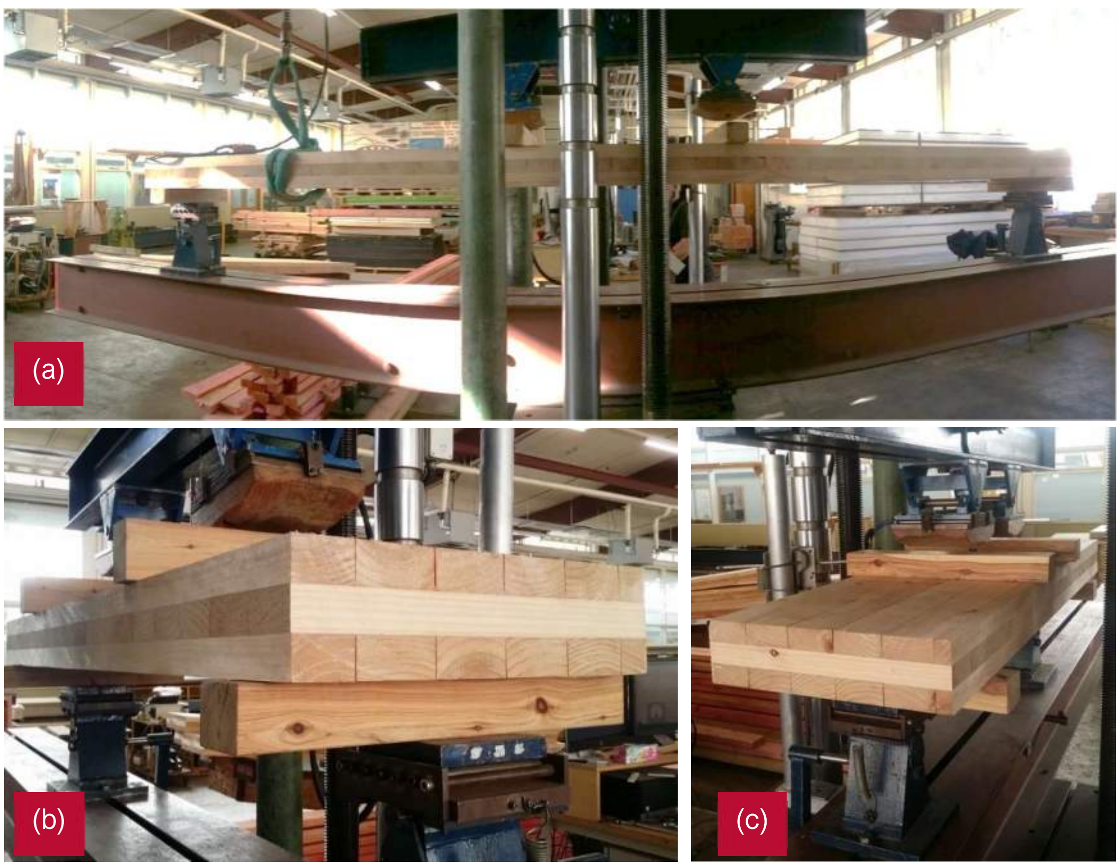


Figure 125: Large scale mechanical testing conducted by SCION; (a) Long span testing; (b) Medium span testing; (c) Short span testing.

29.2 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 126*). 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 126: Delamination testing equipment; a) EWP specimens in pressure vessel; b) EWP specimens in drying chamber.

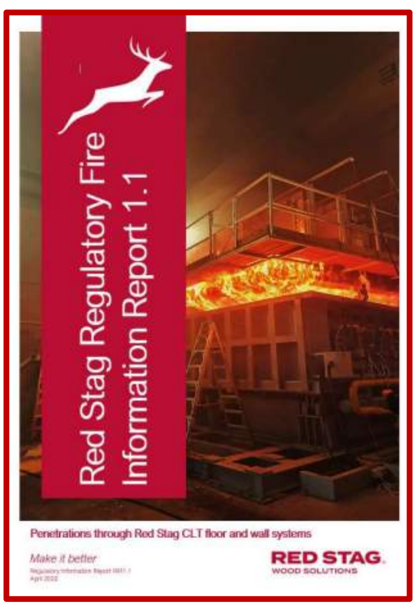
29.3 EWP Fire Performance Testing

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 127*). 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 127: 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.

30. 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, Red Stag Environmental Product Declaration, and Red Stag Regulatory Fire Information Report 1.1.



Section 8

Cross Laminated Timber Complexity Guide

Red Stag CLT Design Guide V1.5
September 2024

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.

31.1 Complexity of Red Stag EWP Elements Based on Type

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

31.1.1. Floors
31.1.2. Walls/Roofs
31.1.3. Stairs
31.1.4. 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.

31.2 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 128*).

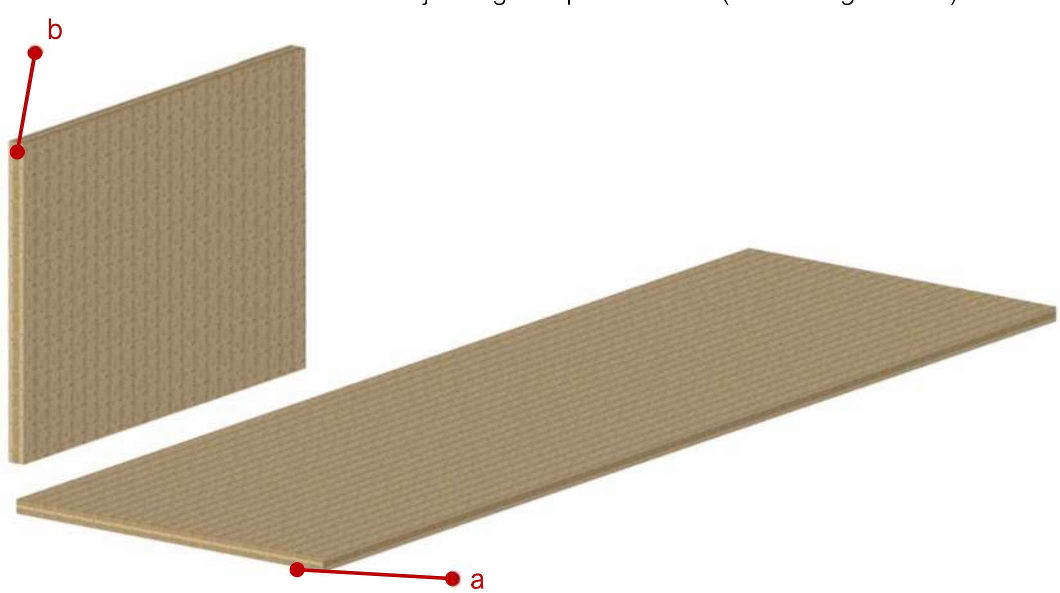


Figure 128: Example of basic complexity processing of Red Stag EWP elements; a) Corner of basic complexity Red Stag CLT floor panel; b) Corner of basic complexity Red Stag CLT wall panel.

31.3 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 129*).

[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.

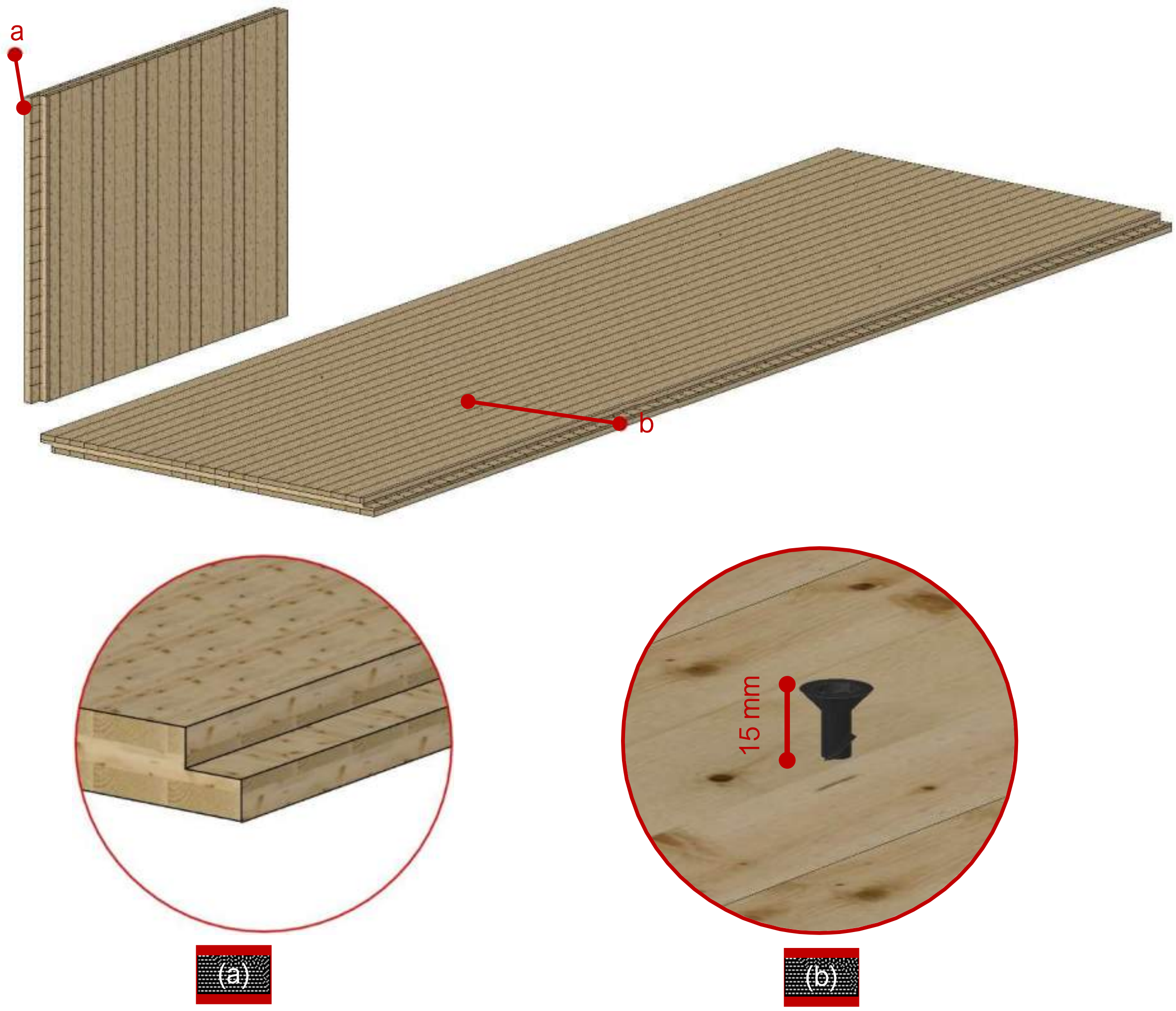


Figure 129: Example of standard complexity processing; a) Two edge lap/spline joint rebate (maximum 80 mm wide), requiring no panel flipping or adjacent panel movement; b) Predrilling/installation of lifting screws.

31.4 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 130*).

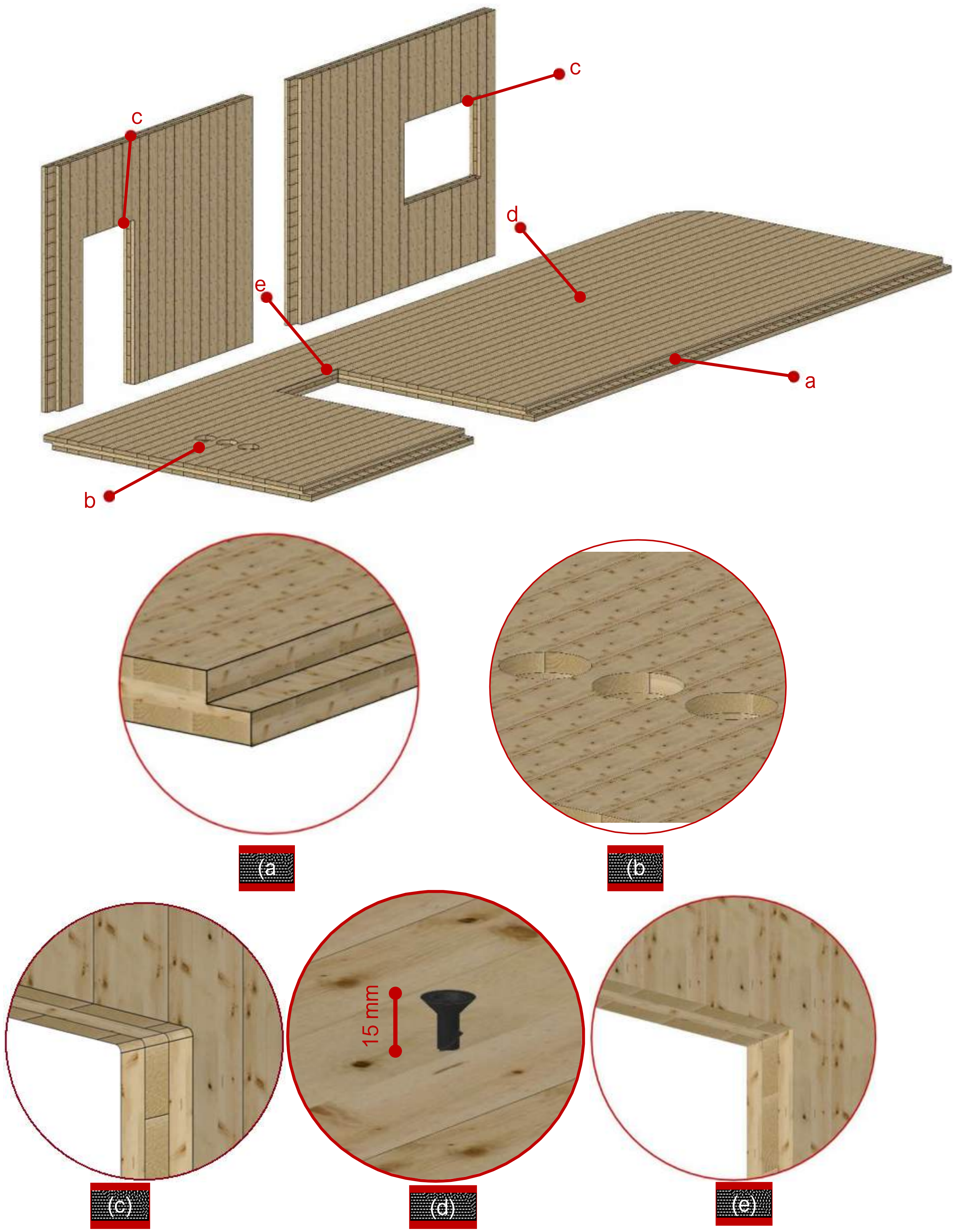
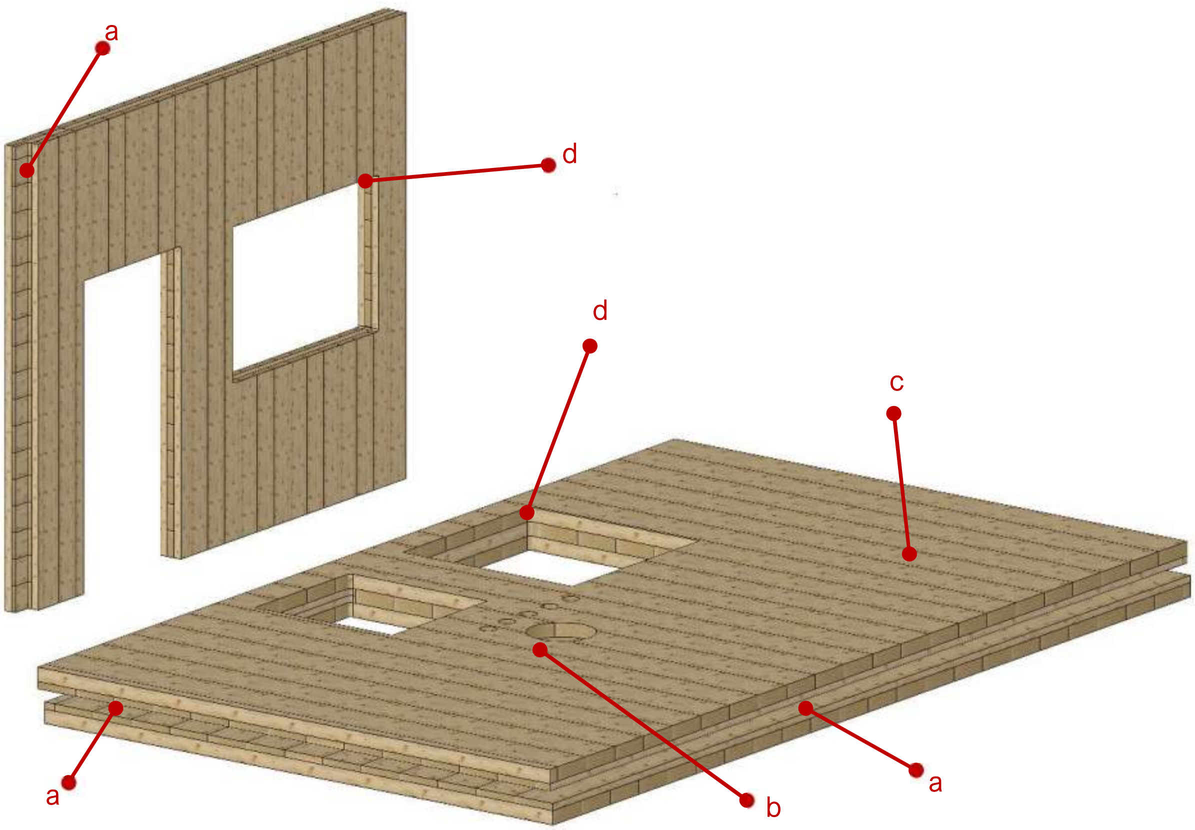


Figure 130: Example of moderate complexity processing of Red Stag EWP elements; a) Lap/spline joint rebate, b) Up to three standard circular penetrations; c) Up to one opening with corner radii transitions; d) Predrilling/installation of lifting screws.

31.5 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 131).



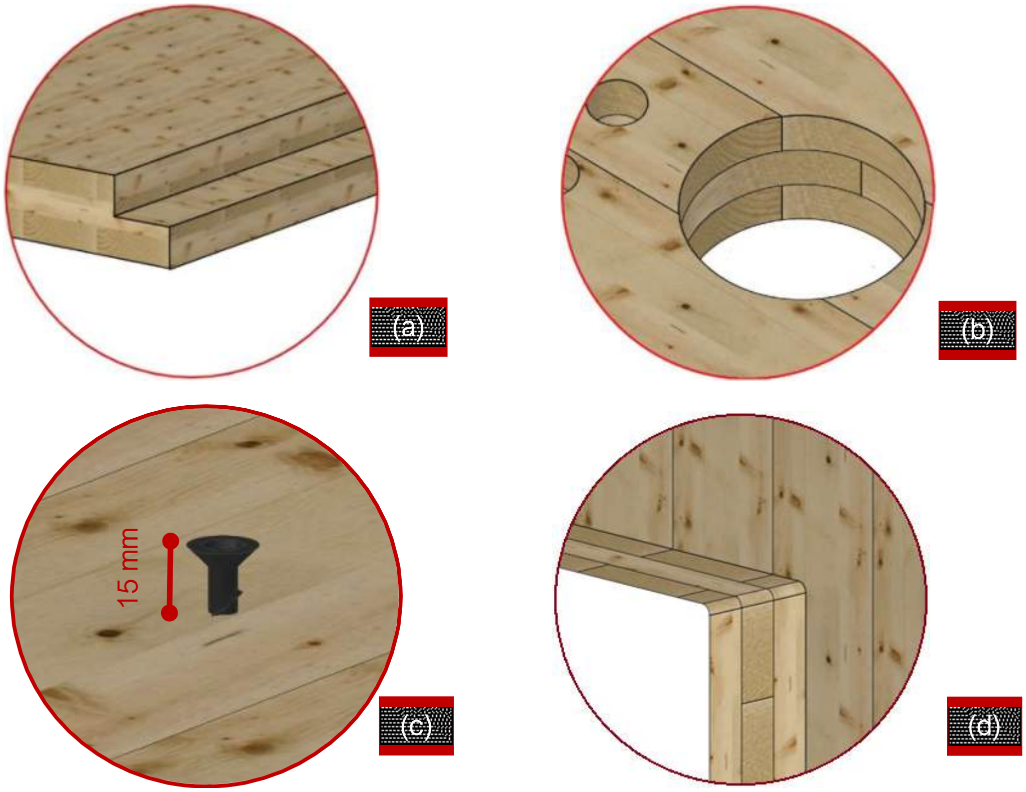


Figure 131: Example of difficult complexity processing of Red Stag EWP elements; a) Lap/spline joint rebate without flipping or panel removal up to 100 mm wide, b) Up to six simple radii penetrations over and above of basic fixing locators, c) Predrilling/installation of lifting screws; d) Square penetration with radii corner.

31.6 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 132*).

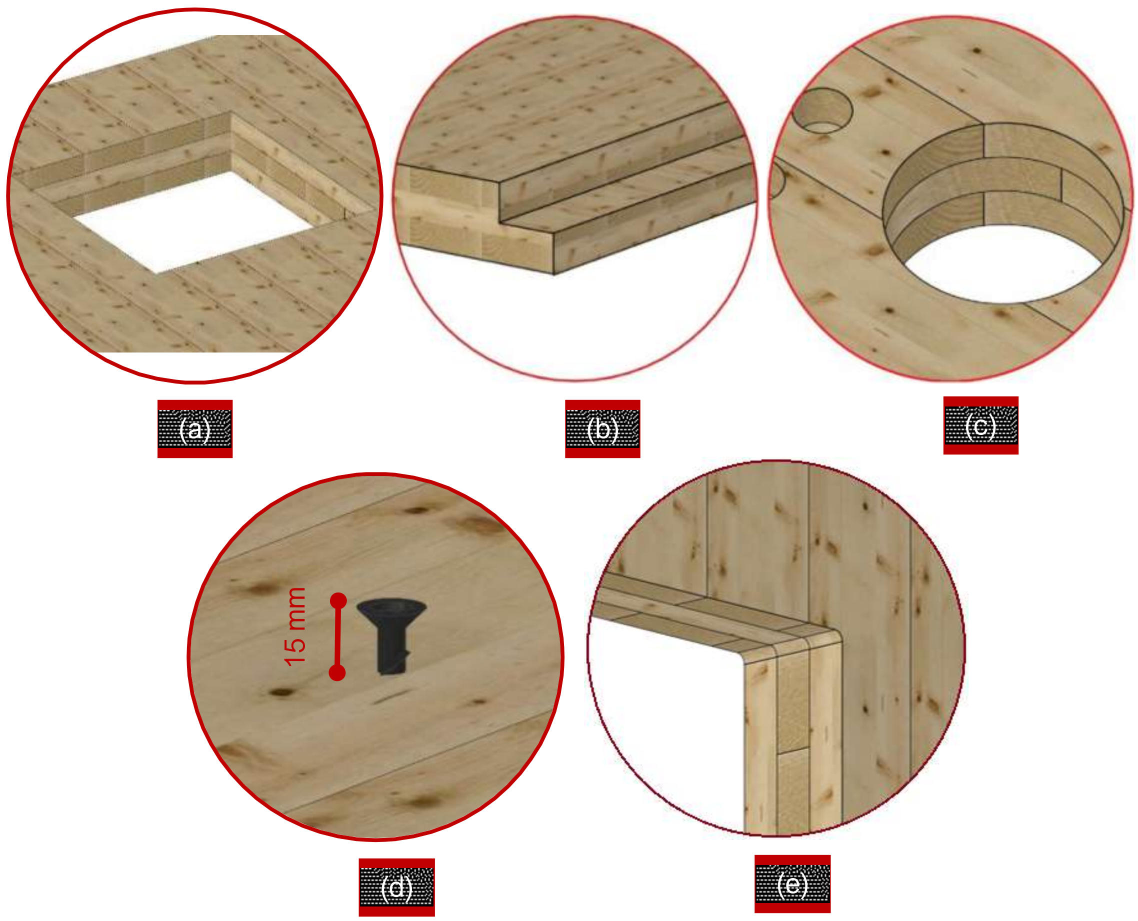


Figure 132: Example of very difficult complexity processing of Red Stag EWP elements; a) Up to three square cut outs (subject to minimum size for tooling); b) Lap/spline joint rebate without flipping or panel removal up to 120 mm wide; c) Up to six simple radii penetrations over and above of basic fixing 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).

31.7 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 133*).

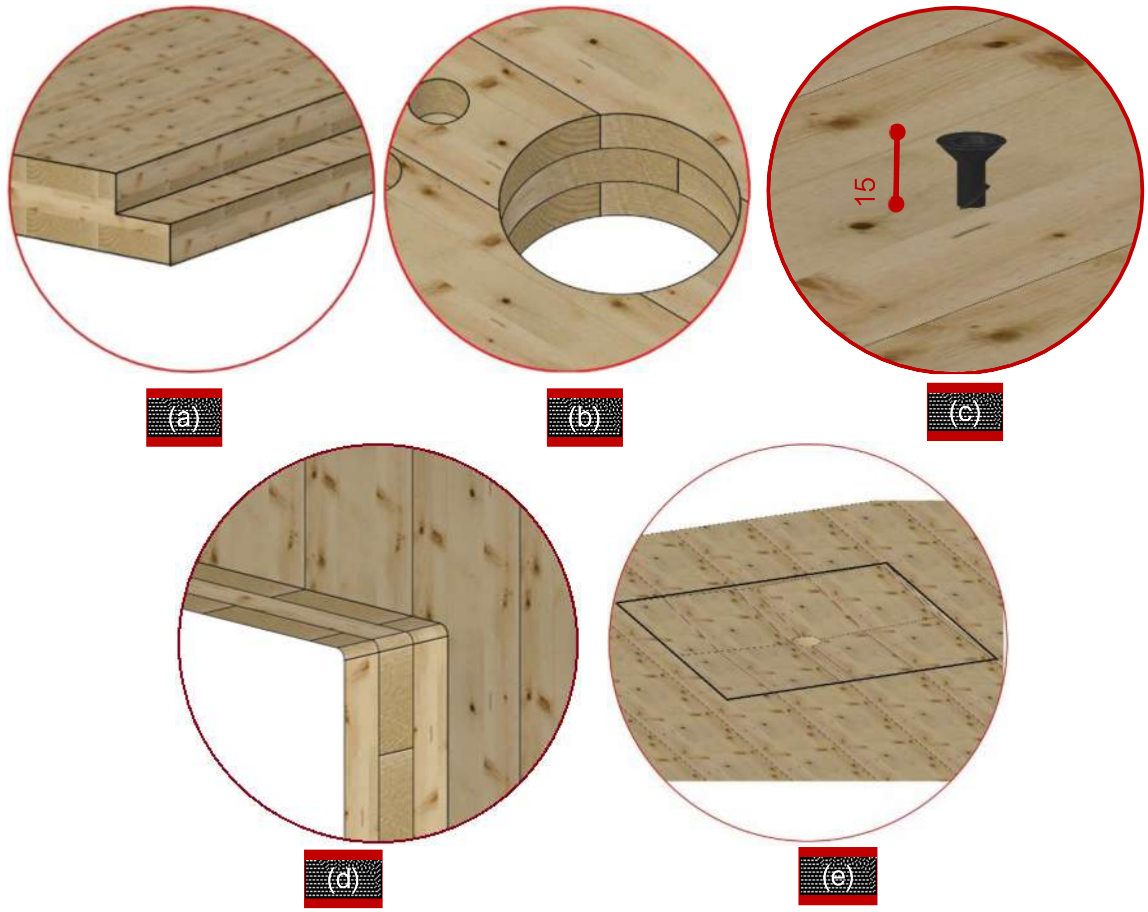


Figure 133: Example of extreme difficultly processing of Red Stag EWP elements; a) Lap/spline joint rebate without flipping or panel removal generally up to 150 mm wide; b) Generally up to eight simple radii penetrations over and above of basic fixing locators; c) Recess for lifting screws; d) Generally up to six openings or two recesses (e.g. doors, windows, trenching) with radii corners or four with square corners subject to tooling restrictions.

31.8 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 134* and *Figure 135*).

Figure 134: Double Spline Joint Plate Connection with two sides CNC process.

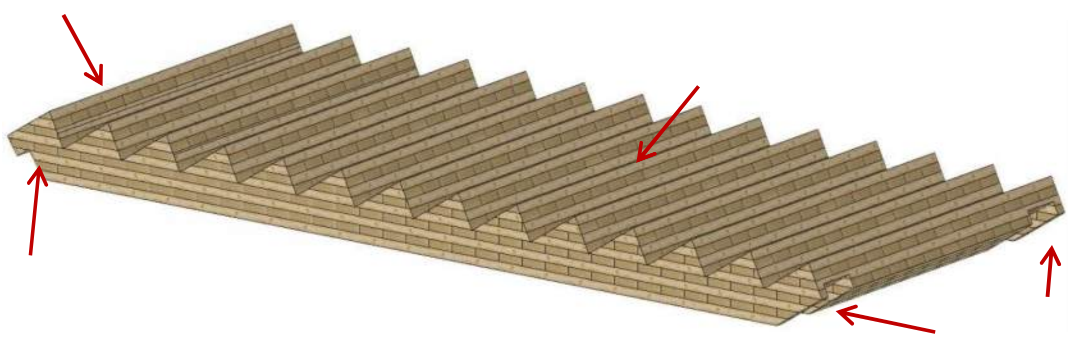


Figure 135: Red Stag CLT Stairs with dual face CNC processing (Very difficult classification).

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 136* and *Figure 137* is 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.

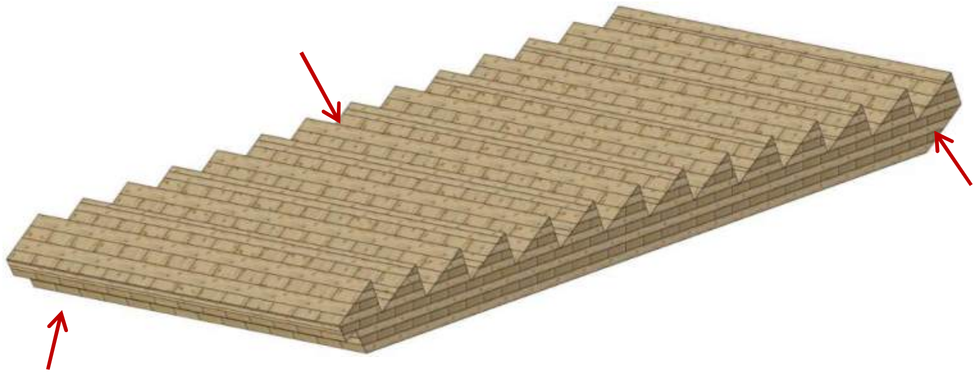


Figure 136: Common Red Stag CLT stairs requiring two face processing.

Figure 137 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.

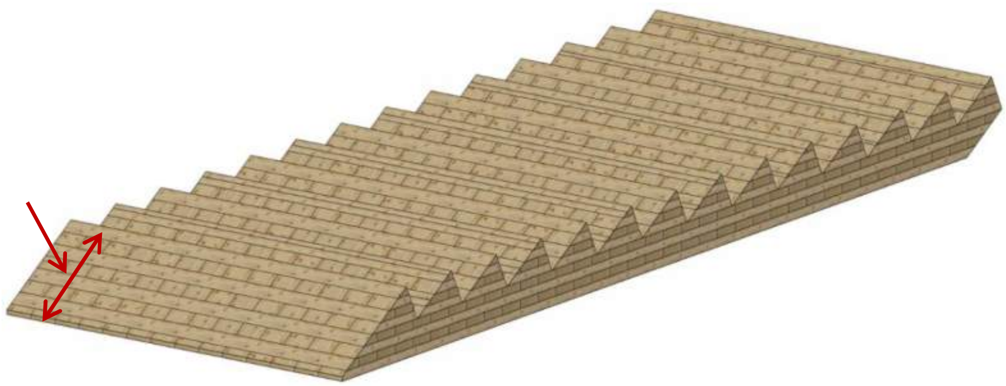
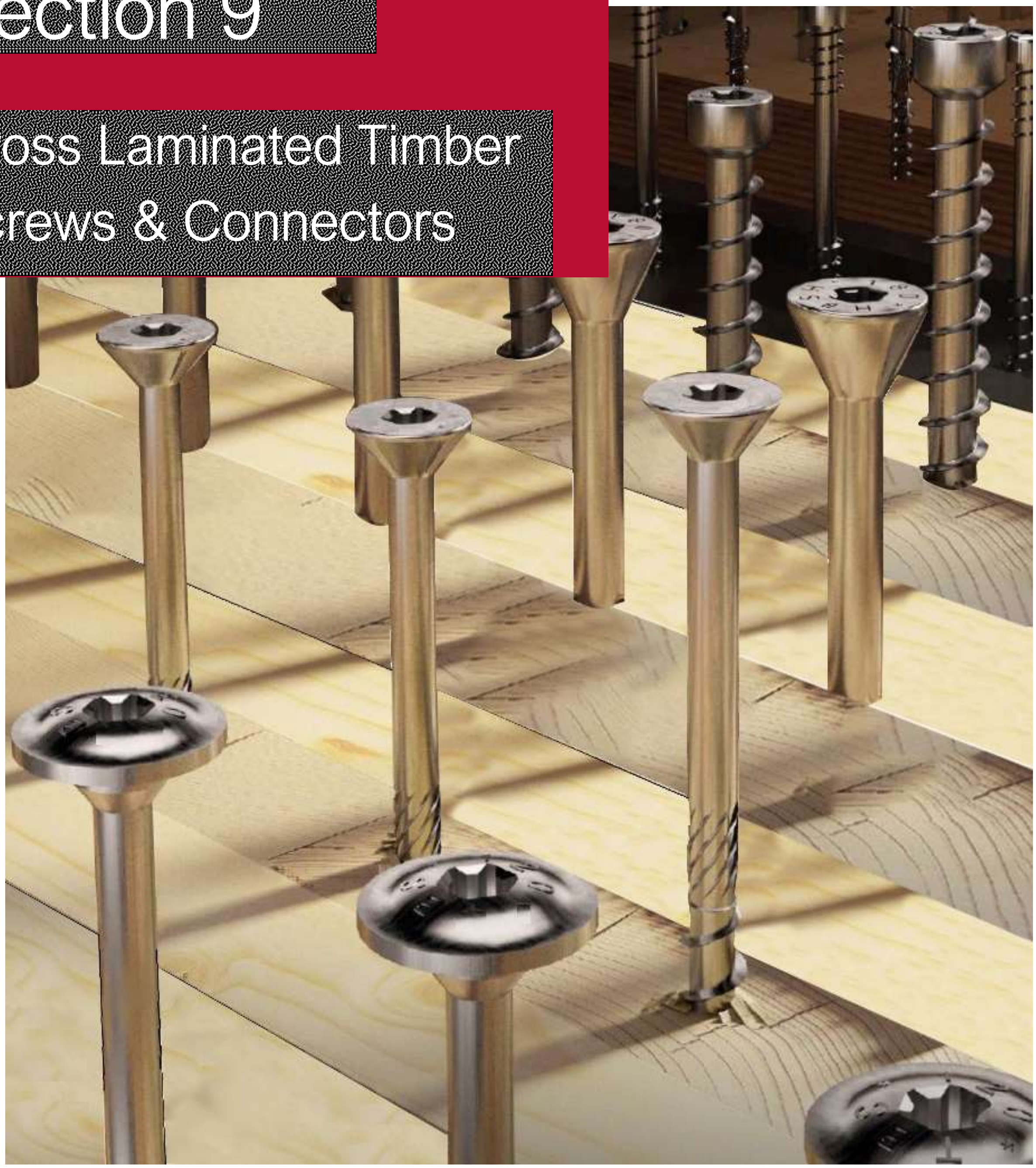


Figure 137: Example of a very difficult Red Stag CLT stair based the extensive mill time.

Section 9

Cross Laminated Timber Screws & Connectors



Red Stag CLT Design Guide V1.5
September 2024

32. 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.

33. 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 138*).

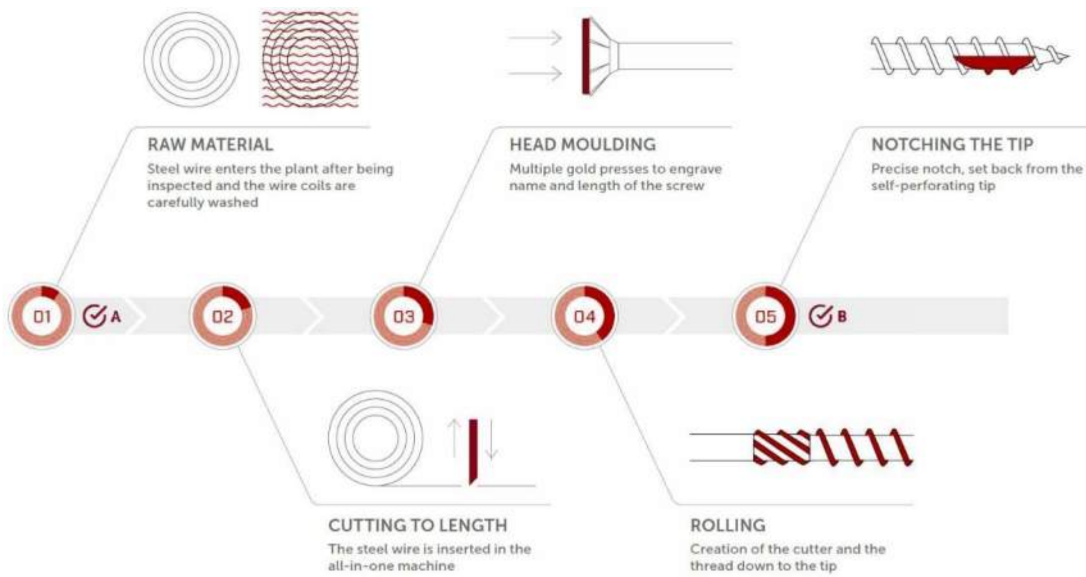


Figure 138: Rothoblaas Production Quality Controls [43].

33.1 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 139*).

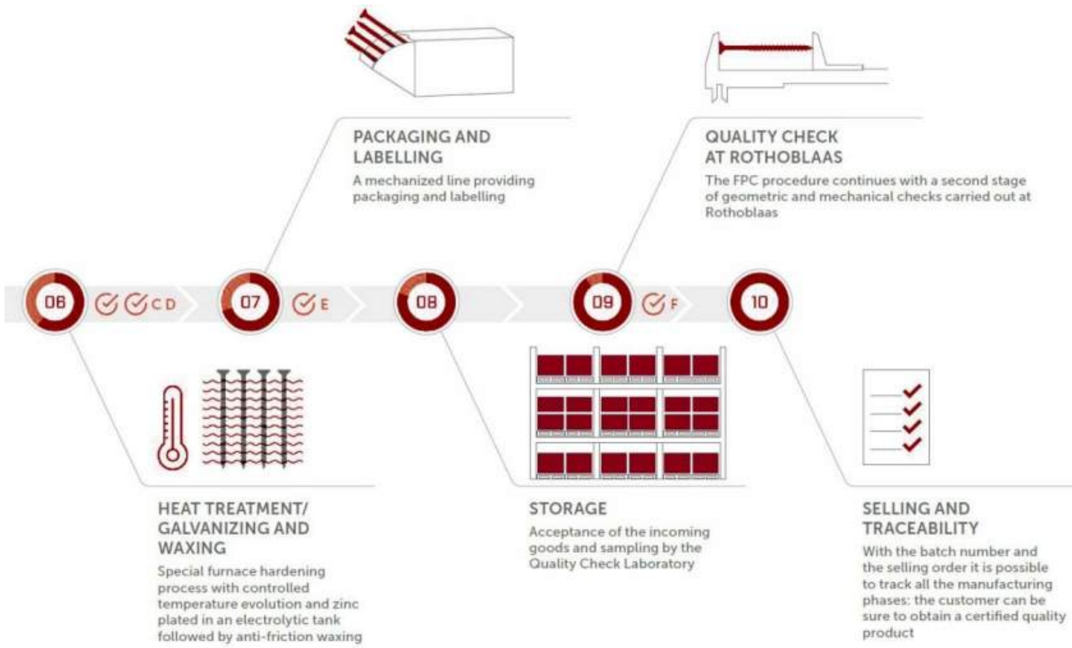


Figure 139: Screw Quality Controls [43].

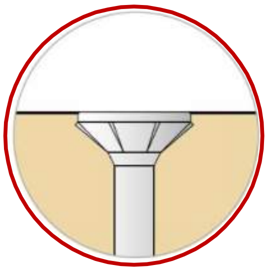
33.1.1 Fixing Control Process

- 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.

34. Screw Specification

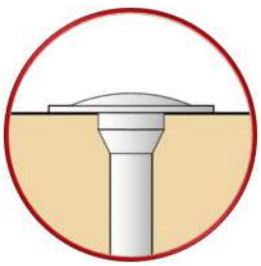
In addition to the dimensions and sizes, screws are technically defined in three main parts: head, thread, and tip [43].

34.1 Heads

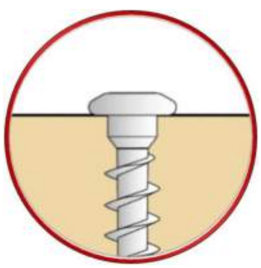


Head Type: Countersunk with ribs.

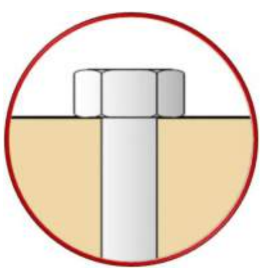
Screw Type: HBS, HBS COIL, HBS EVO, HBS S, HBS S BULK, VGS, SCI A2/A4, SBS, SPP.



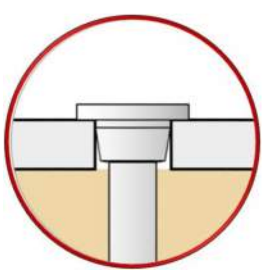
Head Type: Flange.
Screw Type: TBS, TBS MAX, TBS EVO.



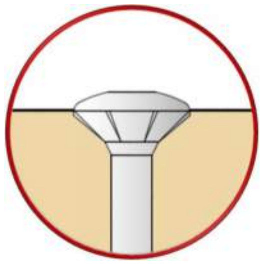
Head Type: Round.
Screw Type: LBS.



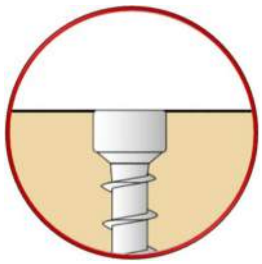
Head Type: Hexagonal.
Screw Type: KOP, SKR, VGS, MTS A2.



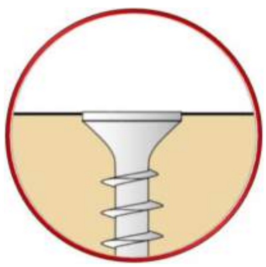
Head Type: Pan Head.
Screw Type: HBS P, HBS P EVO, KKF AISI410.



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

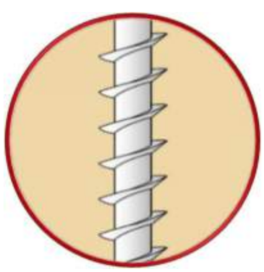


Head Type: Cylindrical.
Screw Type: VGZ, VGZ EVO, VGZ H, DGZ, CTC, MBS, SBD, KKZ A2, KWP A2, KKA AISI410, KKA Colour.

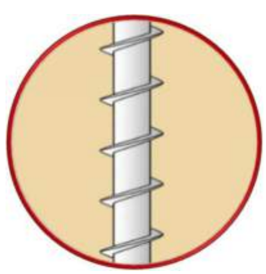


Head Type: Bugle.
Screw Type: DWS, DWS Coli.

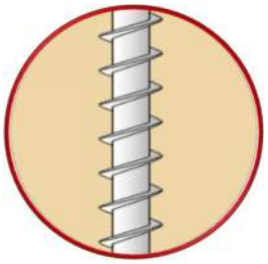
34.2 Thread



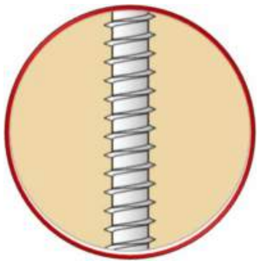
Thread Type: Asymmetric “Umbrella”.
Screw Type: HBS, HBS Coil, HBS S, HBS S Bulk, HBS EVO, HBS P, HBS P EVO, TBS, TBS EVO, SCI A2/A4.



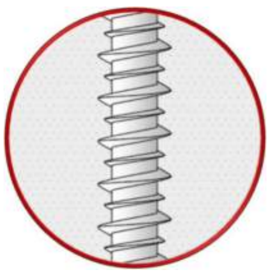
Thread Type: Symmetrical Coarse Thread.
Screw Type: VGZ, VGZ EVO, VGS, SCA A2.



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

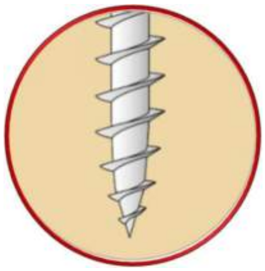


Thread Type: Fine (Metal).
Screw Type: KKA AISI 410, KKA Colour, SBS, SPP, SBS A2, SBN, SBN A2.

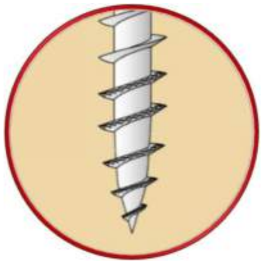


Thread Type: Hi-Low (Concrete).
Screw Type: MBS, SKR, SKS.

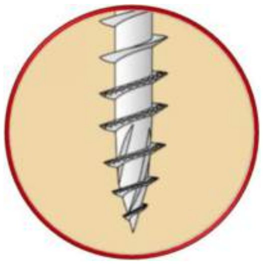
34.3 Tip



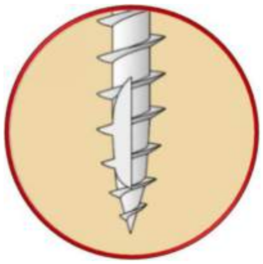
Tip Type: Sharp.
Screw Type: HBS (L ≤ 50 mm), HBS COIL (L ≤ 50 mm), HTS, LBS, DRS, DRT, DWS, DWS Coil, KWP A2, SCA A2, MCS A2.



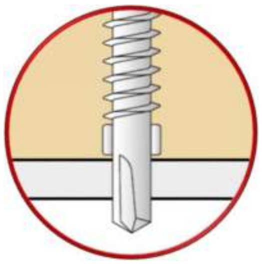
Tip Type: Sharp Saw.
Screw Type: HBS S, HBS S Bulk.



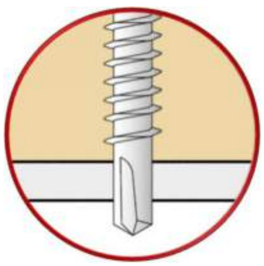
Tip Type: Sharp Saw Nibs.
Screw Type: VGS Ø13.



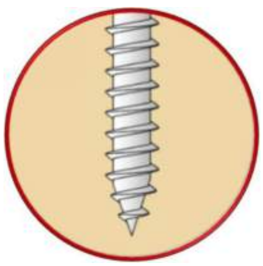
Tip Type: Sharp 1 Cut.
Screw Type: HBS (L > 50 mm), HBS Coil (L > 50 mm), HBS EVO, HBS P, HBS P EVO, TBS, TBS EVO, VGZ, VGZ EVO, VGS, DGZ, CTC, SHS, SHS AISI410,KKT A4 Colour , KKT A4, EWS A2, EWS AISI410, KKF AISI410, SCI A2/A4.



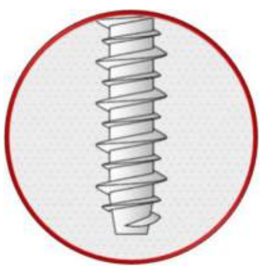
Tip Type: Metal (with Fins).
Screw Type: SBS, SBS A2, SPP.



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.

34.4 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 140*).

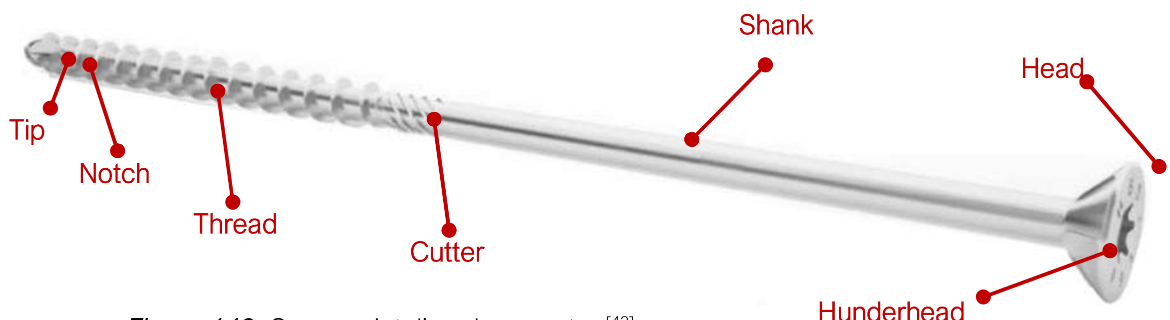


Figure 140: Screws detail and geometry [43].

34.4.1 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.

34.4.2 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.

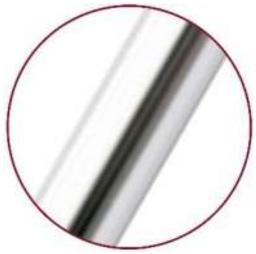
34.4.3 Thread

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.

34.4.4 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.

34.4.5 Shank



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

34.4.6 Underhead

34.4.7 Head

Head geometry defines screw resistance to penetration.

34.5 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 34* to *Table 38* and *Figure 141* summarise the tested values that are certified and calculated for EWP by Rothoblaas.

34.5.1 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

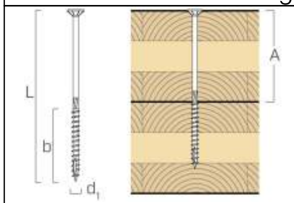
  CLT panels, GLT beams, solid timber, high density timber.

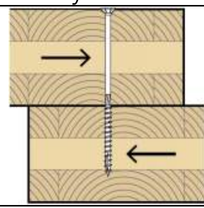
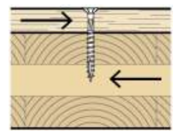
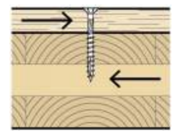
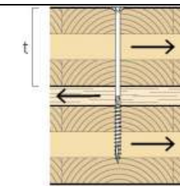
- Dimensional Characteristics

  Diameter from 3.5 mm to 12 mm.

  Length from 30 mm to 600 mm.

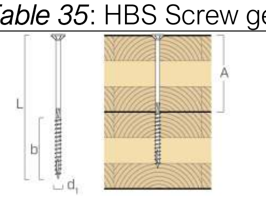
Table 34: HBS Screw geometry and mechanical characteristics [43].

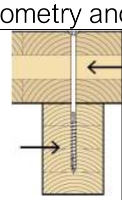
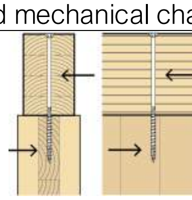
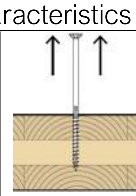
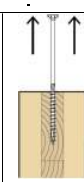
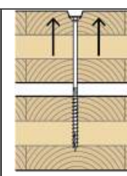
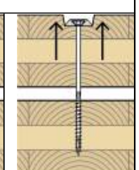


d1 mm	L mm	b mm	A mm	R_{vk} kN	R_{vk} kN		R_{vk} kN		t mm	R_{vk} kN
8	80	52	28	2.42	1.84	Span = 18 mm	2.30	Span = 18 mm	-	-
	100	52	48	3.04	2.13		2.30		40	2.92
	120	60	60	3.11	2.26		2.30		50	2.92
	140	60	80	3.11	2.26		2.30		60	2.92
	160	80	80	3.11	2.58		2.30		70	2.92
	180	80	100	3.11	2.58		2.30		80	2.92
	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

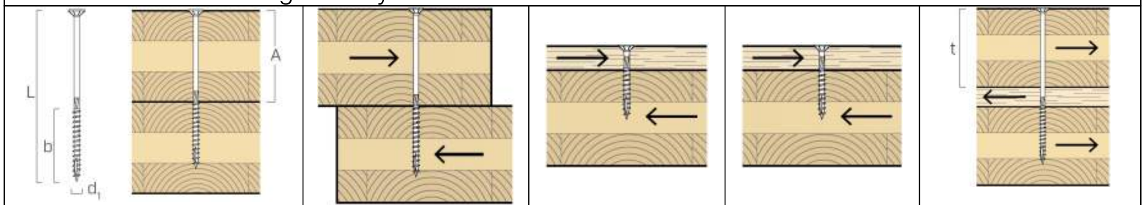
Table 35: HBS Screw geometry and mechanical characteristics [43].



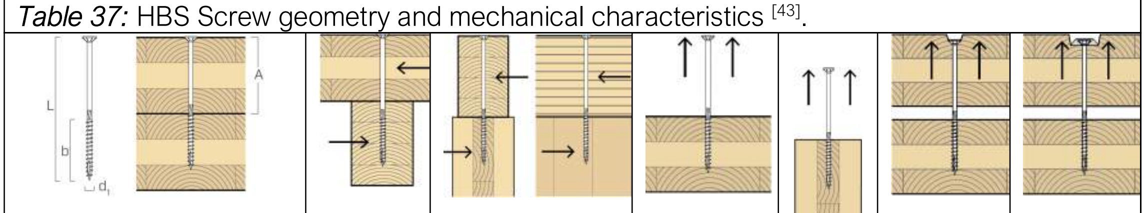
d1 mm	L mm	b mm	A mm	$R_{v,k}$ kN	$R_{v,k}$ kN	$R_{ax,k}$ kN	$R_{ax,k}$ kN	$R_{head,k}$ kN	$R_{head,k}$ kN
8	80	52	28	2.51	2.19	4.87	3.70	2.21	6.56
	100	52	48	3.17	2.19	4.87	3.70	2.21	6.56
	120	60	60	3.17	2.32	5.62	4.21	2.21	6.56
	140	60	80	3.17	2.32	5.62	4.21	2.21	6.56
	160	80	80	3.17	2.66	7.49	5.45	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 36: HBS Screw geometry and mechanical characteristics [43].



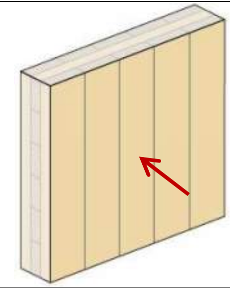
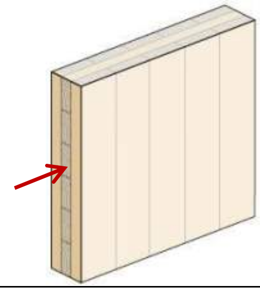
d1 mm	L mm	b mm	A mm	Rvk kN	Rvk kN		Rvk kN		t mm	Rvk kN
10	80	52	28	3.40	2.34	Span = 22 mm	3.31	Span = 22 mm	-	-
	100	52	48	3.86	2.91		3.31		-	-
	120	60	60	4.45	3.03		3.31		50	3.89
	140	60	80	4.49	3.03		3.31		60	3.89
	160	80	80	4.56	3.37		3.31		70	3.89
	180	80	100	4.56	3.37		3.31		80	3.89
	200	80	120	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

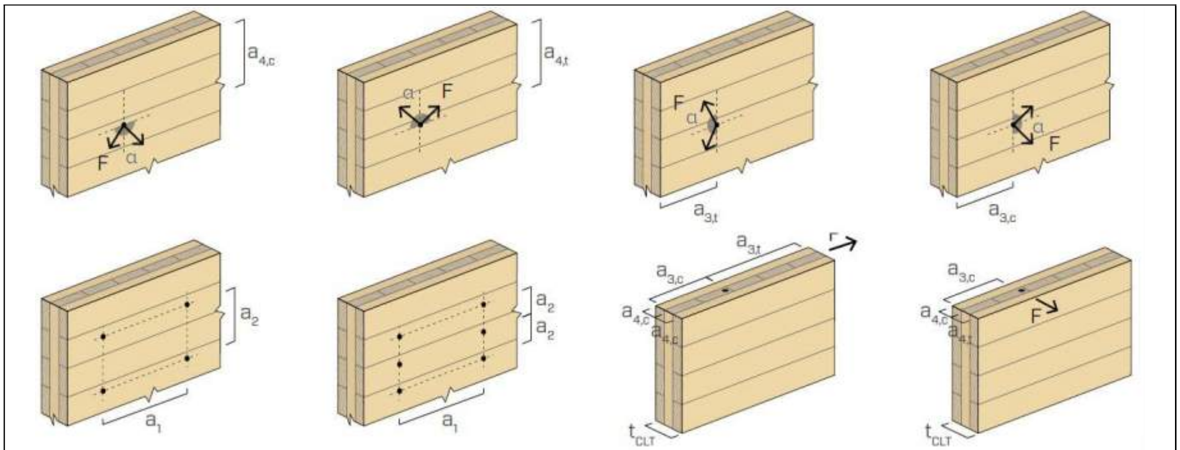
Table 37: HBS Screw geometry and mechanical characteristics [43].



d1 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
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 38: 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 141: Minimum distance and spacing of HBS screws for shear and axial loads in EWP [43].

34.5.2 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 142* and *Table 39*.

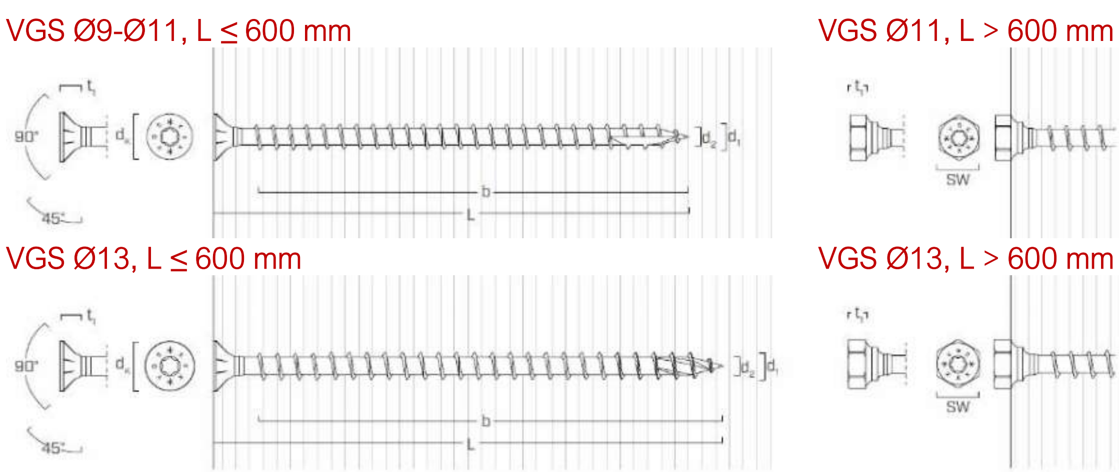


Figure 142: VGS Screw detail and geometry [43].

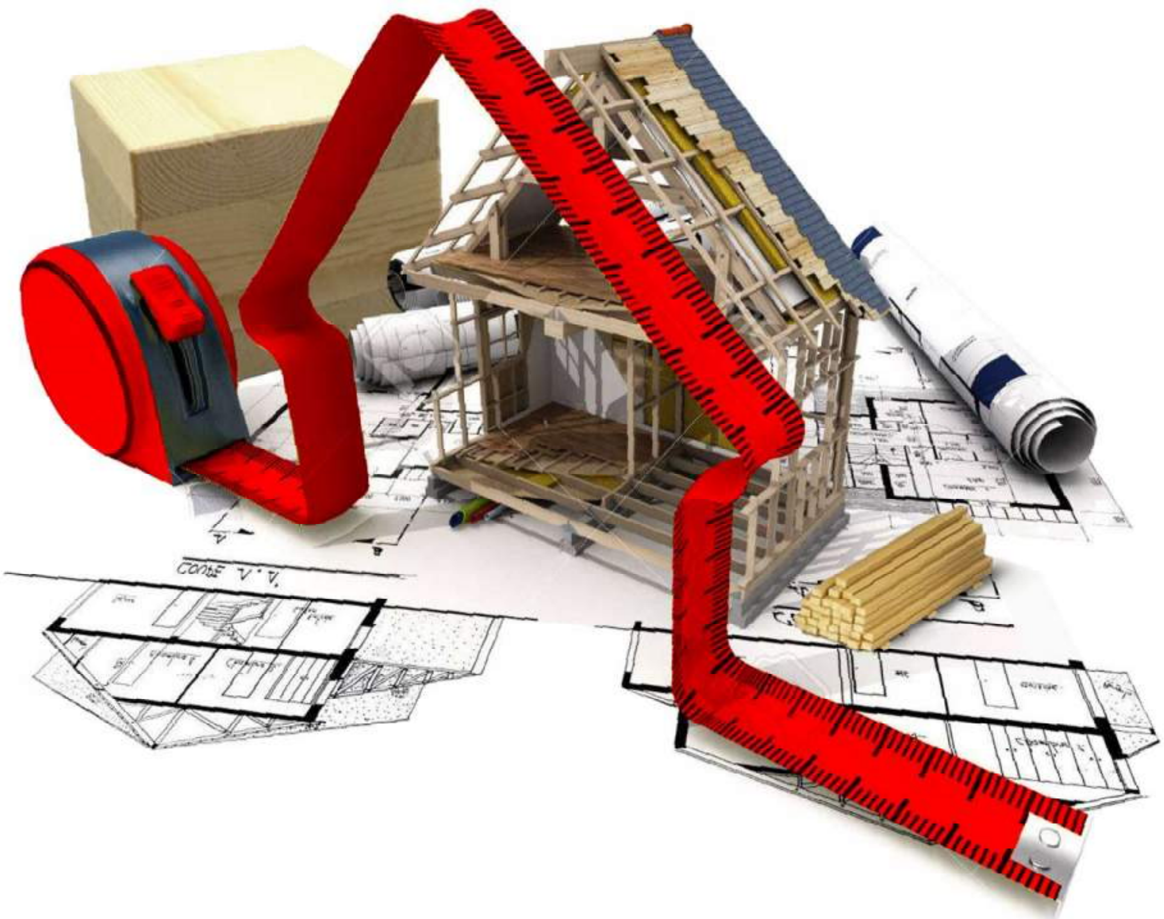
Table 39: VGS Screw geometry and mechanical characteristics [43].

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 Examples



Red Stag CLT Design Guide V1.5
September 2024

35. 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 40*). 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 40: 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.

36.1 CLT Floor Panel Design – Longitudinal Direction

Calculation of the Red Stag CLT floor members is based on the FPInnovation CLT design guide Shear Analogy (KREUZINGER) method.

Figure 143: Red Stag CLT Panel Symmetrical Cross-Section

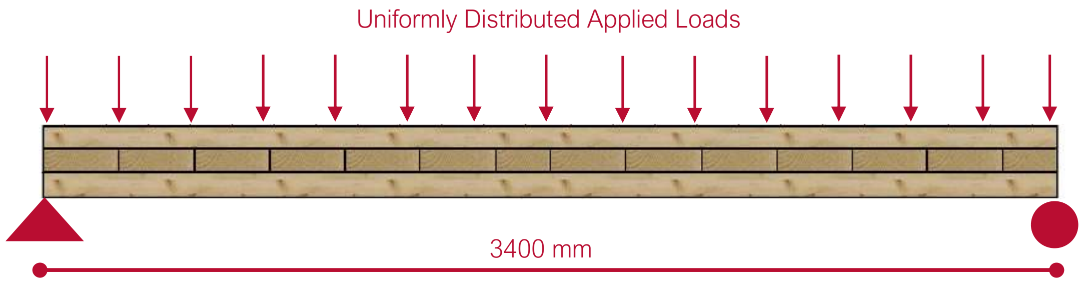


Figure 144: Simply Supported Red Stag CLT Floor Panel Elevation

36.2 Assumption, Applied Loads, and Material Factors

Strength Reduction Factor (Ø) = 0.8

Moisture Factor (k_{12}) = 1

Creep Factor (k_2) = 2

Timber Density (ρ) = 500 kg/m^3

Super Dead Load (SDL) = 0.5 kPa

Live Load (LL) = 2.0 kPa

Ratio of Shear and Rolling Shear Modulus = 10

Ratio of Parallel to Grain and Shear Modulus = 16

36.3 Calculation Based on Shear Analogy (KREUZINGER)

L = Span of panels = 3440 mm

Thickness of laminations (t) = $\begin{bmatrix} 42 \\ 20 \\ 42 \end{bmatrix}$ mm

Elastic modulus of laminations (E) = $\begin{bmatrix} 8000 \\ 6000 \\ 8000 \end{bmatrix}$ MPa

Orientation of laminations (Parallel = 1 or Perpendicular =2) = $\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$

Effective Width

Longitudinal stiffiness of panel

$BI_L \sim B_0 = (744.576 \text{ X } 10^9) \frac{N.mm^2}{m}$

Transverse stiffiness of panel

$BI_T \sim B_0 = (4 \text{ X } 10^9) \frac{N.mm^2}{m}$

Effective width

$B = \min\left(\frac{L}{1.1} \text{ X } \sqrt[4]{\frac{EI_T \sim B_0}{EI_L \sim B_0}}, 1m\right) = 0.837 \text{ m}$

Effective EI:

$EI_{eff} = (6.231 \text{ x } 10^{11}) \text{ N.mm}^2$

Effective GA:

$GA_{eff} = (5.21 \text{ x } 10^6)$

Loading:

Superimposed deadload (worst-case) G_{sdl} = 0.5 kPa

Dead load:

G = 1.01 kPa

Live Load: G= 1.01 kPa

Uniformly distributed load Qu:= 2 kPa
Long term coefficient ψlu:= 0.4

Point load Qc:= 1.8 kN
Long term coefficient ψlc:= 0.6

Deflection

Deflection limit, C1 (for L/C1) C1= 300

Total deformation:

Uniform load deformation $\Delta_u = \Delta_f + \Delta_s$ = 4.776 mm

Concentrated load deformation $\Delta_c = \Delta_{f\_p} + \Delta_{s\_p}$ = 4.314 mm

Short-term $\Delta = \max(\Delta_u, \Delta_c)$ = 4.776 mm

Long-term $\Delta_l = k_2 \cdot \Delta$ = 9.552 mm

Allowable deflection ratio DR= 0.843 CHK= "OK"

Equivalent Flexural Stiffness (for UDL cases only, used for FPI vibration)

Elapp = $\frac{5 \times (W_G + W_{\psi lQ}) \times L^4}{384 \times \Delta_u}$ = (5.518×10^{11}) N.mm^2

NB: Takes into account flexural and shear deformation.

ULS Design Actions

Uniformly distributed loads $Wu_G = \begin{bmatrix} 1.35\ W_G \\ 1.2\ W_G \end{bmatrix}$ $Wu_Q = \begin{bmatrix} 0 \\ 1.5\ W_Q \end{bmatrix}$

Uniformly distributed loads $Pu = \begin{bmatrix} 0 \\ 1.5\ Q_C \end{bmatrix}$

Maximum Moment

$Mu = \begin{bmatrix} 1.649 \\ 5.093 \end{bmatrix}$ kN.m

Maximum Shear

$Vu = \begin{bmatrix} 1.94 \\ 5.993 \end{bmatrix}$ kN

Strength

Bending strength f_b = 14 MPa

Rolling shear strength f_r =1.2 MPa

Load duration factors $k1 = \begin{bmatrix} 0.6 \\ 0.8 \end{bmatrix}$

Moment Capacity

$\phi M_n = \phi \times k_{12} \times k_1 \times f_b \times 0.85 \times Ze = \begin{bmatrix} 8.555 \\ 11.407 \end{bmatrix}$ kN.m

Shear Capacity

$\phi V_n = \phi \times k_{12} \times k_1 \times f_R \times As_{eff} = \begin{bmatrix} 45.455 \\ 45.94 \end{bmatrix}$ kN

Strength Utilization

$SU_1 = \frac{M_u}{\phi M_n} = \begin{bmatrix} 0.193 \\ 0.447 \end{bmatrix}$ $SU_2 = \frac{V_u}{\phi V_n} = \begin{bmatrix} 0.056 \\ 0.13 \end{bmatrix}$

$CHK_1 = \begin{bmatrix} "OK" \\ "OK" \end{bmatrix}$ $CHK_2 = \begin{bmatrix} "OK" \\ "OK" \end{bmatrix}$

Strength Utilization

Frequency limit	$f_{lim} = 6\ s^{-1}$
Concentrated live load	$Q_{cv} = 1$ kN
Deflection limit under concentrated live load	$\Delta_{lim} = 1.5$ mm
Proportion of uniformly distributed live load	$C_Q = 0.1$

Uniformly distributed load

$Wv = W_G + C_Q \times W_Q = 1.013\ \frac{kN}{m}$

Frequency

$f_1 = \frac{\pi}{2 \times L^2} X \sqrt{\frac{EI_{app}}{(\frac{W_v}{g})}} = 9.933\ \frac{1}{s}$ CHK= "OK"

Deflection under point load

$\Delta_v = Q_{cv} \times (\frac{L^3}{48 \times EI_{eff}} + \frac{L}{4 \times GA_{eff}}) = 1.477$ mm

Additional Vibration Checks

FPInnovations (2019):

Effective EI per meter (apparent EI used conservatively):

$EI_{eff\ 1m} = \frac{EI_{eff}}{B} = 7.446 \times 105$ N.m

Span limit

$L_{limit} = 0.11 \times \frac{(\frac{EI_{eff\ 1m}}{N.m})^{0.29}}{(\frac{\rho}{(\frac{kg}{m^3})} \times 1 \times \frac{tt}{m})^{0.12}} \times m$ =3.454 m

CHK = if L ≤ L_{limit} CHK= “OK”

Calculation of the Red Stag CLT roof members is based on the FPInnovation CLT design guide Shear Analogy (KREUZINGER) method.

37.1 CLT Floor Panel Design – Longitudinal Direction

Calculation of the Red Stag CLT floor members is based on the FPInnovation CLT design guide Shear Analogy (KREUZINGER) method.

Figure 145: Red Stag CLT Panel Symmetrical Cross-Section

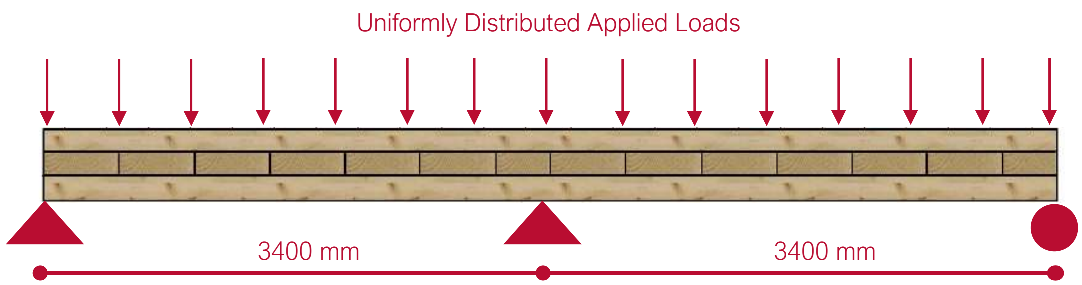


Figure 146: Red Stag CLT Panel Elevation

37.2 Assumption and Applied Loads and Material Factors

Strength Reduction Factor (Ø) = 0.8

Moisture Factor (k_{12}) = 1

Creep Factor (k_2) = 2

Timber Density (ρ) = 500 kg/m^3

Super Dead Load = 0.5 kPa

Live Load = 2.0 kPa

Ratio of Shear and Rolling Shear Modulus = 10

Ratio of Parallel to Grain and Shear Modulus = 16

37.3 Calculation Based on Shear Analogy (KREUSINGER)

L = Span of panels = 3400 mm

Thickness of laminations (t) = $\begin{bmatrix}42\\20\\42\end{bmatrix}$ mm

Elastic modulus of laminations (E) = $\begin{bmatrix}8000\\6000\\8000\end{bmatrix}$ MPa

Orientation of laminations (Parallel = 1 or Perpendicular =2) = $\begin{bmatrix}1\\2\\1\end{bmatrix}$

Effective Width

Longitudinal stiffiness of panel

$BI_L \sim B_0 = (744.576 \text{ X } 10^9)\ \frac{N.mm^2}{m}$

Transverse stiffness of panel

$BI_T \sim B_0 = (4 \text{ X } 10^9)\ \frac{N.mm^2}{m}$

Effective width

$B = \min\left(\frac{L}{1.1} \text{ X } \sqrt[4]{\frac{EI_T \sim B_0}{EI_L \sim B_0}}, 1\text{m}\right) = 0.837 \text{ m}$

Effective EI:

$EI_{eff} = (6.231 \text{ x } 10^{11}) \text{ N.mm}^2$

Effective GA:

$GA_{eff} = (5.21 \text{ x } 10^6)$

Loading:

Superimposed deadload (worst-case) G_{sdl} = 0.5 kPa

Dead load:

G = 1.01 kPa

Live Load: G= 1.01 kPa

Uniformly distributed load Qu:= 2 kPa
Long term coefficient ψlu:= 0.4

Point load
Qc:= 1.8 kN

Long term coefficient ψlc:= 0.6

Deflection

Deflection limit, C1 (for L/C1) C1= 300

Total deformation:

Uniform load deformation $\Delta_u = \Delta_f + \Delta_s$ = 2.843 mm

Concentrated load deformation $\Delta_c = \Delta_{f\_p} + \Delta_{s\_p}$ = 2.531 mm

Short-term $\Delta = \max(\Delta_u, \Delta_c)$ = 2.843 mm

Long-term $\Delta_l = k_2 \cdot \Delta$ = 5.687 mm

Allowable deflection ratio DR= 0.502 CHK= “OK”

Equivalent Flexural Stiffness (for UDL cases only, used for FPI vibration)

$E_{Iapp} = \frac{W_G \times L^4}{185} + \frac{W_{\psi lQ} \times L^4}{109} \times \frac{1}{\Delta_u}$ = (5.034 x 10^{11}) N.mm^2

NB: Takes into account flexural and shear deformation.

ULS Design Actions

Uniformly distributed loads $W_{uG} = \begin{bmatrix} 1.35\, W_G \\ 1.2\, W_G \end{bmatrix}$ $W_{uQ} = \begin{bmatrix} 0 \\ 1.5\, W_Q \end{bmatrix}$

Uniformly distributed loads $P_u = \begin{bmatrix} 0 \\ 1.5\, Q_C \end{bmatrix}$

Maximum Moment

$M_u = \begin{bmatrix} 1.649 \\ 5.093 \end{bmatrix}$ kN.m

Maximum Shear

$V_u = \begin{bmatrix} 1.94 \\ 5.993 \end{bmatrix}$ kN

Strength

Bending strength f_b = 14 MPa

Rolling shear strength $f_r = 1.2$ MPa

Load duration factors $k1 = \begin{bmatrix} 0.6 \\ 0.8 \end{bmatrix}$

Moment Capacity

$\phi M_n = \phi \times k_{12} \times k_1 \times f_b \times 0.85 \times Ze = \begin{bmatrix} 8.555 \\ 11.407 \end{bmatrix}$ kN.m

Shear Capacity

$\phi V_n = \phi \times k_{12} \times k_1 \times f_R \times As_{eff} = \begin{bmatrix} 34.455 \\ 45.94 \end{bmatrix}$ kN

Strength Utilization

$SU_1 = \frac{M_u}{\phi M_n} = \begin{bmatrix} 0.193 \\ 0.447 \end{bmatrix}$ $SU_2 = \frac{V_u}{\phi V_n} = \begin{bmatrix} 0.056 \\ 0.13 \end{bmatrix}$

$CHK_1 = \begin{bmatrix} "OK" \\ "OK" \end{bmatrix}$ $CHK_2 = \begin{bmatrix} "OK" \\ "OK" \end{bmatrix}$

Strength Utilization

Frequency limit	$f_{lim} = 6\ s^{-1}$
Concentrated live load	$Q_{cv} = 1$ kN
Deflection limit under concentrated live load	$\Delta_{lim} = 1.5$ mm
Proportion of uniformly distributed live load	$C_Q = 0.1$

Uniformly distributed load

$Wv = W_G + C_Q \times W_Q = 1.013\ \frac{kN}{m}$

Frequency

$f_1 = \frac{\pi}{2 \times L^2} \times \sqrt{\frac{EI_{app}}{(\frac{W_v}{g})}} = 9.933\ \frac{1}{s}$ CHK= "OK"

Deflection under point load

$\Delta_v = Q_{cv} \times (\frac{L^3}{48 \times EI_{eff}} + \frac{L}{4 \times GA_{eff}}) = 1.477$ mm

Additional Vibration Checks

FPInnovations (2019):

Effective EI per meter (apparent EI used conservatively):

$EI_{eff\ 1m} = \frac{EI_{eff}}{B}$ = 7.446 × 105 N.m

Span limit

$L_{limit} = 0.11 \times \frac{(\frac{EI_{eff\ 1m}}{N.m})^{0.29}}{(\frac{\rho}{\left(\frac{kg}{m^3}\right)} \times 1 \times \frac{tt}{m})^{0.12}} \times m$ =3.454 m

CHK = if L ≤ L_{limit} CHK= “OK”

38.1 Cantilever CLT Roof Panel Design – Longitudinal Direction

Calculation of the cantilever Red Stag CLT roof members is based on the FPInnovation CLT design guide Shear Analogy (KREUZINGER) method.

Figure 147: Red Stag CLT Panel Symmetrical Cross-Section

Figure 148: Cantilever Red Stag CLT Roof Panel Elevation

Considers backspan with no live or superimposed dead load.

Backspan adopts maximum span achievable under simple support assessment.

38.2 Assumption, Applied Loads, and Material Factors

Strength Reduction Factor (Ø) = 0.8

Moisture Factor(k_{12}) = 1

Creep Factor(k_2) = 2

Timber Density (ρ) = 500 kg/m^3

Super Dead Load (SDL) = 0.5 kPa

Live Load (LL) = 2.0 kPa

Ratio of Shear and Rolling Shear Modulus = 10

Ratio of Parallel to Grain and Shear Modulus = 16

38.3 Calculation Based on Shear Analogy (KREUZINGER)

Backspan = 4300 mm = 4.30 m

Cantilever Span = 900 mm = 0.90 m

Thickness of laminations (t) = $\begin{bmatrix} 42 \\ 20 \\ 42 \end{bmatrix}$ mm

Elastic modulus of laminations (E) = $\begin{bmatrix} 8000 \\ 6000 \\ 8000 \end{bmatrix}$ MPa

Orientation of laminations (Parallel = 1 or Perpendicular =2) = $\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$

Effective Width

Effective width

B = min ($\frac{L}{1.1}$ X $\sqrt[4]{\frac{EI_T{\sim}B_0}{EI_L{\sim}B_0}}$, 1m) = 0.9 m

Effective EI:

EI_{eff} = (6.701 x 10^{11}) N.mm^2

Effective GA:

GA_{eff} = (5.60 x 10^6)

Loading:

Superimposed deadload (worst-case) G_{sdl} = 0.25 kPa

Dead load:

G = 0.76 kPa

Uniformly distributed load Qu:= 0.25 kPa
Long term coefficient ψlu:= 0

Point load Qc:= 1.4 kN
Long term coefficient ψlc:= 0

Wind Load:

ULS design wind pessure G_{fig} = 1 $P_{des.Cfig1.ULS}$ = 1.82 kPa

SLS design wind pessure G_{fig} = 1 $P_{des.Cfig1.SLS}$ = 0.75 × $P_{des.Cfig1.SLS}$ = 1.365 kPa

Load pressure factor $K_l = 2$

Downward $G_{fig.down}$= K1×0.6+0.3=1.5 Upward $G_{fig.up}$= K1-1.3-0.7= -3.3

Snow Load:

S_u = 0.9 kPa

Deflection

Deflection limit, C1 (for L/C1) C1= 200

Case 1: Deformation with backspan (UDL Live Load)

Total deformation:

Short term $\Delta_1 = \Delta_{f1} + \Delta_{s1}$ = -2. 362 mm

Long term $\Delta_{1l} = k_2\, \Delta_1$= -4.725 mm

Allowable deflection ratio DR1= 1.05 CHK= “OK”

Case 2: Deformation with backspan (Concentrated Live Load)Total deformation with backspan (concentrated LL):

Short-term $\Delta_2 = \Delta_{f2} + \Delta_{s\,p}$ = -2.362 mm

Long-term $\Delta_{2l} = k_2 \cdot \Delta_2$ = -4.725 mm

Allowable deflection ratio DR2= 1.05 CHK= “OK”

Case 3: Deformation with backspan (UDL Live Load)

Total deformation with backspan:

Short-term $\Delta_3 = \Delta_{f3} + \Delta_{s3}$ = -2.362 mm

Long-term $\Delta_{3l} = k_2 \cdot \Delta_3$ = -4.725 mm

Allowable deflection ratio DR3= 0.066 CHK= “OK”

Case 4: Deformation without backspan (Concentrated Live Load)

Total deformation without backspan:

Short-term $\Delta_4 = \Delta_{f4} + \Delta_{s\,p4}$ = 0.148 mm

Long-term $\Delta_{4l} = k_2 \cdot \Delta_4$ = 0.296 mm

Allowable deflection ratio DR4= 0.066 CHK= “OK”

Deflection limit, C2 (for L/C2) C2= 200

Total deformation $\Delta_{u\,w} = \Delta_{f\,w} + \Delta_{s\,w}$ = 4.008 mm

Allowable deflection ratio DR_W= 0.891 CHK= “OK”

ULS Design Actions

Uniformly distributed loads

$$Wu_G = \begin{bmatrix} 1.35\ W_G \\ 1.2\ W_G \\ 0.9\ W_G \\ 1.2\ W_G \\ 1.2\ W_G \end{bmatrix} \qquad Wu_Q = \begin{bmatrix} 0 \\ 1.5\ W_Q \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$Wu_w = \begin{bmatrix} 0 \\ 0 \\ W_{W.ULS.up} \\ W_{W.ULS.down} \\ 0 \end{bmatrix} \qquad Wu_Q = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ W_{Snow} \end{bmatrix}$$

Uniformly distributed loads

$$Pu = \begin{bmatrix} 0 \\ 1.5\ Q_C \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Maximum Moment

$$Mu = \begin{bmatrix} 0.374 \\ 2.222 \\ 0.249 \\ 0.332 \\ 0.332 \end{bmatrix} \text{ kN.m}$$

Maximum Shear

$$Vu = \begin{bmatrix} 0.831 \\ 2.839 \\ 0.554 \\ 0.739 \\ 0.739 \end{bmatrix} \text{ kN}$$

Strength

Bending strength $f_b = 14$ MPa

Rolling shear strength $f_r = 1.2$ MPa

Load duration factors

$$k1 = \begin{bmatrix} 0.6 \\ 1 \\ 1 \\ 1 \\ 1` \end{bmatrix}$$

Moment Capacity

$$\phi M_n = \phi \times k_{12} \times k_1 \times f_b \times 0.85 \times Ze = \begin{bmatrix} 8.555 \\ 11.407 \end{bmatrix} \text{ kN.m}$$

Shear Capacity

$$\phi V_n = \phi \times k_{12} \times k_1 \times f_R \times As_{eff} = \begin{bmatrix} 45.455 \\ 45.94 \end{bmatrix} \text{ kN}$$

Strength Utilization

$$SU_1 = \frac{M_u}{\phi M_n} = \begin{bmatrix} 0.041 \\ 0.145 \\ 0.016 \\ 0.022 \\ 0.022 \end{bmatrix} \qquad SU_2 = \frac{V_u}{\phi V_n} = \begin{bmatrix} 0.022 \\ 0.046 \\ 0.009 \\ 0.012 \\ 0.012 \end{bmatrix}$$

$$CHK_1 = \begin{bmatrix} \text{"OK"} \\ \text{"OK"} \\ \text{"OK"} \\ \text{"OK"} \\ \text{"OK"} \end{bmatrix} \qquad CHK_2 = \begin{bmatrix} \text{"OK"} \\ \text{"OK"} \\ \text{"OK"} \\ \text{"OK"} \\ \text{"OK"} \end{bmatrix}$$

Vibration

Concentrated live load Q_{cv} = 1 Kn

Deflection limit under concentrated live load Δ_{lim} = 1 mm

Deflection under point load

$\Delta_v = Q_{cv} \times (\frac{L^3}{3 \times EI_{eff}} + \frac{L}{GA_{eff}})$ = 0.523 mm CHK= "OK"

39.1 CLT Stair Design – Longitudinal Direction

Calculation of the Red Stag CLT stair members is based on the FPInnovation CLT design guide Shear Analogy (KREUZINGER) method.

.

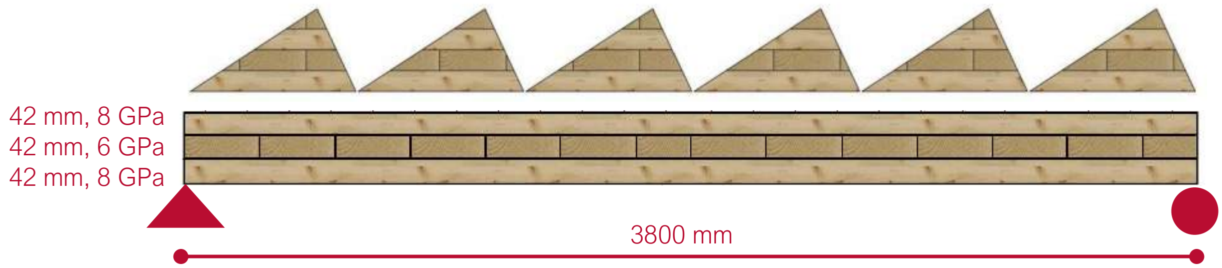


Figure 149: Red Stag CLT Panel Elevation

39.2 Assumption, Applied Loads, and Material Factors

Strength Reduction Factor (Ø) = 0.8

Moisture Factor(k_{12}) = 1

Creep Factor(k_2) = 2

Timber Density (ρ) = 500 kg/m^3

Super Dead Load (SDL) = 0.5 kPa

Live Load (LL) = 2.0 kPa

Ratio of Shear and Rolling Shear Modulus = 10

Ratio of Parallel to Grain and Shear Modulus = 16

39.3 Calculation Based on Shear Analogy (KREUZINGER)

L = Span of panels = 3800 mm

Stair angle = 37 °

Tributary with of panel = 900 mm

Rise = 190 mm

Thickness of laminations (t) = $\begin{bmatrix} 42 \\ 42 \\ 42 \end{bmatrix}$ mm

Elastic modulus of laminations (E) = $\begin{bmatrix} 8000 \\ 6000 \\ 8000 \end{bmatrix}$ MPa

Orientation of laminations (Parallel = 1 or Perpendicular =2) = $\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$

Effective EI:

EI_{eff} = (1.156 x 10^{12}) $N.mm^2$

Effective GA:

GA_{eff} = (5.27 x 10^6) N

Loading:

Superimposed deadload (worst-case) G_{sdl} = 0.25 kPa

Dead load:

G_{proj} = 1.866 kPa

Live Load:

Uniformly distributed load $Qu_{projected}$:= 2 kPa
Long term coefficient ψlu:= 0.4

Point load $Qc_{projected}$:= 1.8 kN
Long term coefficient ψlc:= 0.6

Deflection

Deflection limit, C1 (for L/C1) C1= 300

Total deformation:

Uniform load deformation $\Delta_u = \Delta_f + \Delta_s$ = 5.916 mm

Concentrated load deformation $\Delta_c = \Delta_{f\_p} + \Delta_{s\_p}$ = 5.886 mm

Short-term $\Delta = \max(\Delta_u, \Delta_c)$ = 5.916 mm

Long-term $\Delta_l = k_2 \cdot \Delta$ = 11.833 mm

Allowable deflection ratio DR= 0.934 CHK= "OK"

Equivalent Flexural Stiffness (for UDL cases only, used for FPI vibration)

Elapp = $\frac{5\times(W_G+W_{\psi lQ})\times L^4}{384\times\Delta_u}$ = (9.717×10^{11}) $N.mm^2$

NB: Takes into account flexural and shear deformation.

ULS Design Actions

Uniformly distributed loads $Wu_G = \begin{bmatrix} 1.35\ W_G \\ 1.2\ W_G \end{bmatrix}$ $Wu_Q = \begin{bmatrix} 0 \\ 1.5\ W_Q \end{bmatrix}$

Uniformly distributed loads $Pu = \begin{bmatrix} 0 \\ 1.5\ Q_C \end{bmatrix}$

Maximum Moment

$Mu = \begin{bmatrix} 3.406 \\ 7.901 \end{bmatrix}$ kN.m

Maximum Shear

$Vu = \begin{bmatrix} 3.585 \\ 8.316 \end{bmatrix}$ kN

Strength

Bending strength $f_b = 14$ MPa

Rolling shear strength $f_r = 1.2$ MPa

Load duration factors $k1 = \begin{bmatrix} 0.6 \\ 0.8 \end{bmatrix}$

Moment Capacity

$\phi M_n = \phi \times k_{12} \times k_1 \times f_b \times 0.85 \times Ze = \begin{bmatrix} 13.099 \\ 17.465 \end{bmatrix}$ kN.m

Shear Capacity

$\phi V_n = \phi \times k_{12} \times k_1 \times f_R \times As_{eff} = \begin{bmatrix} 47.174 \\ 17.465 \end{bmatrix}$ Kn

Strength Utilization

$SU_1 = \frac{M_u}{\phi M_n} = \begin{bmatrix} 0.26 \\ 0.452 \end{bmatrix}$ $SU_2 = \frac{V_u}{\phi V_n} = \begin{bmatrix} 0.076 \\ 0.132 \end{bmatrix}$

CHK$_1$ = $\begin{bmatrix} "OK" \\ "OK" \end{bmatrix}$ CHK$_2$ = $\begin{bmatrix} "OK" \\ "OK" \end{bmatrix}$

Strength Utilization

Frequency limit	$f_{lim} = 6\ s^{-1}$
Concentrated live load	$Q_{cv} = 1$ kN
Deflection limit under concentrated live load	$\Delta_{lim} = 1.5$ mm
Proportion of uniformly distributed live load	$C_Q = 0.1$

Uniformly distributed load

$Wv = W_G + C_Q \times W_Q = 1.578\ \frac{kN}{m}$

Frequency

$f_1 = \frac{\pi}{2 \times L^2} \times \sqrt{\frac{EI_{app}}{(\frac{Wv}{g})}} = 8.4555\ \frac{1}{s}$ CHK= "OK"

Deflection under point load

$\Delta_v = Q_{cv} \times (\frac{L^3}{48 \times EI_{eff}} + \frac{L}{4 \times GA_{eff}}) = 1.169$ mm

Additional Vibration Checks

FPInnovations (2019):

Effective EI per meter (apparent EI used conservatively):

$EI_{eff\ 1m} = \frac{EI_{eff}}{B} = 1.284 \times 10^6$ N.m

Span limit

$L_{limit} = 0.11 \times \frac{(\frac{EI_{eff\ 1m}}{N.m})^{0.29}}{(\frac{\rho}{(\frac{kg}{m^3})} \times 1 \times \frac{tt}{m})^{0.12}} \times m = 3.953$ m

CHK = if $L \le L_{limit}$ CHK= "OK"

40.1 CLT Wall Panel Design

Red Stag CLT Wall Panels under Pure Axial Capacity.

Red Stag CLT Wall Panel Thickness = 104 mm.

Figure 150: Red Stag CLT Panel Symmetrical Cross-Section

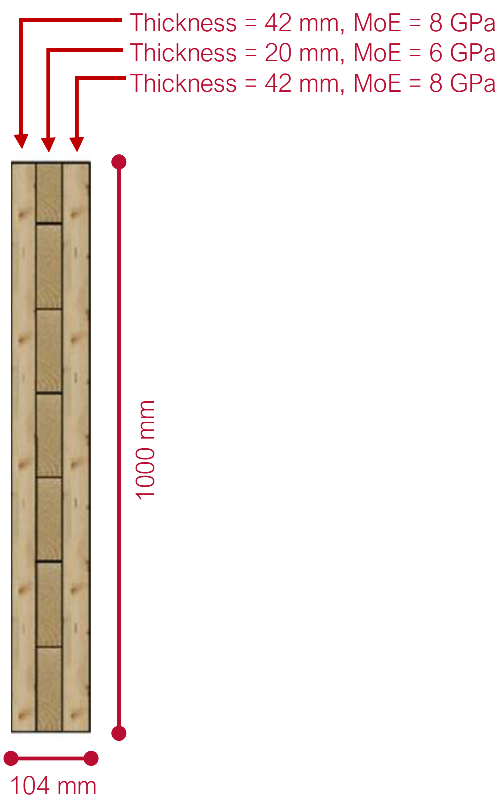


Figure 151: Red Stag CLT Panel Symmetrical Elevation.

40.2 Material Factors, Geometry and Material Factors

Strength Reduction Factor (Ø) = 0.8

Moisture Factor (k_{12}) = 1

Load Duration Factor (k_1) = 0.8

Bearing Area Factor (k_3) = 1

Timber Density (ρ) = 500 kg/m^3

Loading (N) = 290 kN

Ratio of Shear and Rolling Shear Modulus = 10

Ratio of Parallel to Grain and Shear Modulus = 16

Depth of panel (b) = 1000 mm = 1m

Number of laminations (nl) = 3

Thickness of laminations (t) = $\begin{bmatrix} 42 \\ 20 \\ 42 \end{bmatrix}$ mm

Elastic modulus of laminations (E) = $\begin{bmatrix} 8000 \\ 6000 \\ 8000 \end{bmatrix}$ MPa

Orientation of laminations (Parallel = 1 or Perpendicular =2) = $\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix}$

Member Actions

Load case	LC = 1.2g + 1.5Q
Axial force (+compression, -tension)	N_x = 310 kN
Y axis Shear (Peinc.)	V_Y = 0 kN
Y axis Moment (Minor)	M_Y = 0 kN.m
Z axis Shear (Minor)	V_Z = 0 kN
Z axis Moment (Peinc.)	M_Z = 0 kN.m

Member Restrain Length

Panel height	L = 2700 mm
Lateral restraint length (Z axis)	L_{az} = 2700 mm
Lateral restraint length (Y axis)	L_{ay} = 2700 mm
Effective length factor	K_{10} = 0.7
Eccentricity	$\Delta = \frac{h}{2} + \frac{h}{3}$ =17 mm

Basic Characteristic Stress

Bending Stress	f_b = 14 MPa
Tension Stress	f_t = 6 MPa
Compression Stress	f_c = 18 MPa
Perp Compression Stress	f_p = 4.7 MPa
Shear Stress	f_s = 1.2 MPa

Section Capacity

Bending capacity

Principal axis $\varnothing M_{nz} = \varnothing \times k_1 \times k_{12} \times k_{8bp} \times Z_P$ = 105 kN.m

Minor axis $\varnothing M_{ny} = \varnothing \times k_1 \times k_{12} \times k_{8bm} \times Z_m$ = 16 kN.m

Compression capacity

Principal axis $\varnothing N_{ncz} = \varnothing \times F_C \times A_{eff} \times K_{Zc} \times K_{Cz}$ = 1177 kN

Minor axis $\varnothing N_{ncy} = \varnothing \times F_C \times A_{eff} \times K_{Zc} \times K_{Cy}$ = 653 kN

Tension capacity $\varnothing N_{nt} = \varnothing \times k_1 \times k_{12} \times f_t \times A_{eff}$ = 323 kN

Shear capacity $\varnothing V_n = \varnothing \times k_1 \times k_{12} \times f_s \times A_{eff}$ = 15 kN

Euler buckling load adjusted for shear deformation $P_{E.v}$ = 868 Kn

Perpendicular to grain bearing capacity

$\varnothing N_n = \varnothing \times k_1 \times k_3 \times h \times b \times f_P$ = 15 kN

Combined Stress Ratio

Axial compression

$CSR_{c1} = \frac{M_z}{\varnothing M_{nz}} + \frac{N_x}{\varnothing N_{ncz}}$ = 0.26 $CSR_{c3} = \frac{M_y}{\varnothing M_{ny}} + \frac{N_x}{\varnothing N_{ncy}}$ = 0.42

$CSR_{c2} = \left(\frac{M_z}{\varnothing M_{nz}}\right)^2 + \frac{N_x}{\varnothing N_{ncy}}$ = 0.26 $CSR_{c4} = \frac{M_z}{\varnothing M_{nz}} + \frac{M_y}{\varnothing M_{ny}}$ = 0.00

Tension Stress

$CSR_{t1} = \frac{M_z}{\varnothing M_{nz}} + \frac{N_x}{\varnothing N_{nt}}$ = 0.95 $CSR_{t3} = \frac{M_z}{\varnothing M_{nz}} + \frac{M_y}{\varnothing M_{ny}}$ = 0.00

$CSR_{t1} = \frac{M_y}{\varnothing M_{ny}} + \frac{N_x}{\varnothing N_{nt}}$ = 0.95

Shear

$CSR_{s1} = \frac{V_y}{\varnothing V_n}$ = 0.00 $CSR_{s2} = \frac{V_z}{\varnothing V_n}$ = 0.00

Euler out of plane buckling

CSR$_{e1}$ = $\frac{N_x}{ØN_{ncy}} + \frac{1}{ØM_{ny}} \times \left(M_y + \frac{N_x \times \Delta}{1-\frac{N_x}{P_{Ev}}}\right)$= 0.87

Perp-to grain bearing

PrepB = $\frac{N_x}{ØN_b}$ = 0.98 CHK= “OK”

Section 11

Cross Laminated Timber Acoustic Performance

41. 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 many 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.

42. 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 152*).

.

43. 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 152*).

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.

44. Direct and Flanking Transmission

Often sound is 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 152*).

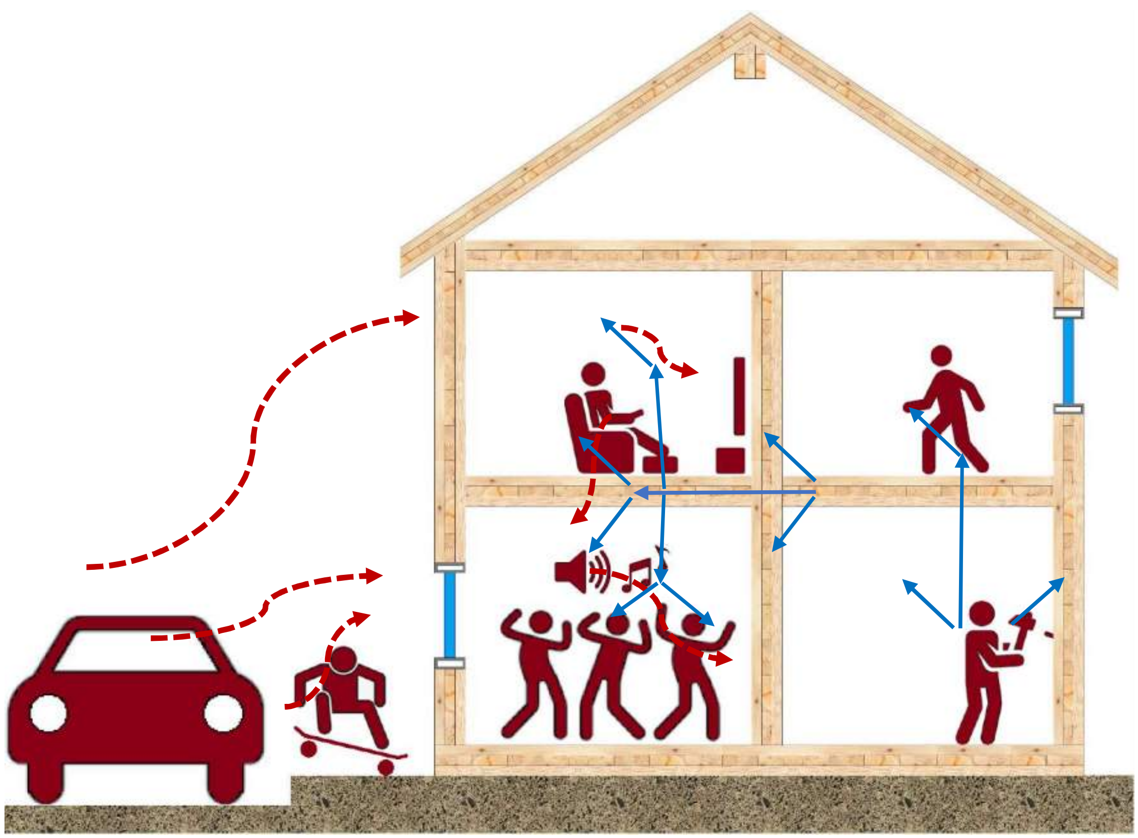


Figure 152: Examples of impact and airborne sound.

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* 153).

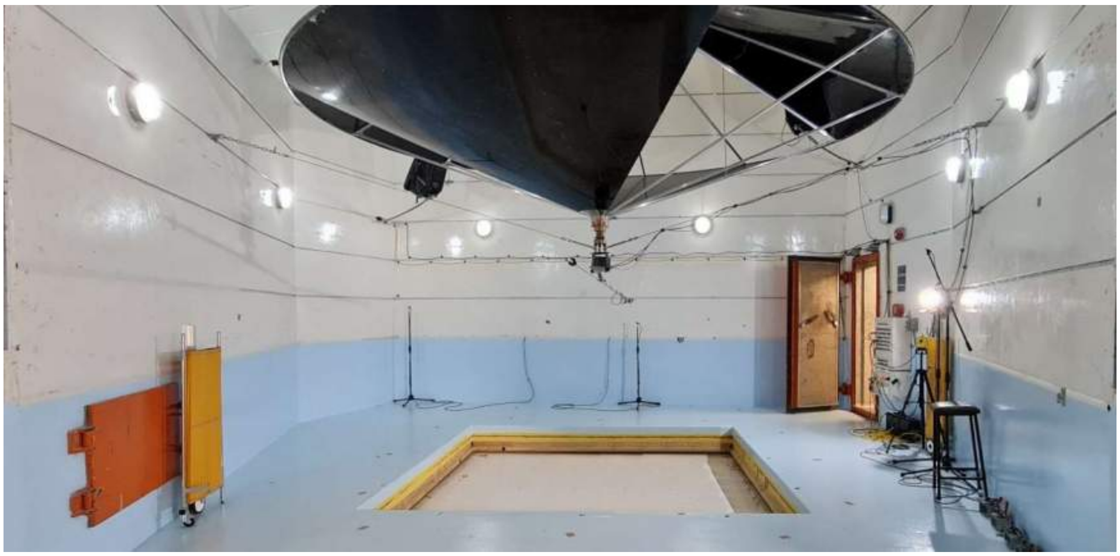


Figure 153: Accredited laboratory acoustical chamber.

45.1 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 154 and Figure 155).

Figure 154: 126 mm thick three-layer Red Stag CLT panel with lap joint installed in the acoustic chamber at the testing laboratory.

Figure 155: 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 41* to *Table 51*. *Figure 156* to *Figure 162* illustrate the combinations of tested floor system components with Red Stag CLT.

Figure 156: Three-layer Red Stag CLT panel with lap joint.

Figure 157: Five-layer Red Stag CLT panel with lap joint.

Figure 158: Strandboard layer.

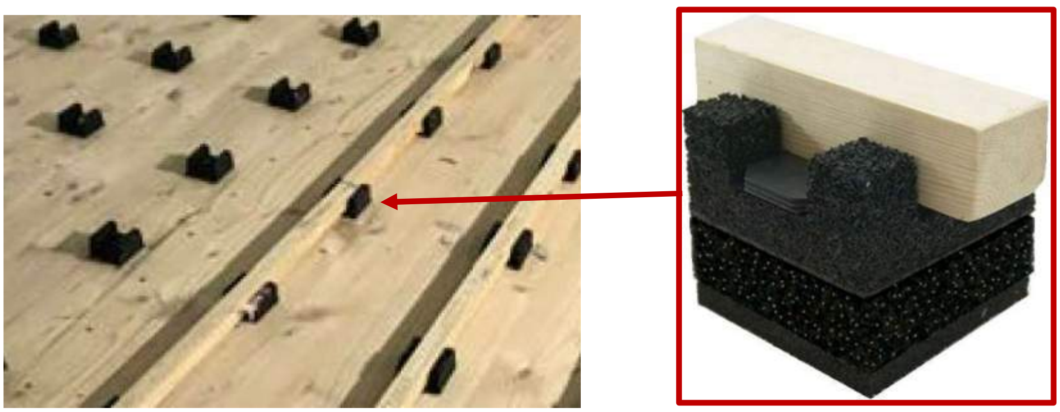


Figure 159: Acoustic cradles.

Figure 160: Cradle system with thermal insulation.

Figure 161: 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 162: Gib Fireline.

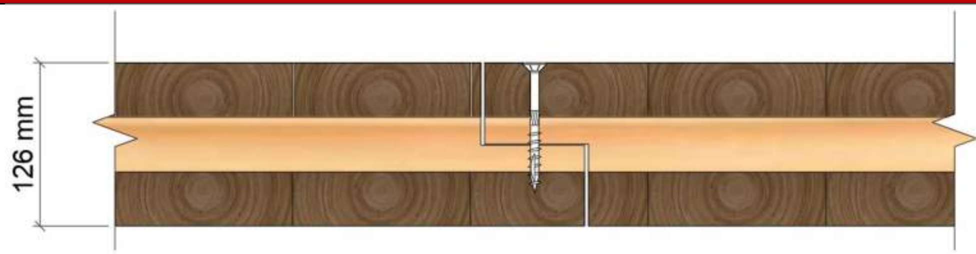
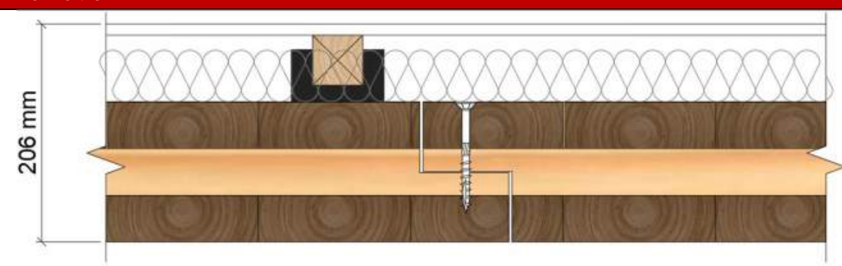
Table 41: Combination 1 (Bare 126 mm Thick Red Stag CLT Panel).		
		
Floor: Red Stag CL3/126 CLT flooring comprising: 40 mm x 45 mm LVL perimeter battens, one lap joint through the centre with screw fixing only.		
Insulation: NIL		
Linings: NIL		
Total Thickness: 126 mm	STC: 35 dB	IIC: 20 dB

Table 42: Combination 2.		
		
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: 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

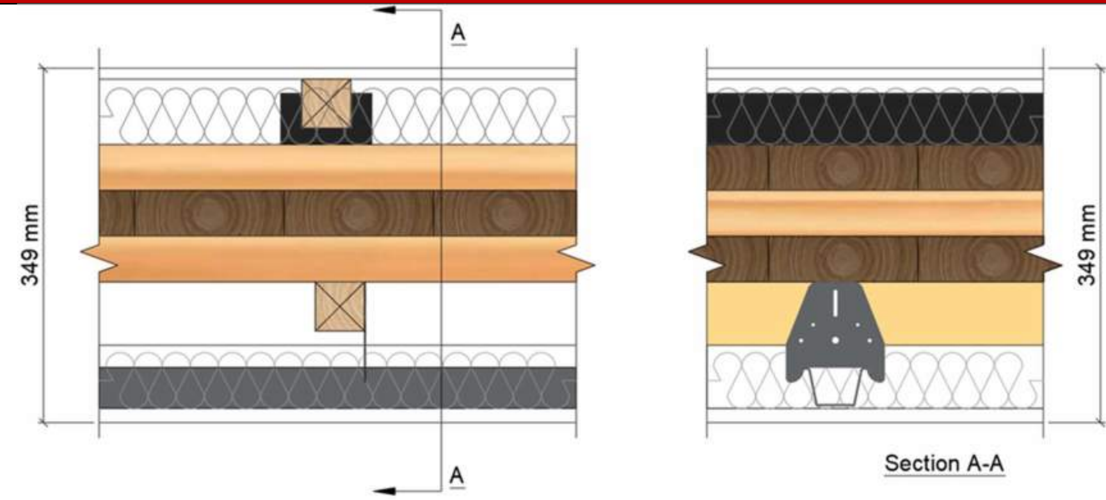
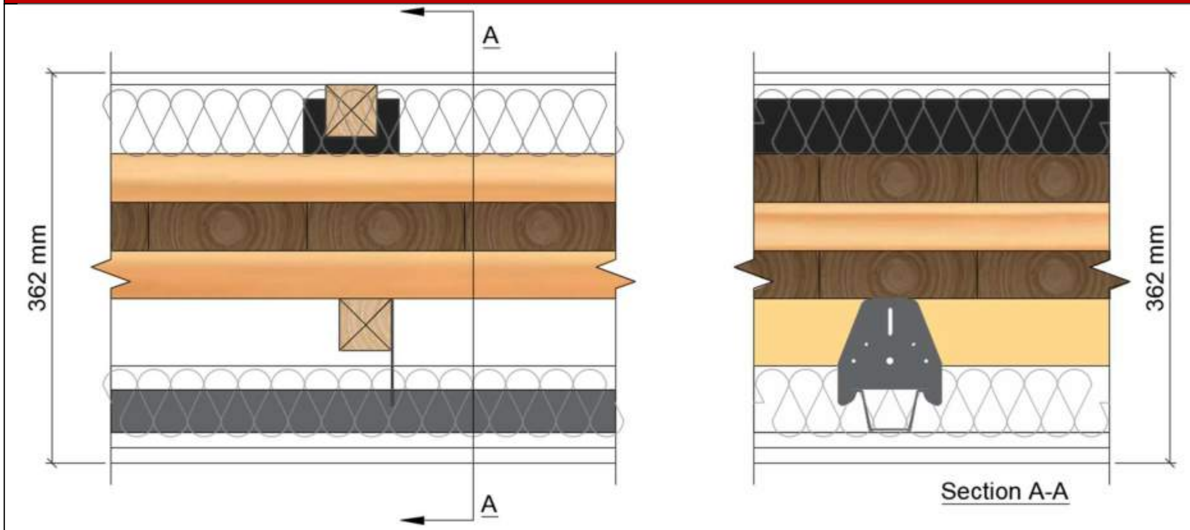
<table>
<tr><th colspan="3">Table 43: Combination 3.</th></tr>
<tr><td colspan="3">
</td></tr>
<tr><th colspan="3">Layout Specifications</th></tr>
<tr><td colspan="3">Flooring:
One layer of 20 mm Laminex Strandfloor screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten and Cradle LVL battens. Battens spaced at 400 mm centres seated in Batten and Cradle rubber cradles spaced at 450 mm centres.</td></tr>
<tr><td colspan="3">Insulation:
50 mm thick R1.2 Pink Batts fibreglass insulation.</td></tr>
<tr><td colspan="3">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.</td></tr>
<tr><td colspan="3">Insulation:
90 mm thick R2.2 Pink Batts fibreglass insulation.</td></tr>
<tr><td colspan="3">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).</td></tr>
<tr><td>Total Thickness: 349 mm</td><td>STC: 64 dB</td><td>IIC: 47 dB</td></tr>
</table>

Table 44: 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.
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: 67 dB	IIC: 56 dB

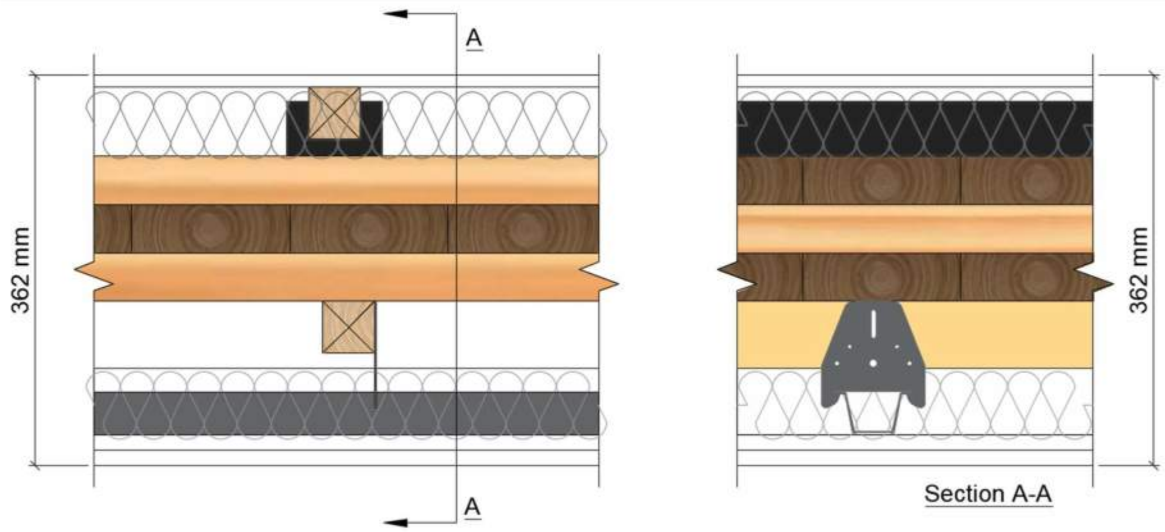
Table 45: Combination 5.		
		
Layout Specifications		
Flooring: One layer of 20 mm Laminex Superpine MR Particleboard screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten and Cradle LVL battens. Battens spaced at 400 mm centres seated in Batten and Cradle rubber cradles spaced at 450 mm centres.		
Insulation: 50 mm thick R1.2 Pink Batts fibreglass insulation.		
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: 65 dB	IIC: 55 dB

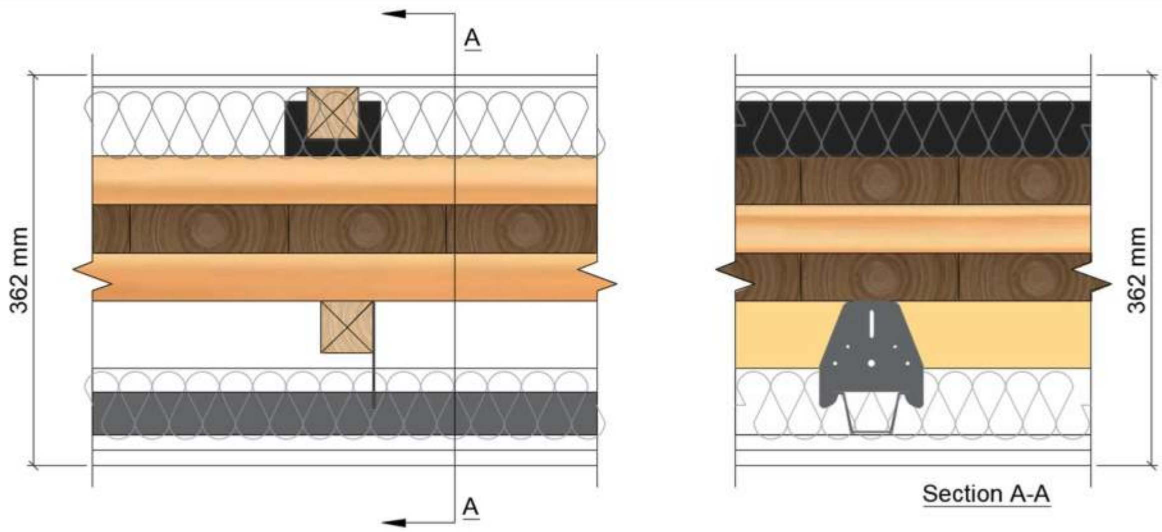
Table 46: Combination 6.		
		
Layout Specifications		
Flooring: One layer of 20 mm James Hardie Secura Interior Flooring screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten and Cradle LVL battens. Battens spaced at 400 mm centres seated in Batten and Cradle rubber cradles spaced at 450 mm centres.		
Insulation: 50 mm thick R1.2 Pink Batts fibreglass insulation.		
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

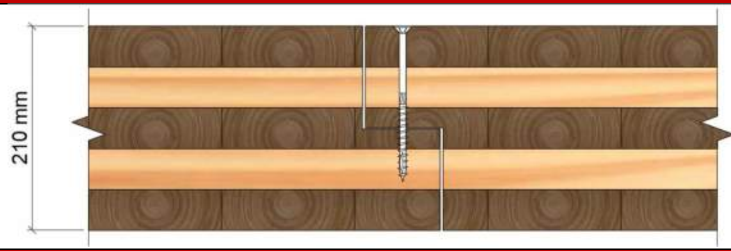
Table 47: Combination 7 (Bare 210 mm Thick Red Stag CLT Panel).		
		
Layout Specifications		
Floor: 210 mm thick Red Stag CL5/210 Cross Laminated Timber (CLT) flooring comprising three lap jointed uniformly spaced panels. CLT screw fixed along the two lap joints at 200 mm centres and sealed around perimeter only.		
Insulation: NIL		
Linings: NIL		
Total Thickness: 210 mm	STC: 39 dB	IIC: 24 dB

Table 48: 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: NIL		
Linings: NIL		
Total Thickness: 290 mm	STC: 54 dB	IIC: 44 dB

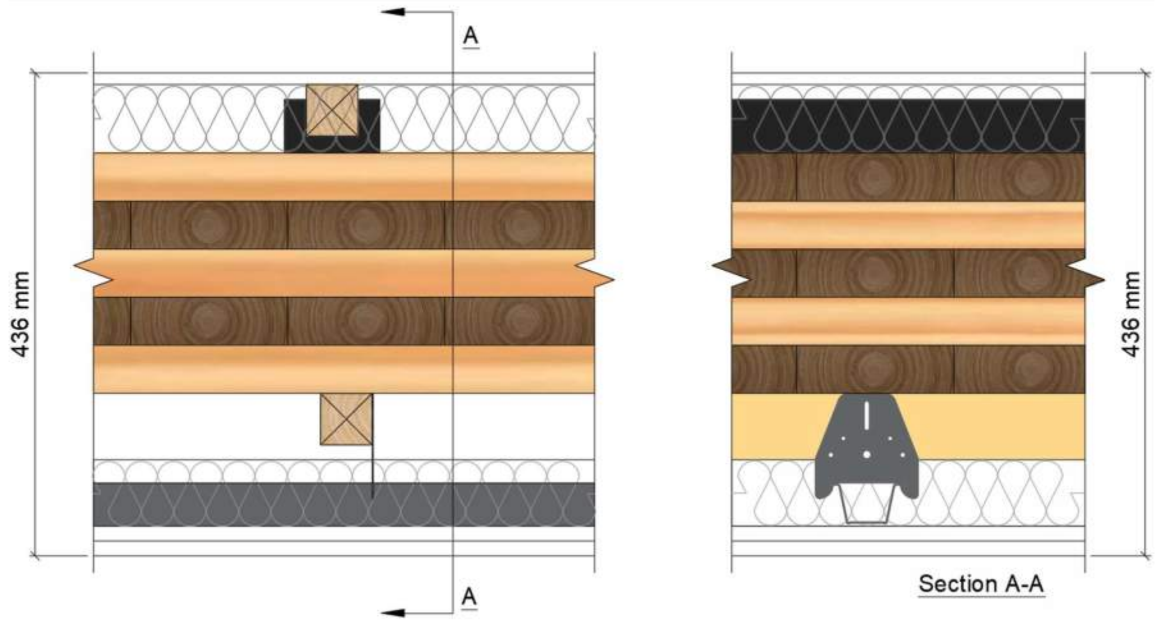
Table 49: Combination 9.		
		
Layout Specifications		
Flooring: One layer of 20 mm Laminex Strandfloor screw fixed at 200 mm centres to 42 mm (H) x 40 mm (W) Batten.		
Insulation: 50 mm thick R1.2 Pink Batts fibreglass insulation.		
Floor: 210 mm thick Red Stag CL5/210 Cross Laminated Timber (CLT) flooring 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: 436 mm	**STC:** 66 dB	**IIC:** 60 dB

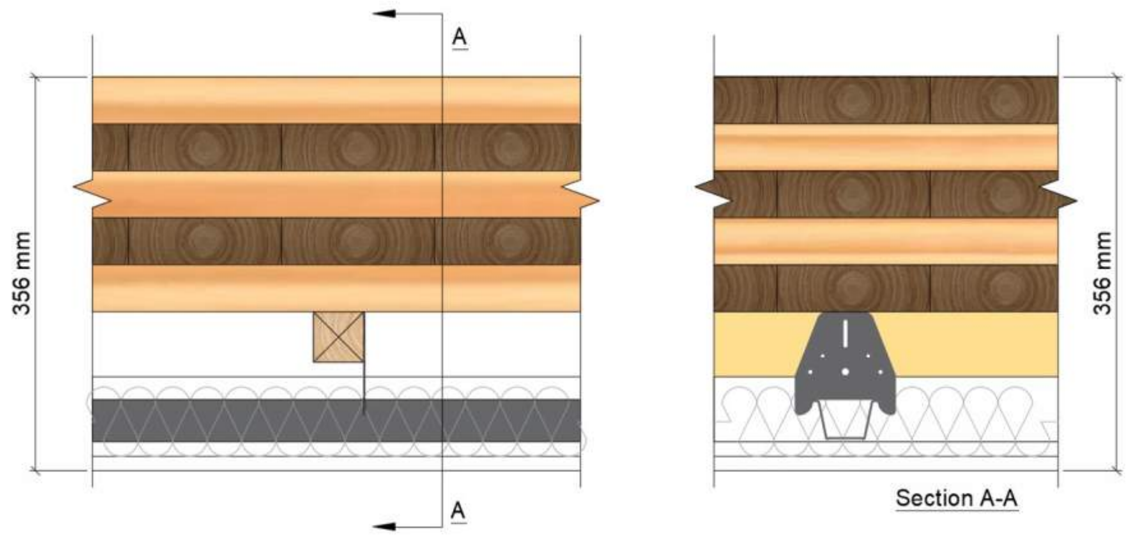
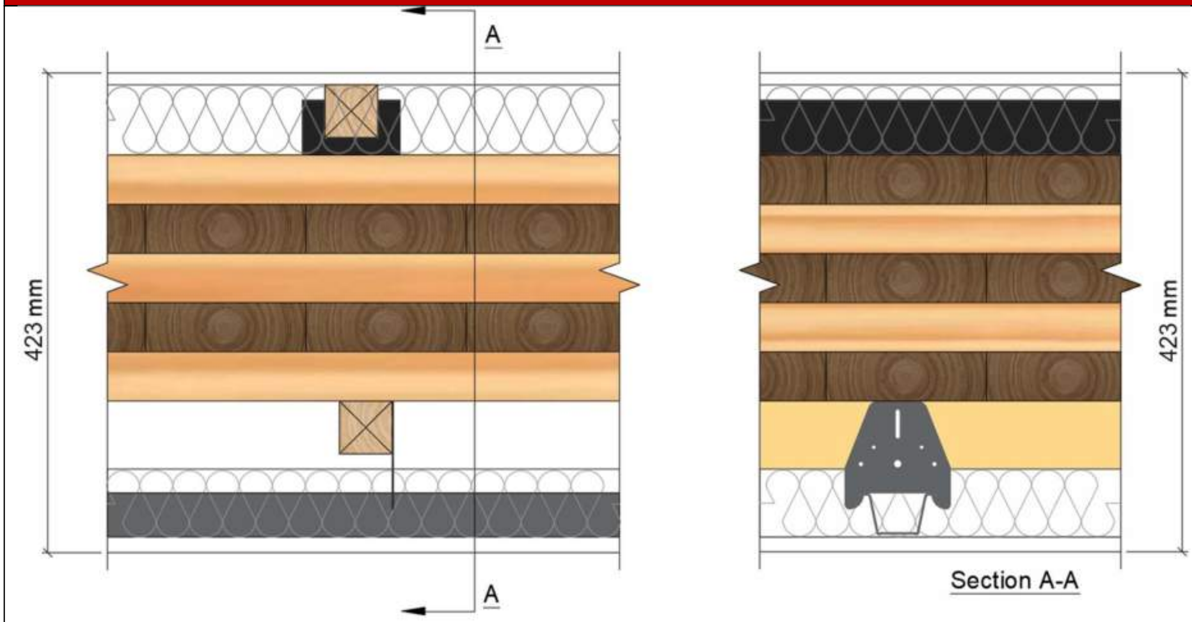
Table 50: Combination 10.		
		
Layout Specifications		
Floor: 210 mm thick Red Stag CL5/210 Cross Laminated Timber (CLT) flooring comprising three lap jointed uniformly spaced panels. CLT screw fixed along the lap joints at 200 mm centres and sealed around perimeter only.		
Insulation: 90 mm thick R2.2 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

Table 51: Combination 11.		
		
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: One 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: 423 mm	STC: 64 dB	IIC: 53 dB

126 mm thick Red Stag CLT panels have been tested in a new series of flooring systems (build ups) independently. The STC and IIC results of the tested flooring configurations are summarised in *Table 52* to *Table 57*. *Figure 163* to *Figure 168* illustrate the combinations of tested floor system components with Red Stag CLT.

Figure 163: Sample installed in the chamber with tapping machine.

Figure 164: Three-layer Red Stag CLT panel with lap joint.

Figure 165: Underlay and upper layer installation.

Figure 166: Suspended ceiling in the lower chamber.

Figure 167: R3.6 insulation material

Figure 168: Plaster adhesive.

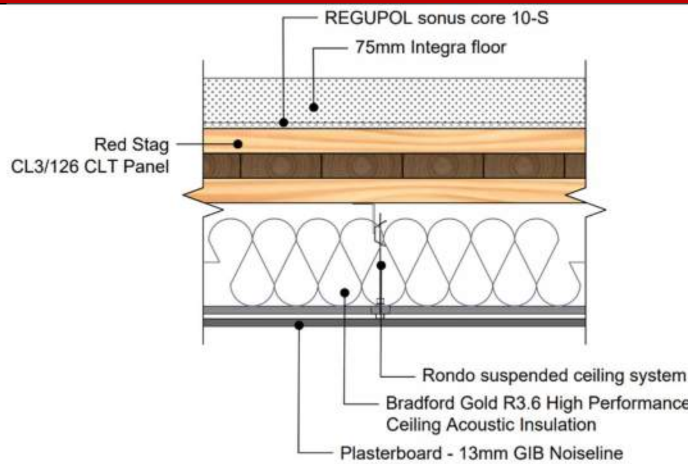
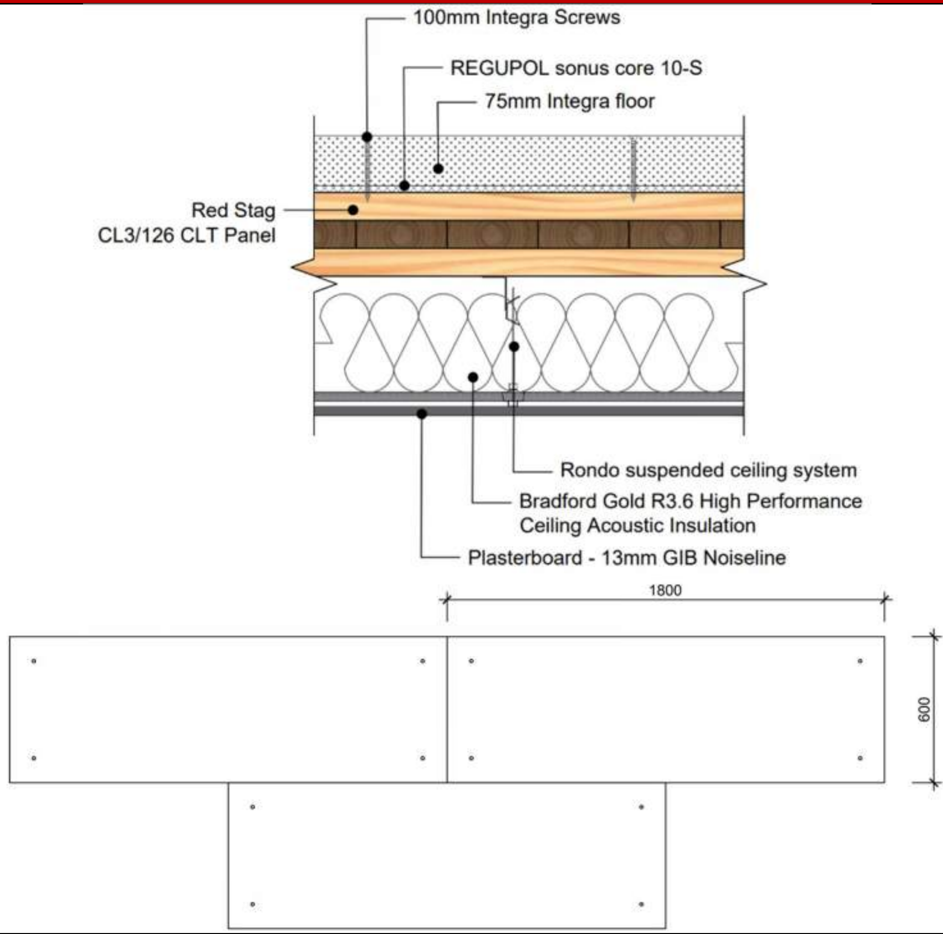
Table 52: Combination 12.		
		
Layout Specifications		
Flooring: An array of 1800 mm x 600 mm X 75 mm Resene Integra panels (steel reinforced aerated concrete) adhered together with Resene Plaster Systems AAC Adhesive around the perimeter of each panel, the panel loose laid on 5 mm thick Regupol Sonus core 10-5 rubber underlay loose laid on Red Stag CLT flooring.		
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.		
Ceiling: Rondo 28 mm FC 0.50BTM furring channel in Rondo 139 furring channel clip in Rondo 25 mm TCR 0.75BMT rail in Rondo 2534 suspension clip hung with the steel rod to Rondo 547 clip screw fixed to the underside of Red Stag CLT panel providing 225 mm ceiling cavity.		
Insulation: One layer of CSR Bradford Gold 185 mm thick R3.6 High Performance Ceiling Insulation.		
Linings: One layer of 13 mm GIB Braceline/Noiseline plasterboard screw fixed at 300 mm centres to Rondo furring channel.		
Total Thickness: 444 mm	STC: 68 dB	IIC: 64 dB

Table 53: Combination 13.



Layout Specifications		
Flooring: An array of 1800 mm x 600 mm X 75 mm Resene Integra panels (steel reinforced aerated concrete) adhered together with Resene Plaster Systems AAC Adhesive around the perimeter of each panel, each panel end screw fixed to CLT with 2 X 100 mm Integra screws through 5 mm thick Regupol Sonus core 10-5 rubber underlay loose laid on Red Stag CLT flooring panels.		
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.		
Ceiling: Rondo 28 mm FC 0.50BTM furring channel in Rondo 139 furring channel clip in Rondo 25 mm TCR 0.75BMT rail in Rondo 2534 suspension clip hung with the steel rod to Rondo 547 clip screw fixed to the underside of Red Stag CLT panel providing 225 mm ceiling cavity.		
Insulation: One layer of CSR Bradford Gold 185 mm thick R3.6 High Performance Ceiling Insulation.		
Linings: One layer of 13 mm GIB Braceline/Noiseline plasterboard screw fixed at 300 mm centres to Rondo furring channel.		
Total Thickness: 444 mm	STC: 69 dB	IIC: 61 dB

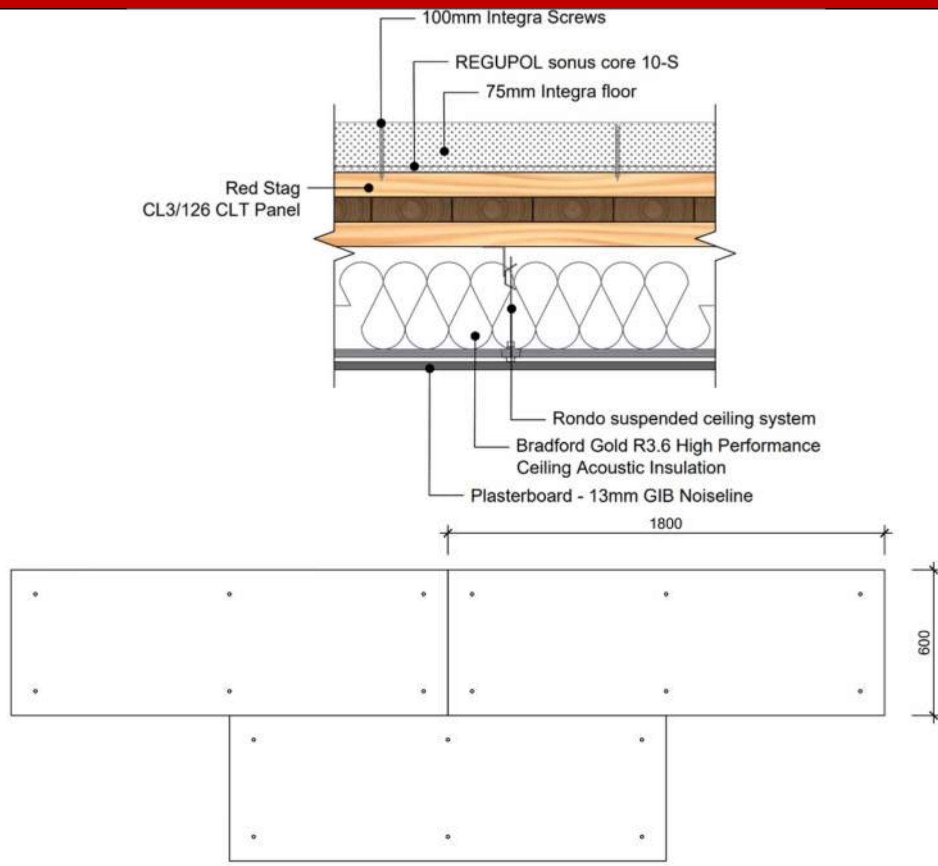
Table 54: Combination 14.		
		
Layout Specifications		
Flooring: An array of 1800 mm x 600 mm X 75 mm Resene Integra panels (steel reinforced aerated concrete) adhered together with Resene Plaster Systems AAC Adhesive around the perimeter of each panel, each panel end screw fixed at 800 mm X 450 mm centres around perimeters to CLT with 100 mm Integra screws through 5 mm thick Regupol Sonus core 10-5 rubber underlay loose laid on Red Stag CLT flooring panels.		
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.		
Ceiling: Rondo 28 mm FC 0.50BTM furring channel in Rondo 139 furring channel clip in Rondo 25 mm TCR 0.75BMT rail in Rondo 2534 suspension clip hung with the steel rod to Rondo 547 clip screw fixed to the underside of Red Stag CLT panel providing 225 mm ceiling cavity.		
Insulation: One layer of CSR Bradford Gold 185 mm thick R3.6 High Performance Ceiling Insulation.		
Linings: One layer of 13 mm GIB Braceline/Noiseline plasterboard screw fixed at 300 mm centres to Rondo furring channel.		
Total Thickness: 444 mm	STC: 69 dB	IIC: 60 dB

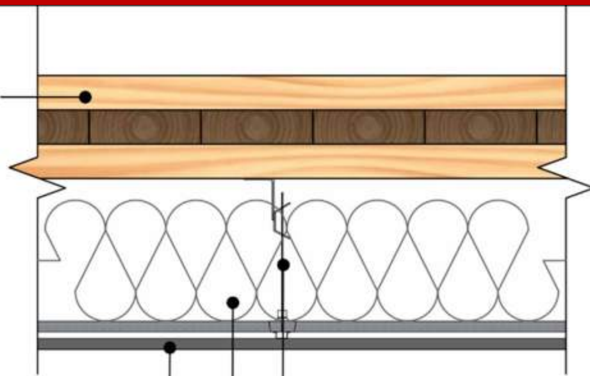
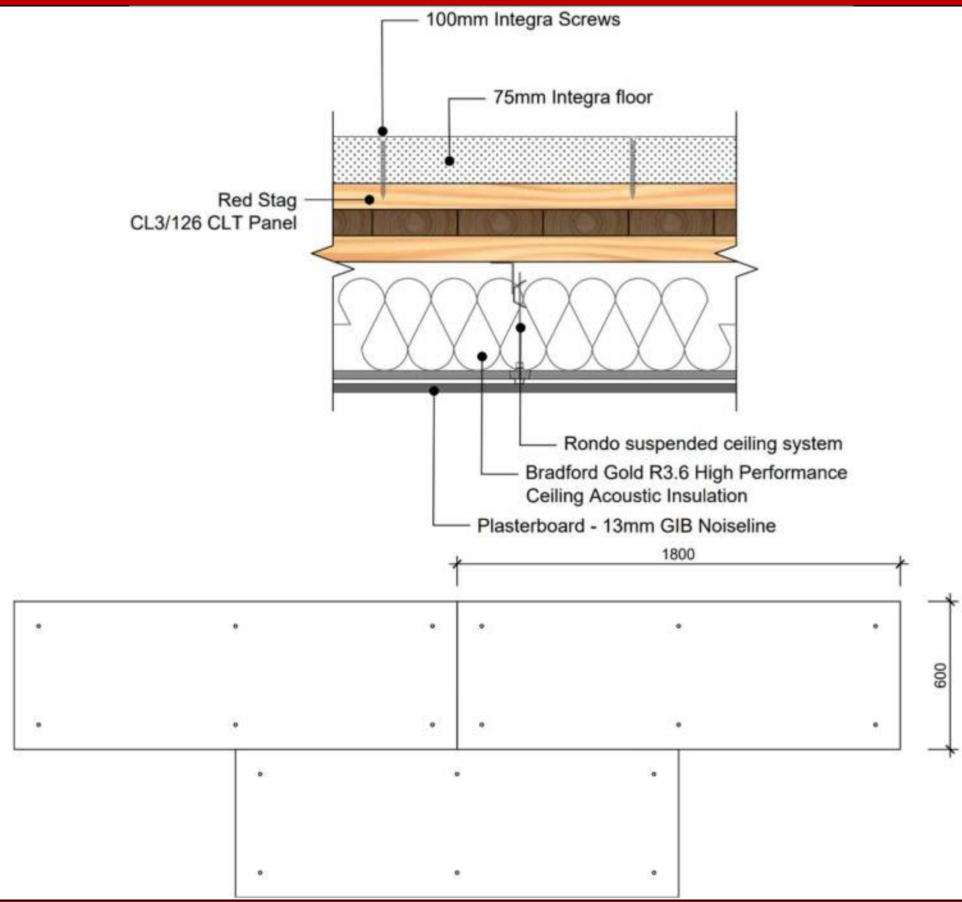
Table 55: Combination 15.		
		
Layout Specifications		
Flooring: NIL		
Floor: 126 mm thick Red Stag CL3/126 Cross Laminated Timber (CLT) flooring comprising two panels lap jointed through the centre. CLT screw fixed along lap joint at 200 mm centres and sealed around perimeter only.		
Ceiling: Rondo 28 mm FC 0.50BTM furring channel in Rondo 139 furring channel clip in Rondo 25 mm TCR 0.75BMT rail in Rondo 2534 suspension clip hung with the steel rod to Rondo 547 clip screw fixed to the underside of Red Stag CLT panel providing 225 mm ceiling cavity.		
Insulation: One layer of CSR Bradford Gold 185 mm thick R3.6 High Performance Ceiling Insulation.		
Linings: One layer of 13 mm GIB Braceline/Noiseline plasterboard screw fixed at 300 mm centres to Rondo furring channel.		
Total Thickness: 364 mm	STC: 63 dB	IIC: 52 dB

Table 56: Combination 15.



Layout Specifications

Flooring:
An array of 1800 mm x 600 mm X 75 mm Resene Integra panels (steel reinforced aerated concrete) adhered together with Resene Plaster Systems AAC Adhesive around the perimeter of each panel, each panel end screw fixed at 800 mm X 450 mm centres around perimeters to CLT with 100 mm Integra screws around perimeters to the Red Stag CLT floor.

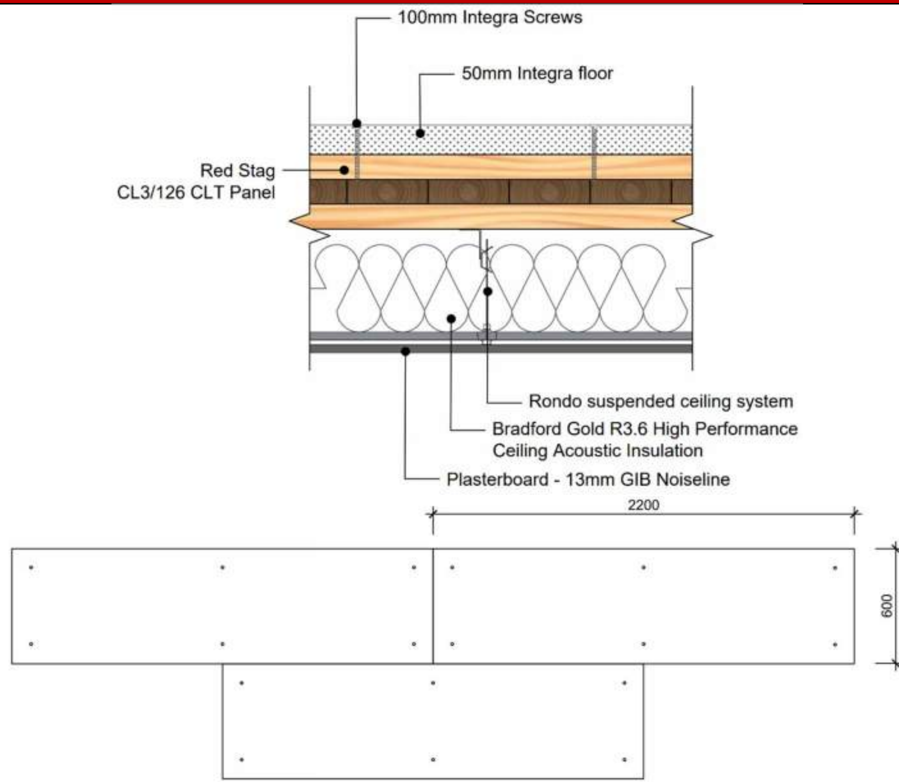
Floor:
126 mm thick Red Stag CL3/126 Cross Laminated Timber (CLT) flooring comprising two panels lap jointed through the centre. CLT screw fixed along lap joint at 200 mm centres and sealed around perimeter only.

Ceiling:
Rondo 28 mm FC 0.50BTM furring channel in Rondo 139 furring channel clip in Rondo 25 mm TCR 0.75BMT rail in Rondo 2534 suspension clip hung with the steel rod to Rondo 547 clip screw fixed to the underside of Red Stag CLT panel providing 225 mm ceiling cavity.

Insulation:
One layer of CSR Bradford Gold 185 mm thick R3.6 High Performance Ceiling Insulation.

Linings:
One layer of 13 mm GIB Braceline/Noiseline plasterboard screw fixed at 300 mm centres to Rondo furring channel.

Total Thickness: 444 mm	STC: 69 dB	IIC: 60 dB

Table 57: Combination 16.


Layout Specifications

Flooring:
An array of 1800 mm x 600 mm X 75 mm Resene Integra panels (steel reinforced aerated concrete) adhered together with Resene Plaster Systems AAC Adhesive around the perimeter of each panel, each panel end screw fixed at 800 mm X 450 mm centres around perimeters to CLT with 100 mm Integra screws around perimeters to the Red Stag CLT flooring.

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. Red Stag CLT panels placed on 140 mm X 45 mm perimeter joints fixed to test collar.

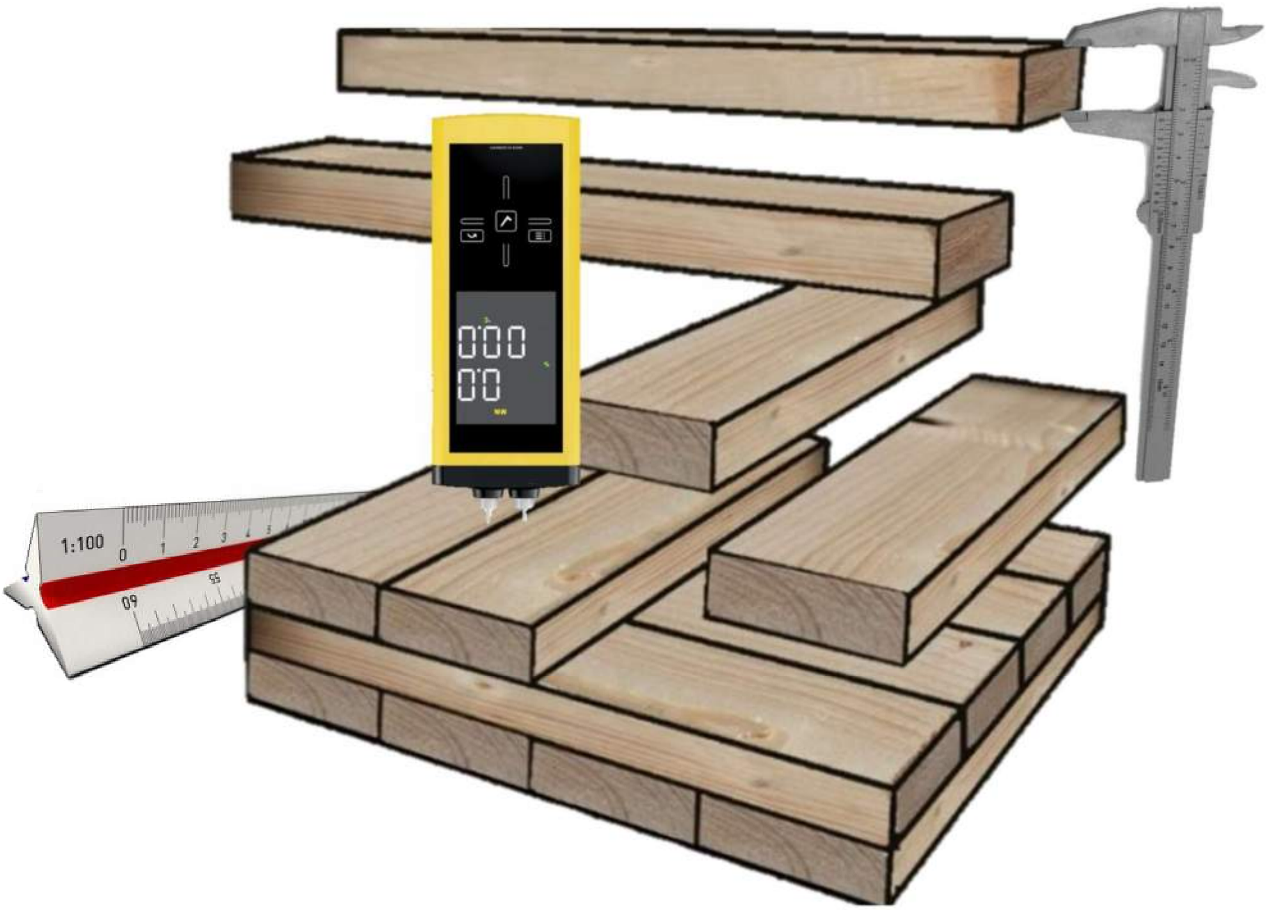
Ceiling:
Rondo 28 mm FC 0.50BTM furring channel in Rondo 139 furring channel clip in Rondo 25 mm TCR 0.75BMT rail in Rondo 2534 suspension clip hung with the steel rod to Rondo 547 clip screw fixed to the underside of Red Stag CLT panel providing 225 mm ceiling cavity.

Insulation:
One layer of CSR Bradford Gold 185 mm thick R3.6 High Performance Ceiling Insulation.

Linings:
One layer of 13 mm GIB Braceline/Noiseline plasterboard screw fixed at 300 mm centres to Rondo furring channel.

Total Thickness: 414 mm	STC: 68 dB	IIC: 57 dB

Section 12
Red Stag Engineered Wood Product Specifications



Red Stag CLT Design Guide V1.5
September 2024

47. Product Dimensions

47.1 Red Stag Cross Laminated Timber Dimensions

Red Stag can manufacture some of the largest Cross Laminated Timber (CLT) billets in the world up to 16.5 x 4.5 x 0.42 m (Length × Width × Depth). Red Stag CLT panels are typically in three to eleven layers, with thicknesses ranging from approximately 60 mm to 420 mm depending on the structural requirements (refer to *Figure 10*). Red Stag may have the opportunity to manufacture slightly larger if absolutely required for a project; however, this needs to be considered in conjunction with transportation restrictions. Panels above 3.0 m in width will generally require piloting (3.1 m is the maximum width on New Zealand roads without a pilot vehicle and the width includes all tie downs and covers). Similarly, loads longer than 14 m also generally require the support of pilot vehicle(s). Wide and overlength loads are more challenging when needing to cross water ways such as the Cook Straight.

47.2 Red Stag Glue Laminated Timber Dimensions

Red Stag has refined its alternative solution for the manufacture and supply of Glue Laminated Timber (GLT). Red Stag GLT_b will primarily focus on a bricked vertical face laminated lamella configuration (refer to *Figure 169b*). To accommodate the light timber framed market, Red Stag predominantly manufacture lintels and beams to a GL8 specification using feedstock with a Modulus of Elasticity (MoE) of 8 GPa. The maximum length for GLT_b members in the configuration illustrated in *Figure 169* is currently 17 m. Bricked GLT_b elements will be manufactured in similar thicknesses to CLT, with the addition of 88 ± 1 mm width and typically in standard structural timber/Laminated Veneer Lumber (LVL) depths (height). To support larger portal and beam commercial structures, Red Stag will also be releasing a standard portfolio of beam sizes (height and width), and provide the opportunity for beams as thick as 420 mm. In essence, beams can be as large as 2.2 m wide x 0.42 m thick x 17 m long.

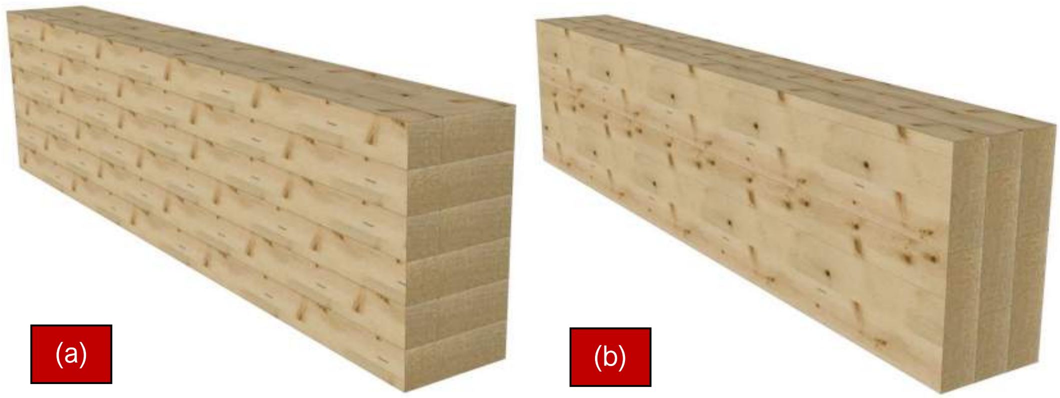


Figure 169: GLT 3D views; a) GLT horizontal brick layout; b) GLT vertical brick layout.

48. Product Tolerances

All Red Stag EWPs are manufactured to the same tolerances regardless of the configuration (i.e. CLT or GLT). A summary of the Red Stag EWP tolerances at the point of machining is summarised in *Table 58*.

Table 58: Red Stag EWP dimensional tolerances.

Item	**Tolerance**
Length	The greater of ± 3 mm, or ± 0.4 mm per
Width (CLT; GLT)	± 3 mm; ± 1.5 mm
Hypotenuse	The greater of ± 4 mm, or ± 0.4 mm per
Thickness Overall	The greater of ± 2 mm, or ± 0.4 mm per layer.
Lap Depth	± 2 mm
Lap Width	± 2.5 mm
Position and Size of Penetrations & Machining, etc	± 3 mm
Moisture Level in Lamella at the Point of Manufacture	4 - 16% (Corrected for Treatment)[1, 2]

[1] Boron treatment causes both probe and capacitance moisture meters to read higher than the actual moisture content due to the salts in the treatment chemicals. Please refer to the Red Stag Timber web site for correlation tables (www.redstagtimber.co.nz).

[2] BS EN 16351-2021 Timber Structures - Cross Laminated Timber Requirements.

49. Aesthetic Grading (Grade)

The lamella (boards) making up each layer of Red Stag EWP are not edge glued, leaving the joints between lamella free to expand and contract in response to changes in temperature and relative humidity. This format provides a natural humidity buffer for comfortable occupation and reduces the frequency of surface checking (longitudinal cracks in the timber grain) within individual boards in each lamella.

Regardless of the grade (standard or visual) of EWP, a slight gap may exist between lamella in each layer. Due to the hygroscopic properties of timber, this board gap may increase as the timber dries and may reduce when the Environmental Moisture Content (EMC) increases. Refer to *Figure 170*.

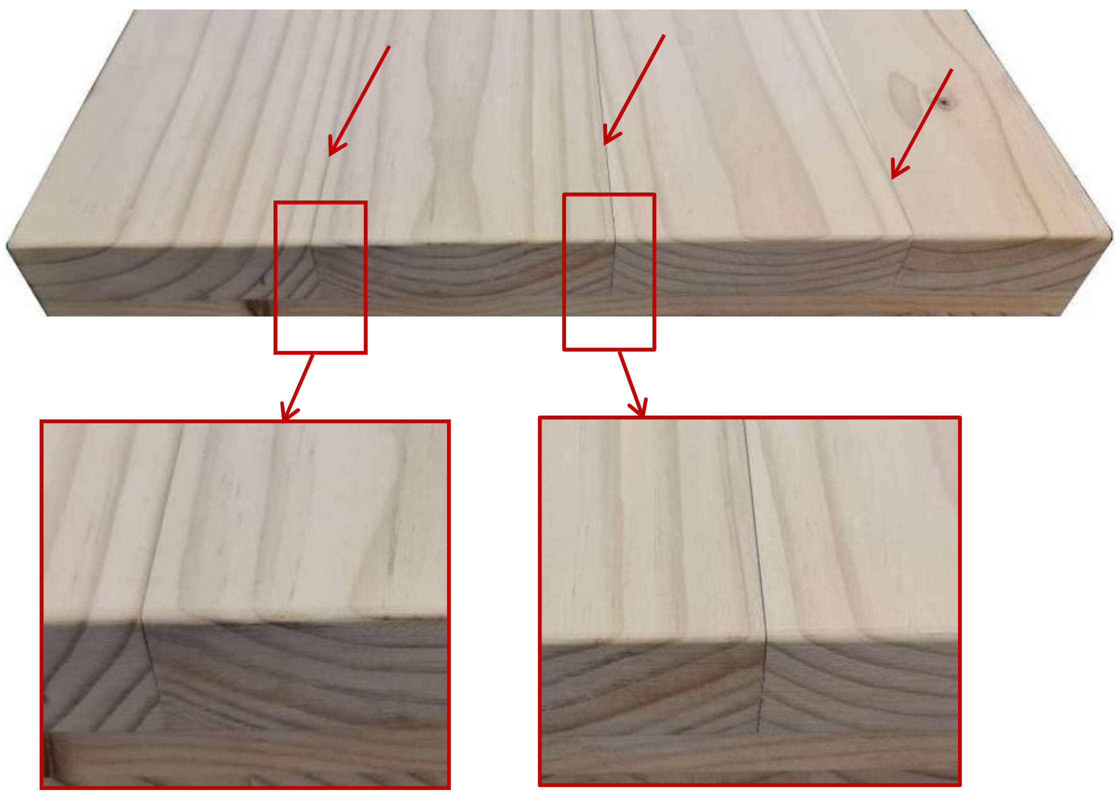


Figure 170: Gaps between lamella in each layer of Red Stag EWP elements.

Red Stag EWP lamella are Finger Jointed (FJ) across the face of each board with a 7 mm finger that is visible. The finger joints are bonded using a relatively clear Polyurethane Reactive adhesive (PUR). Typically, FJ are no closer than 0.8 m apart, and generally separated between 0.8 – 4.8 m. Examples of vertical and horizontal finger joints are demonstrated in *Figure 171*. Red Stag is reviewing the FJ and grading solutions that may include a mixed mode of FJ types. Note changes in FJ type are not typically expected to be inside 4.6 m.

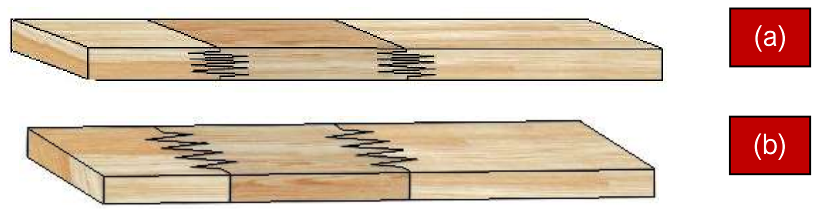


Figure 171: Red Stag EWP elements; a) Horizontal FJ, b) Vertical FJ.

49.1 Standard (Non-Visual) Grade

Red Stag's standard grade is a cost-effective option for structural applications. Standard grade has been developed for applications where the surface will not be seen or where the Client is comfortable with larger knots and visible defects such as wane, markings, loose knots, inclusions, resin, face and edge skip, etc. As standard grade is effectively a non-visual grade, no filling, aesthetic repairs, sanding or finishing is completed in factory (refer to *Figure 172*).

The sole focus for standard grade EWP is its structural performance. Red Stag Timber control the stiffness of all incoming feedstock (boards) to a required MoE (GPa), confirming the performance of each board, including any defects (e.g. knots, etc) to ensure all feedstock conforms with the specified structural requirements.

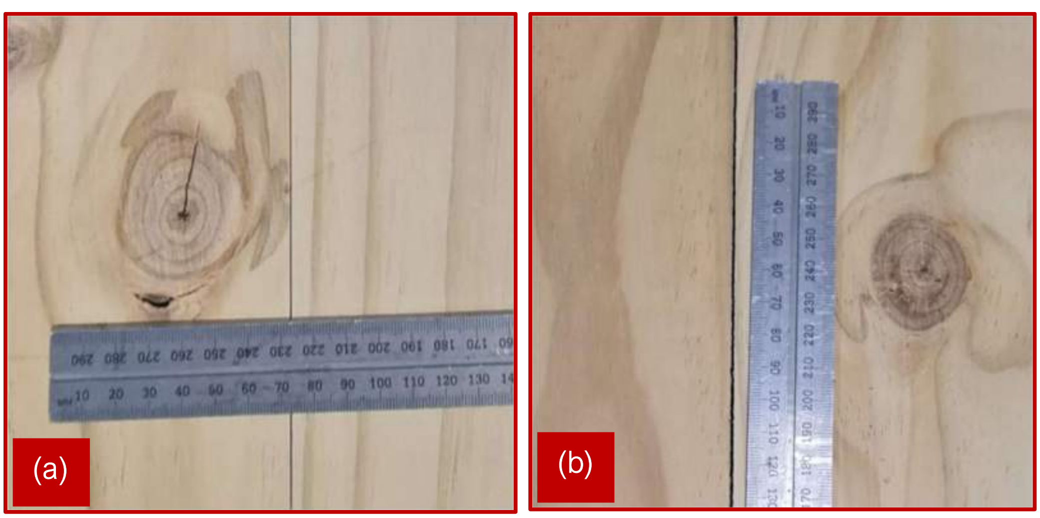
Regardless of the grade (standard or visual), Red Stag completes secondary grading on all incoming boards into the front end of the EWP remanufacturing line1. For standard grade, the focus is only on defecting sections of the incoming boards that could adversely impact the laminating process (e.g. loose knots, inclusions with bark or fibrous debris, larger ratio of wane/reduction in face gluing surface area, etc), or the material handling of the lamella through the line (larger knots or splits that may cause the lamella to break while propagating through the remanufacturing line to the pressing areas).

In standard grade, glue "squeeze through" may be visible between boards or through knots and visual defects. Knot voids where loose knots have been removed or have dropped out, are not uncommon in standard grade EWP.

Figure 172: Example of surface on standard grade EWP; a) H1.2 Treatment; b) H3.2 Treatment.

49.1.1 Standard (Non-Visual) Grade Common Properties

Figure 173a to g illustrate common grading inclusions in standard grade EWP. Represented dimensions in the figures are examples only and should be considered in addition to the details provided in section 50.1 above.



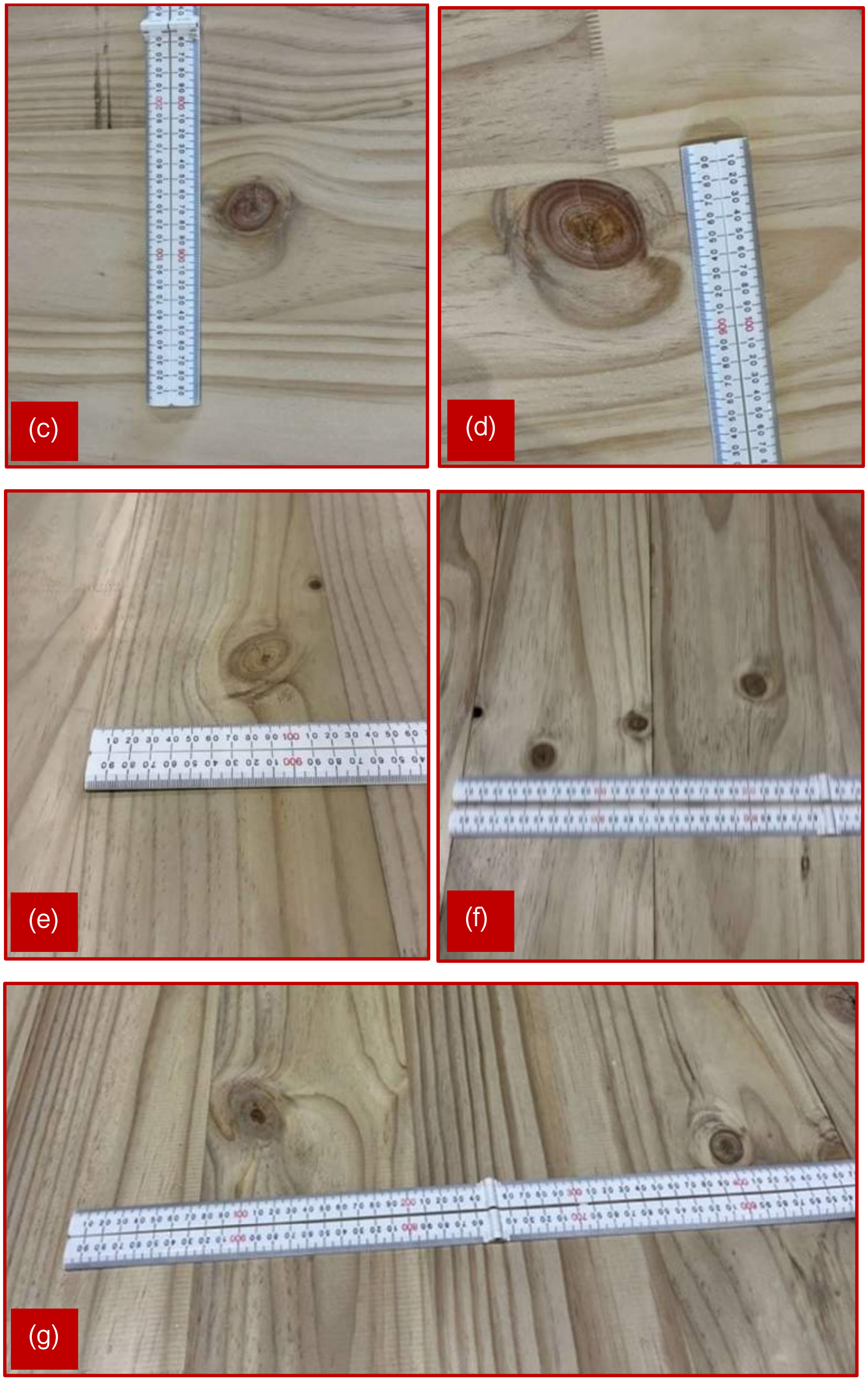


Figure 173: Example of knots, wane and knot voids in Standard (Non-Visual) Grade of CLT panels.

49.2 Visual Grade

Visual grade EWP has the same structural properties as standard grade. The only difference is the improved aesthetics generated by a higher aesthetic grading criterion. Visual grading is defined into three categories (refer to *Figure 174*):

1. Visual F1: One visual face only.
2. Visual F2: Two visual faces only.
3. Visual All: All layers are visually graded. Typically, only utilised for elements that have exposed processing through the cross section such as stairs.

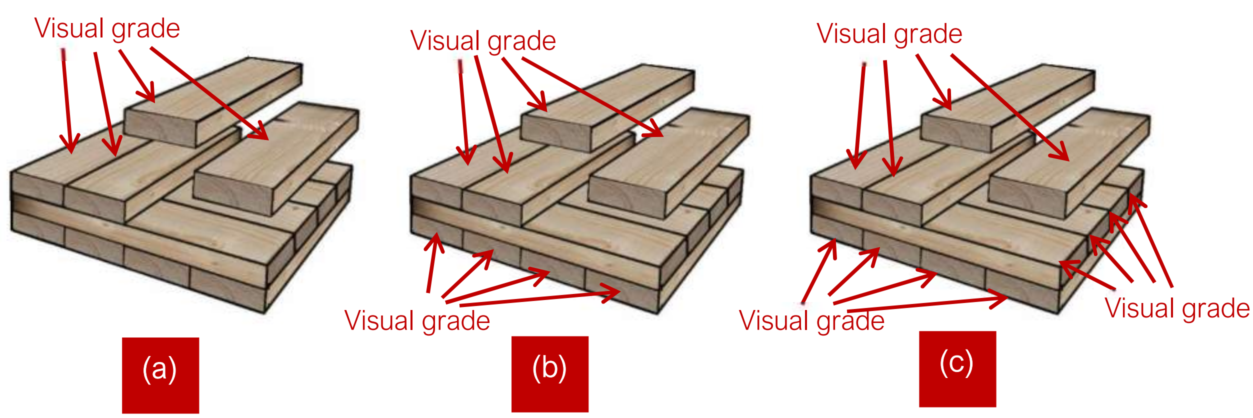


Figure 174: Visual grade options; a) Visual F1, b) Visual F2, c) Visual All.

The details on the higher grading criteria associated with a visual grade are detailed in *Figure 174*, *Figure 175* ,and summarised as follows:

- Larger knots will be removed so that their surface area on the visible face is generally no greater than 25 cm2.
- Free of resin as much as practically possible.
- Free of planer skip.
- Little to no wane, typically no more than 4 mm bevel on each lamella edge
- Lose knots and knot voids generally no greater than 10 cm2.

Filling and sanding is not included in visual grade EWP as a default service. The option exists for filling and sanding EWP elements; however, this needs to be specified, quoted, and agreed in advance with Red Stag. Typically the recommendation would be to do this on site, so that finishing can be completed once the building is fully enclose, water tight and completed with finishing trades.

If filling and sanding services are agreed for the element(s), Red Stag will use its default filler colour and type unless specifically advised by the Client and agreed by Red Stag (the specifics must be including in the Red Stag quotation for this option to be processed). Examples of visually graded EWP billets are shown in *Figure 175*.

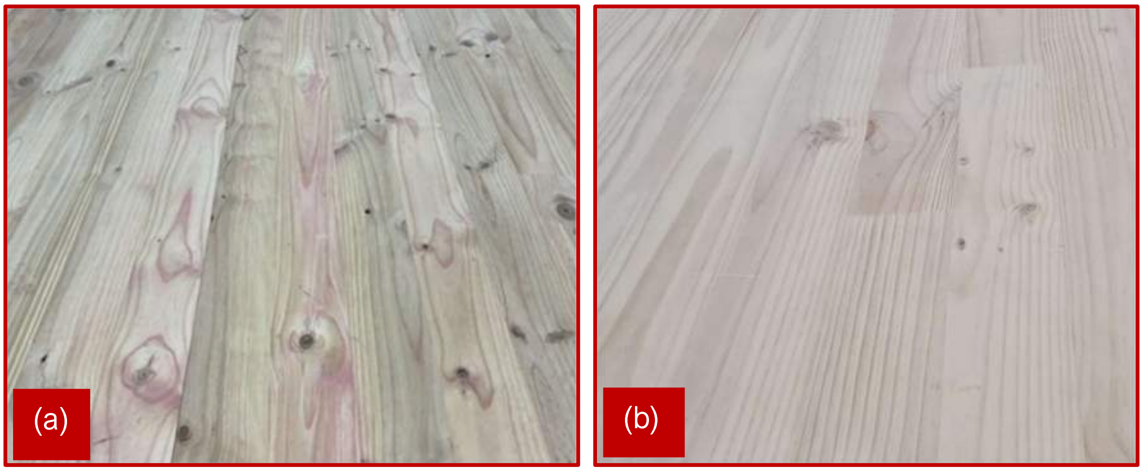


Figure 175: EWP Visual Grade Surface; a) Standard Grade Surface; a) Visual Grade Surface.

49.3 Lamella Feedstock

Unless specified by the Client and accepted in the Red Stag order confirmation, all lamella widths will be based on the available feedstock at the time of manufacture. The feedstock lamella widths may vary between panels in a project but will not vary in the face of each billet. Please note that slight variances in the finished lamella widths will exist due to the automated software management of the remanufacturing process by the supplier's Prolam software (refer to *Section 49*).

As at the time of this document being created, the primary incoming feedstock board width at Red Stag (pre-planed) is 140x45 mm; however can technically range between 90 – 305 mm in width. Based on the dimensions of the raw billet, the Red Stag remanufacturing line Prolam control software will automatically plane all lamella in each layer of a billet to the same width to ensure the overall billet dimensions are obtained via a whole number of boards (all boards in the layer produced to a uniform width within tolerances).

If the finished gauge lamella width is particularly important for a Client, they must specify this at the onset of the project, and have it agreed to in writing in advance and specifically referenced in the Red Stag quotation. Tolerances of no less than ± 4 mm in feedstock width will still exist due to the automation of the manufacturing software to customise the lamella width with the overall billet width.

For standard grade billets, unless there is a specific fixing detail that requires a board width specification, all lamella will have a default feedstock width.

Please note that Red Stag conducted a series of tests with Scion to determine the impact on board width to thickness on the rolling shear performance in EWP panels. The results confirmed that a lamella width to thickness ratio of 2:1 still performed in excess of the design criteria for Red Stag CLT (over 1.6 MPa in testing).

49.4 Treatment

Red Stag treat all EWP feedstock to a minimum of H1.2 (Boron). H1.2 treatment is suitable for the majority of EWP applications; however, the option also exists for H3.2 (Copper Chromium Arsenic (CCA)) treatment in applications that have higher risk of exposure to moisture. It is essential that Clients refer to the Building Code and the project design specifications to confirm the correct treatment solution is selected for each application and EWP element.

EWP elements must be manufactured with the same treatment solution throughout the cross section (the opportunity does not exist to treat different layers with alternate treatment options).

49.4.1 H1.2 Boron

Boron is a natural element that is used to support the preservation of timber. Boron is frequently added to soil to lift the nutrient uptake and human dietary supplements to improve health and wellbeing.

Typically boron treatment has a light fast pink dye added to illustrate the presence of treatment. As Red Stag provides visual grade options, investment has been made in clear boron treatment infrastructure. The clear boron solution ensures the performance of all treated feedstock (raw feedstock) adheres to the New Zealand NZS3640:2003 (Chemical preservation of round and sawn timber) standard.

Based on clear Boron feedstock being used, Clients should not see any tangible aesthetic difference between Red Stag's H1.2 treated EWP and untreated alternates. Examples of Red Stag EWP with traditional dyed H1.2 and clear H1.2 treatments are shown in *Figure 176*.

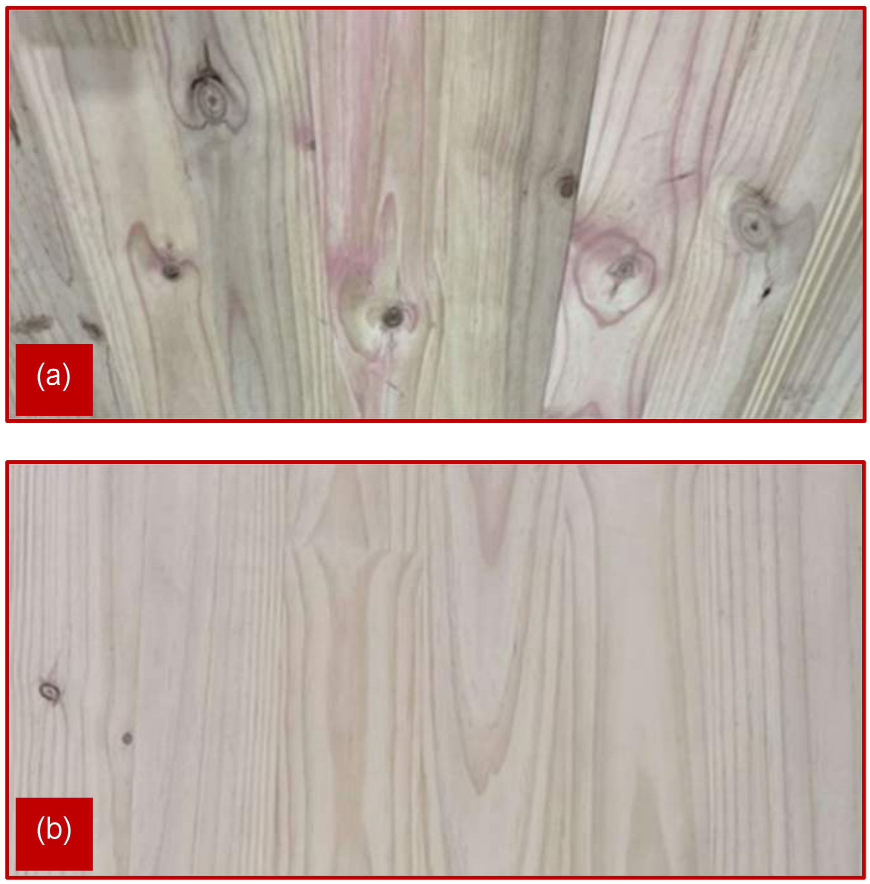


Figure 176: Red Stag H1.2 treated EWP panels: a) Traditional pink dyed H1.2 treatment; b) Clear H1.2 Treatment.

49.4.2 H3.2 CCA

Red Stag also provides the option to treat to a H3.2 level for applications where there is a higher risk of exposure to moisture.

Due to the chemical composition of H3.2 treatment (Copper, Chromium and Arsenic), the finished EWP will have a slightly green appearance in the timber (refer to *Figure 177*).

Figure 177: Red Stag H3.2 treated EWP panels generating a slight green tinge; a) Open View; b) Close View.

Section 13

Red Stag CLT Composite Products

Red Stag CLT Design Guide V1.5
September 2024

50. Red Stag Composite Components

Red Stag CLT composite Tee, Double-Tee, and Box beams represent three efficient and economical forms of structural Engineered Wood Product (EWP) composite beam elements to support a wide range of structural applications for multi-storey buildings. Refer to Figure 178.

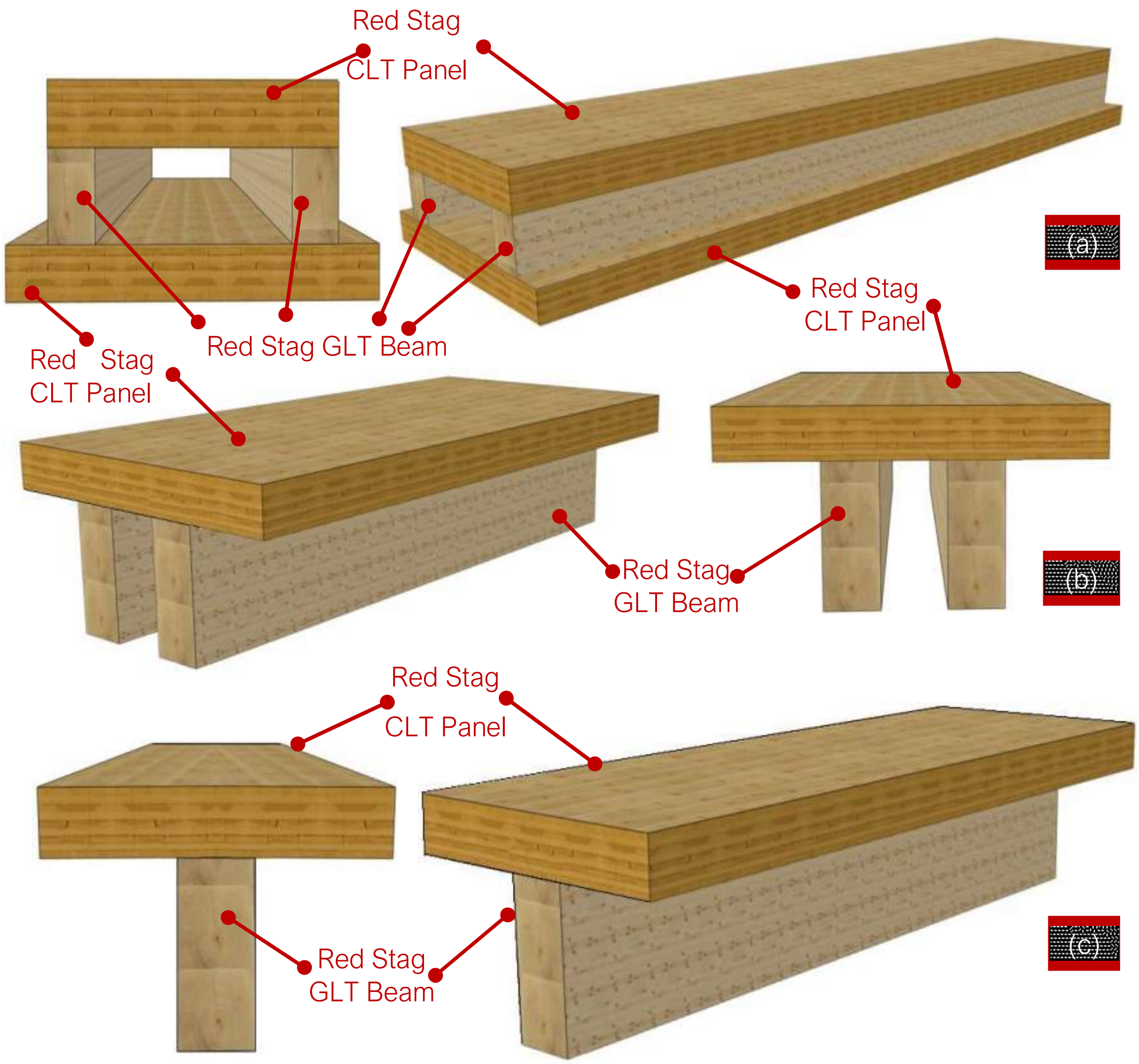


Figure 178: Red Stag EWP composite beams; (a) Red Stag CLT and GLT_b composite Box beam; (b) Red Stag CLT composite Double-Tee beam; (c) Red Stag CLT composite Tee beam.

Red Stag CLT composite Tee, Double-Tee, and Box beams consist of a Red Stag CLT flange panel attached to either a Red Stag CLT or GLT_b girder (beam). The

Red Stag CLT flange panels are machined/predrilled and mechanically connected by screws to the Red Stag girder. Depending on the design criteria, Red Stag can combined adhesive (e.g. epoxy) with mechanical fixings to enhance the connect. Refer to *Figure 179*.

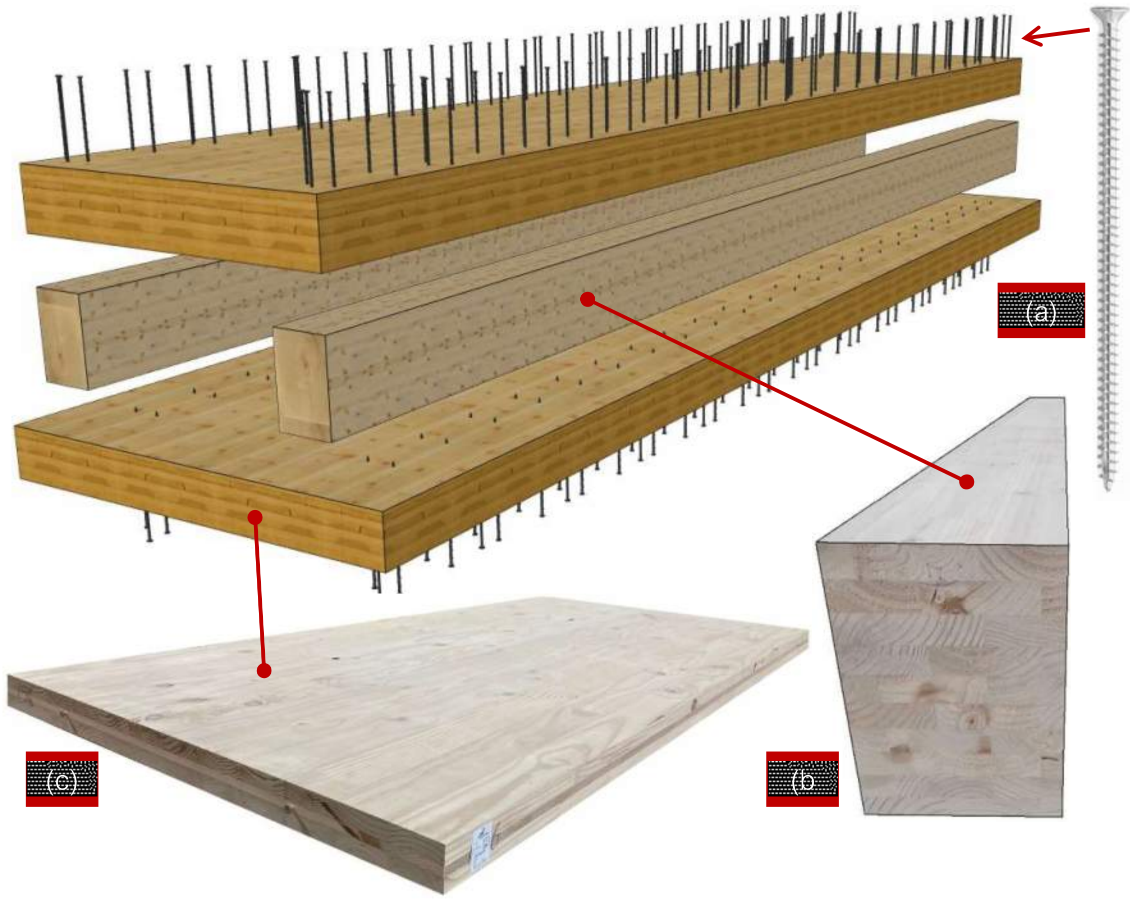


Figure 179: Example of Red Stag EWP composite beam components and assembly; (a) Red Stag CLT panels; (b) Red Stag GLT_b girders (beams); (c) Long structural screws.

Red Stag's expertise, experience, and modern manufacturing facilities provide the capability to manufacture large complex symmetric or asymmetric EWP composite beam systems (Refer to *Figure 179* and *Figure 180*). The structural performance of Red Stag CLT composite beams to carry heavy service loads strongly depends on the shear connection between the flanges and web girders.

Red Stag offers a combination of high-quality long structural screws and structural adhesive for connecting the elements to minimise shear between the flanges and webs.

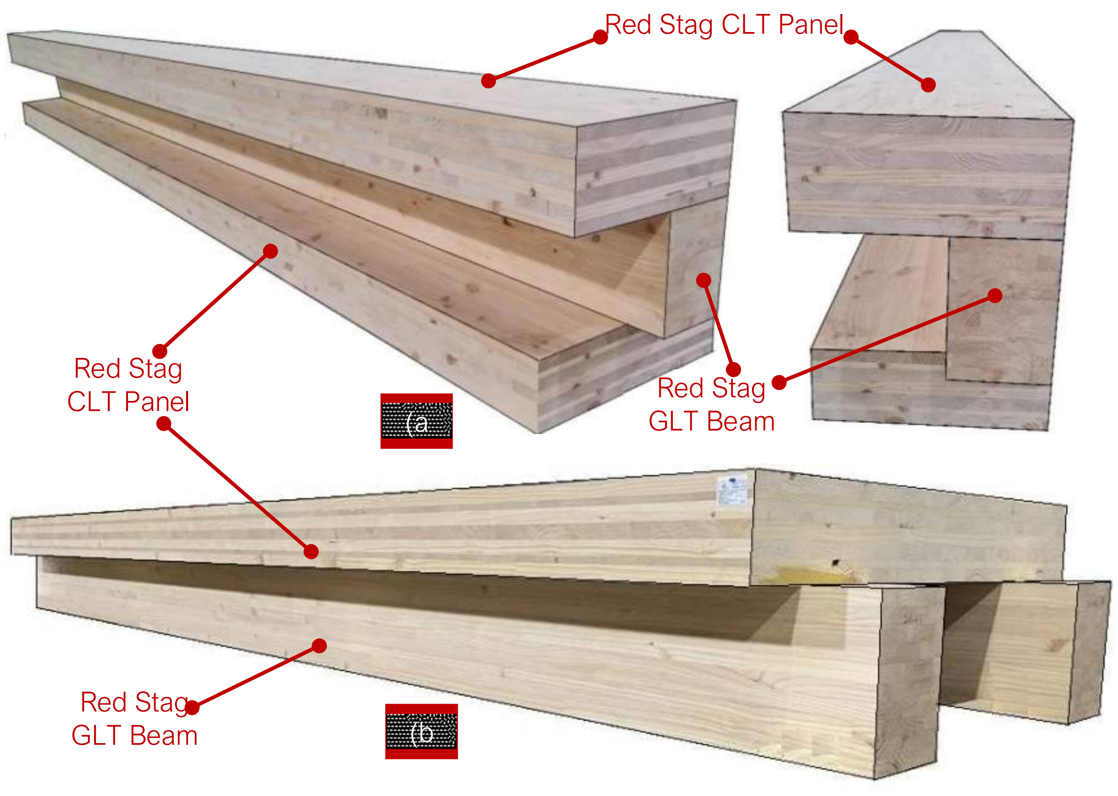


Figure 180: Examples of Red Stag CLT composite beams; (a) Red Stag CLT and GLT_b composite Box beam; (b) Red Stag CLT composite Double-Tee beam, (c) Red Stag CLT composite Tee beam.

When a solid CLT and GLT_b (or CLT) composite system with zero shear between the CLT flange and girder (GLT_b or CLT), has a positive bending moment applied as a result of service loads, the flange of the girder resists compression. Refer to *Figure 181*.

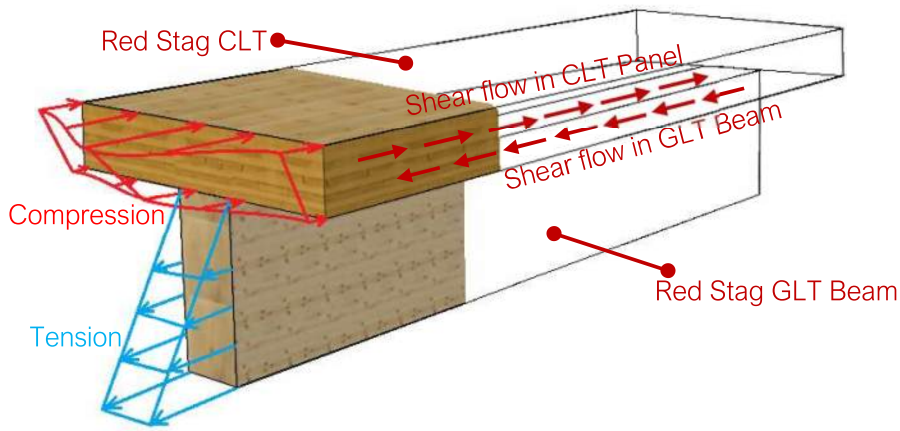


Figure 181: Internal forces in Red Stag composite EWP Tee beam.

The combination of Red Stag CLT flanges and EWP beams creates a high static load-bearing capacity with comparatively low weight. This makes the system a tremendous structural choice for long-span structures and large open areas featuring unobstructed, column-free spaces. Red Stag EWP composite elements are lightweight, cost-competitive, and environmentally friendly compared to equivalent Concrete-Steel composite elements.

Some of the benefits of Red Stag EWP composite structural elements in building design and construction are summarised below:

- Prefabricated and lightweight Red Stag EWP composite beams allow for rapid integration at the construction site. The installation rate is faster than all other alternates with fewer pieces to install, and precision fabrication. Refer to *Figure 182*.

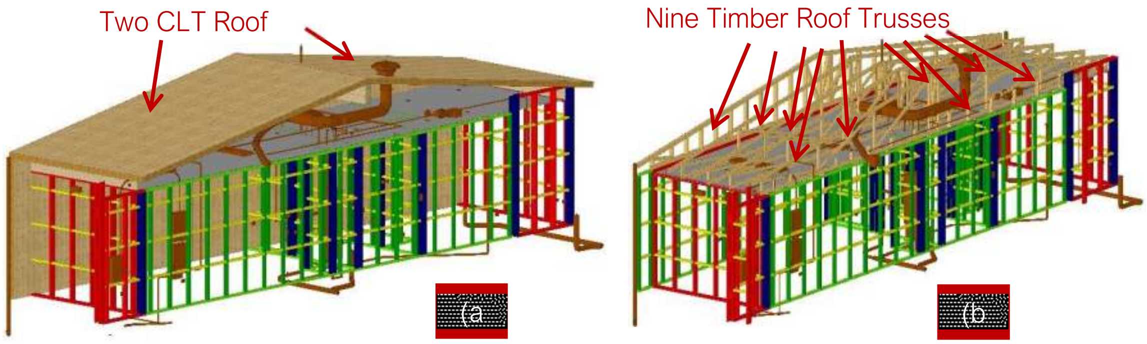


Figure 182: Number of elements in CLT composite system versus Timber Frame and Truss system; a) CLT roof; b) Timber roof truss.

- Red Stag EWP composite structural elements can be left exposed within the building envelope for a beautiful aesthetic appearance. Refer to *Figure 183*.

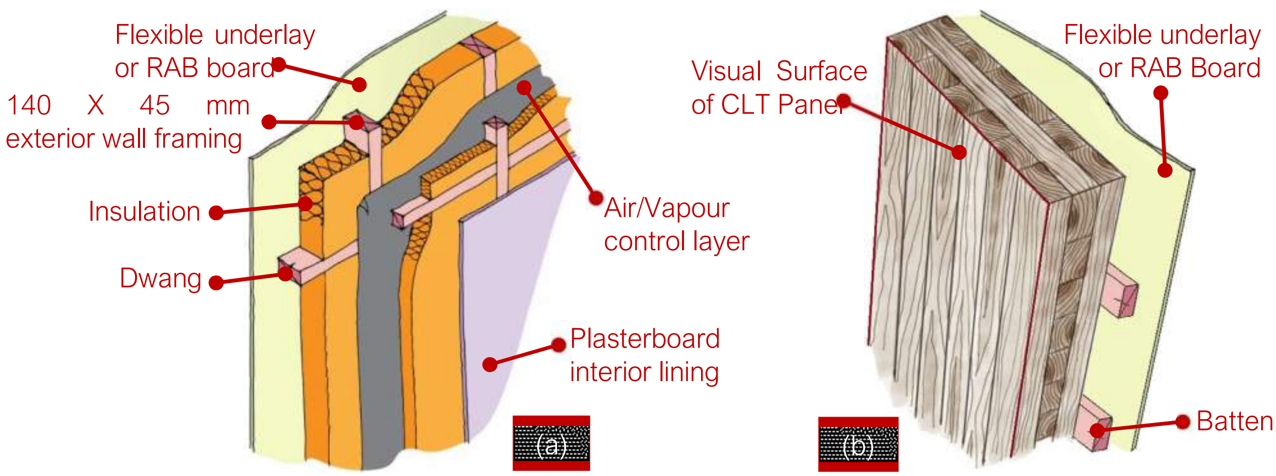


Figure 183: Timber construction systems; a) Timber frame and truss system, b) CLT composite system.

- Red Stag CLT composite beams have natural fire-resistant properties without the need to add protective cladding or painting (refer to Figure 184).

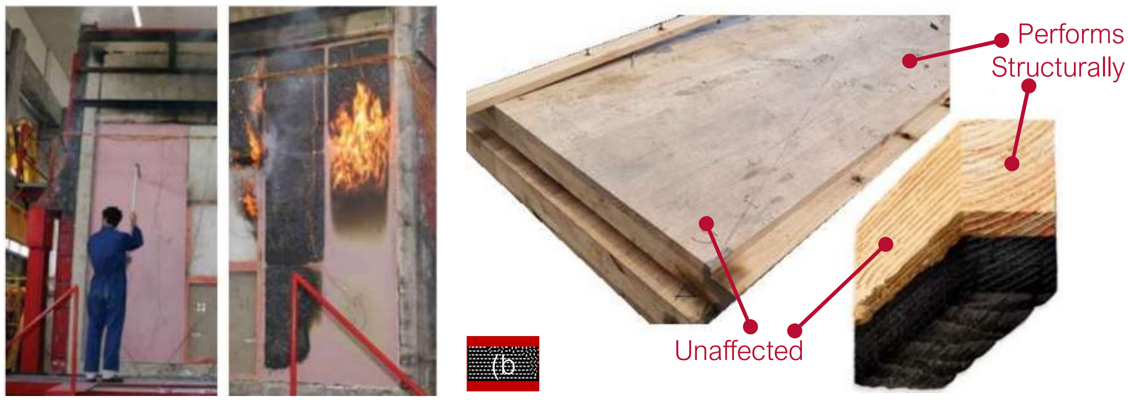


Figure 184: Fire Performance of various timber structural systems; a) Timber frame and truss system, b) CLT composite system without surface protection after 60 minutes fire event.

- Red Stag CLT composite beams have high static load-bearing capacity with low weight compared to composite concrete beam (refer to *Figure 185*).

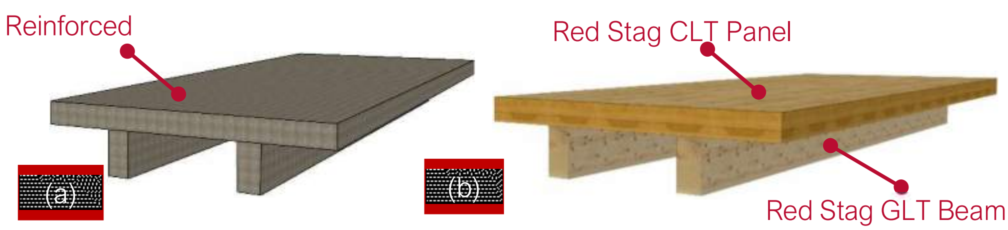


Figure 185: Composite beams; a) Reinforced concrete composite beam, b) Red Stag CLT composite beam.

- Red Stag CLT composite beams are a great structural option for large spans and thus column-free rooms possible.
- Red Stag CLT composite beams have a high degree of prefabrication and simple connection of the ceiling elements for fast and economical assembly.
- Red Stag composite CLT beams are a sustainable alternative to steel-concrete composite beams with reinforced concrete slabs.

Red Stag CLT composite beams are effective and economical structural solutions for spans longer than 6 meters. By choosing a Red Stag CLT composite beam, a raw of columns and beams can easily be omitted and increasing open plan space and making the layout more flexible. Refer to *Figure 186*.

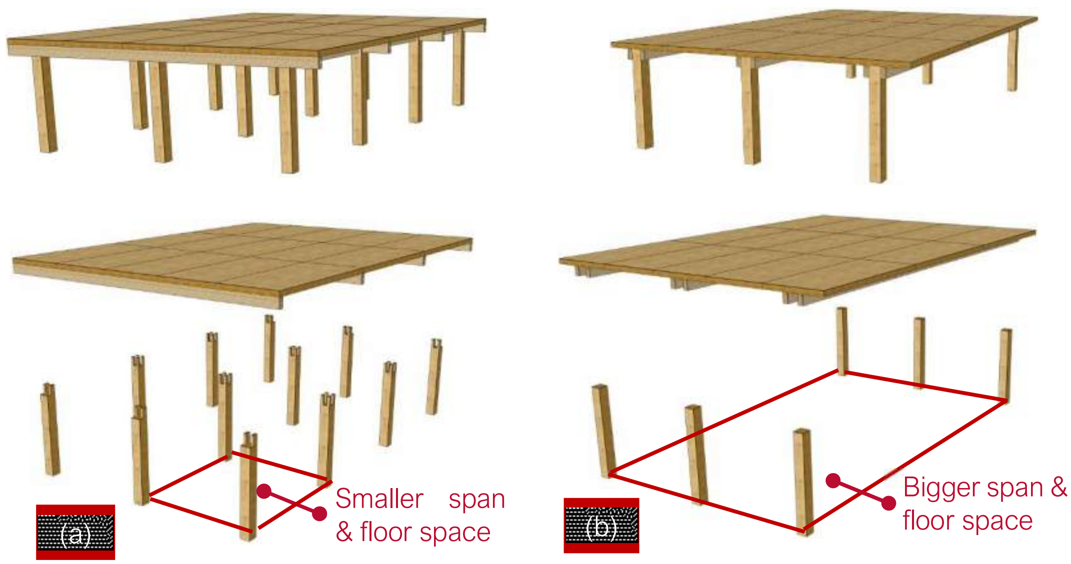


Figure 186: Effect of using Red Stag CLT composite Double Tee beams on structural girds and its impact on floor space and spans; a) post and beam system, b) Red Stag CLT composite beam system.

- Red Stag CLT composite beams have superior strength, stability, and high load caring bearing capacity, at a low weight.
- The space between the GLT girders of Red Stag CLT composite beams can be used to route service lines or other installations.
- The Red Stag CLT composite beams can be ideal for building that required good vibration performance because of higher stiffness (EI).
- Red Stag CLT composite beams are great option for commercial projects with poor soil conditions by reduction of weight of building to reduce the size foundation and related cost.

Red Stag CLT composite beams are comprised of Red Stag CLT panel and Red Stag GLT beams which are high-performance mass timber product that comprises treated, graded boards, which are glued on top of together in cross-layered and brick manner respectively. Red Stag CLT and GLT are 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 187* and *Figure 188*).

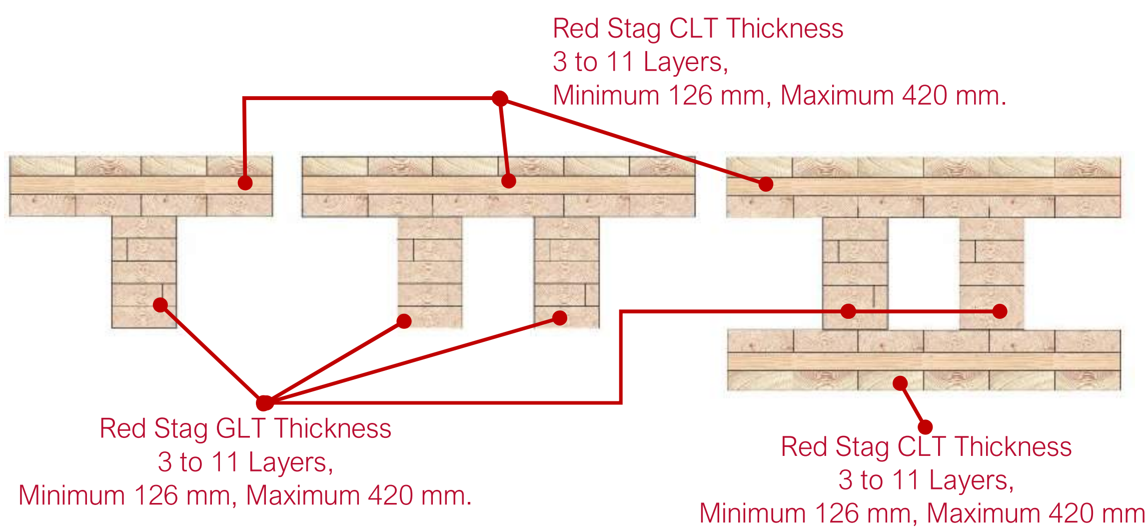


Figure 187: Red Stag CLT and GLT production lamella options.

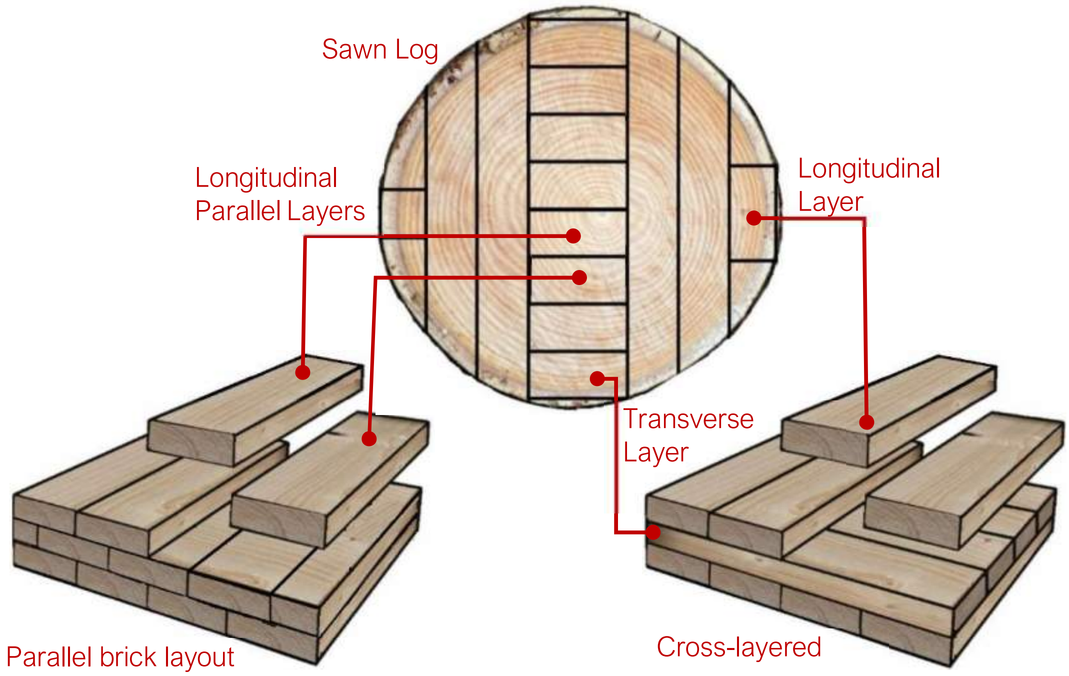


Figure 188: Red Stag CLT panel and GLT beam board arrangements.

New Zealand construction market is using CLT panels and composite CLT structural elements increasingly. Multi-stories CLT buildings are not new phenomenon in New Zealand anymore. An example of Red Stag CLT composite elements application for a multi-stories project in Wellington/New Zealand is shown in *Figure 189*.

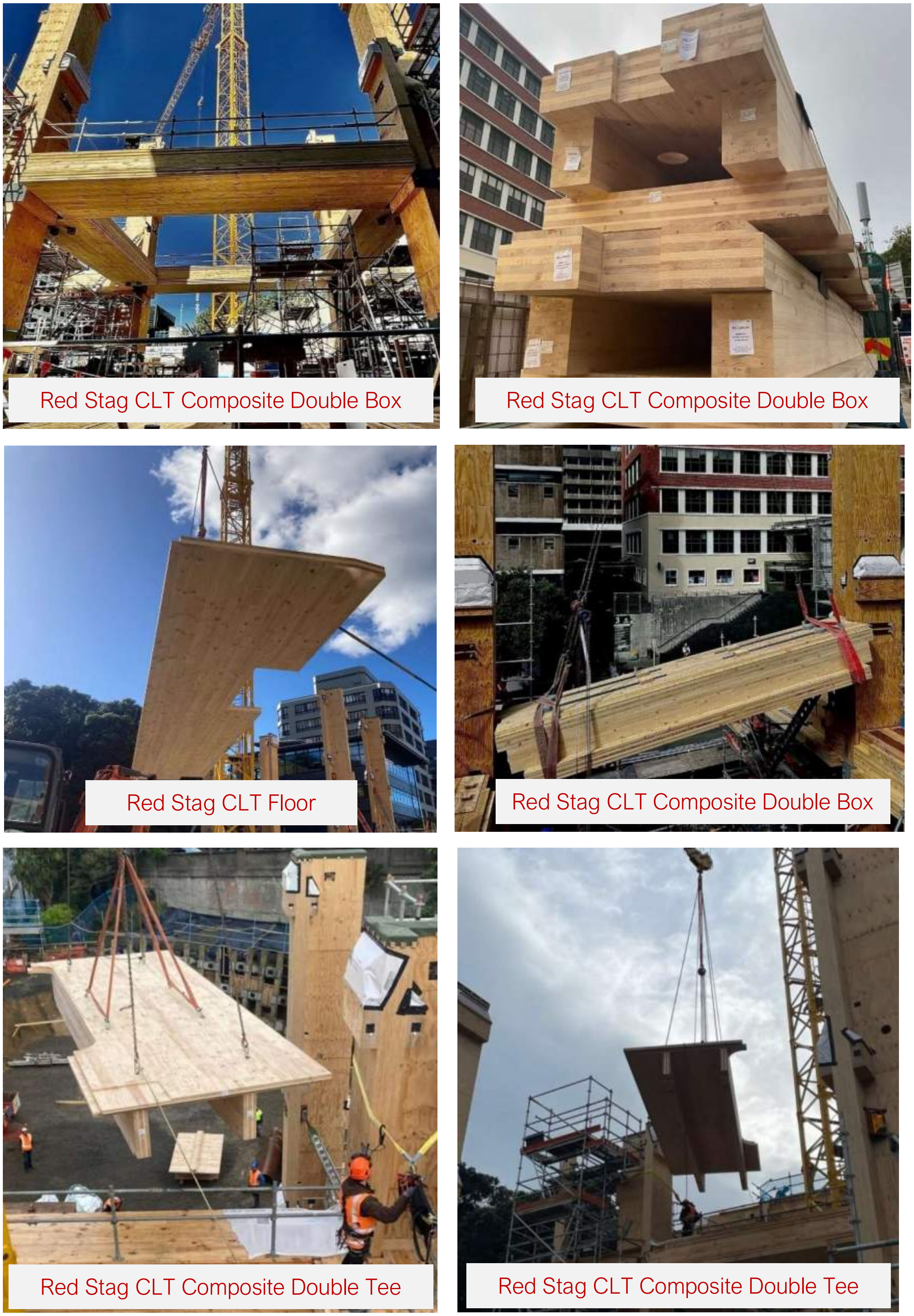
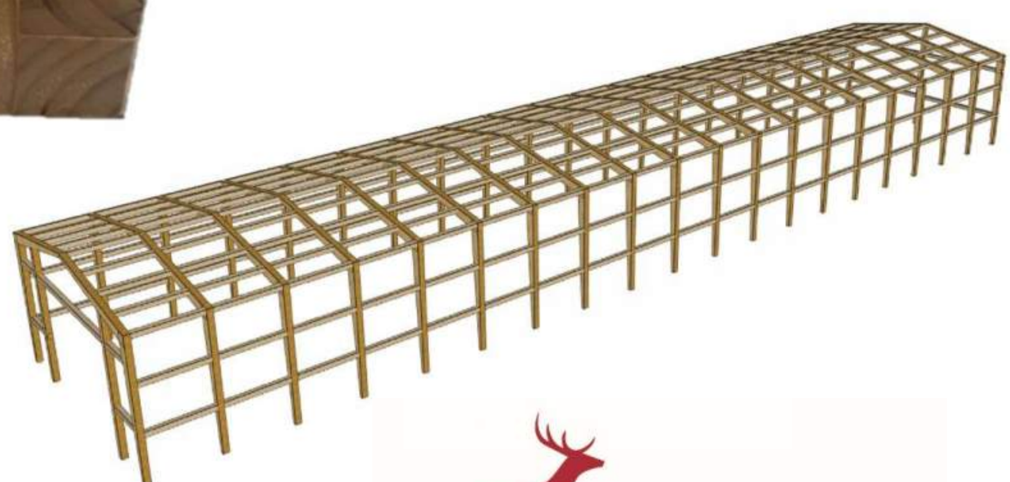


Figure 189: Red Stag CLT composite product installation in Living Pa Project site, Wellington/New Zealand.

Section 13
Red Stag CLT Beam



Red Stag CLT Design Guide V1.5
September 2024

51. Red Stag CLT Beams Overview

Cross Laminated Timber (CLT) beams are a relatively new application for a well proven product. CLT has grown in popularity in the construction sector over the past decade for its speed of installation, reduced mass and environmental benefits. CLT beams are manufactured using the same manufacturing process as any other CLT element (opposing layers glued together 90 degrees out of phase with the previous layer) (refer to *Figure 190*).

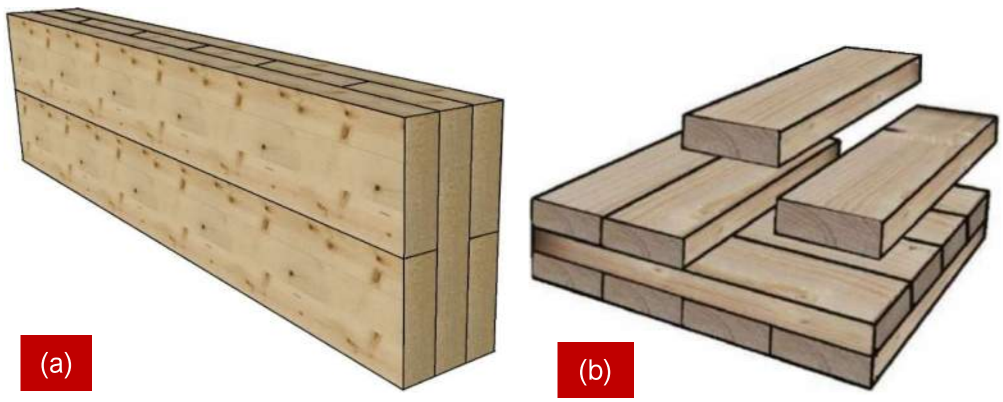


Figure 190: Red Stag CLT beam; a) CLT beam installed orientation; b) Lamella arrangement.

The CLT beam's mechanical behaviour differs from traditional CLT applications (i.e. floors and walls). To support in confirming the mechanical performance of CLT in beam applications, Red Stag has completed extensive internally testing via third party calibrated, and certified equipment used for compliance testing. The internal test programme is in addition to comprehensive testing conducted by third parties (e.g. SCION).

Ongoing test results confirm the performance and suitability of Red Stag CLT in structural beam applications. Advanced compliance test configurations and equipment are illustrated in *Figure 191*.

Figure 191: Large-scale mechanical testing of Red Stag CLT beams conducted by Red Stag; a & b) End Elevation; c) Elevation.

CLT beams provide a very high strength-to-weight ratio comparable to concrete. CLT beams are typically no less than five times lighter, reducing the mass loading on building foundations, which is particularly valuable on sites with poor soil conditions.

Tensile strength is a major advantage of CLT beams over GLT. The perpendicular opposing layers create high tensile strength perpendicular to the CLT beam length/span, making the CLT beams less susceptible to rupture (Refer to *Figure 192*).

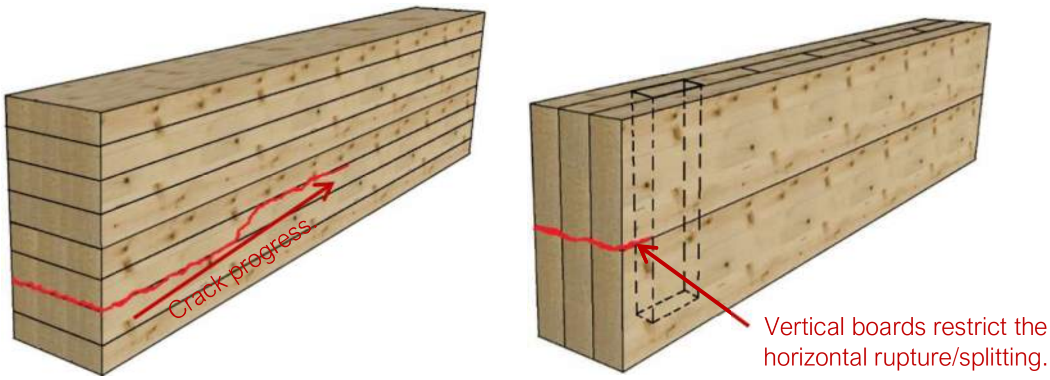


Figure 192: Progressive cracks in beams; a) Traditional GLT beams with continuous progressive rupture; b) CLT beam's perpendicular lamella restrict the rupture from progressing down the span.

CLT beams have superior performance to solid wood for the following reasons:

- Larger knots and defects (Refer to *Figure 193a*) are removed through the remanufacturing process, with shook connected via structural FJ.
- Laminating generates a uniform, homogenous system, with a higher average structural performance (Refer to *Figure 193b*), with improved stability.

CLT beams have a lower risk of lateral deflection compared to structural timber beams due to the fibre layers running in the transverse direction. The risk of lateral deflection increases in deep beams, making CLT beams a superior alternative to GLT in deep formats.

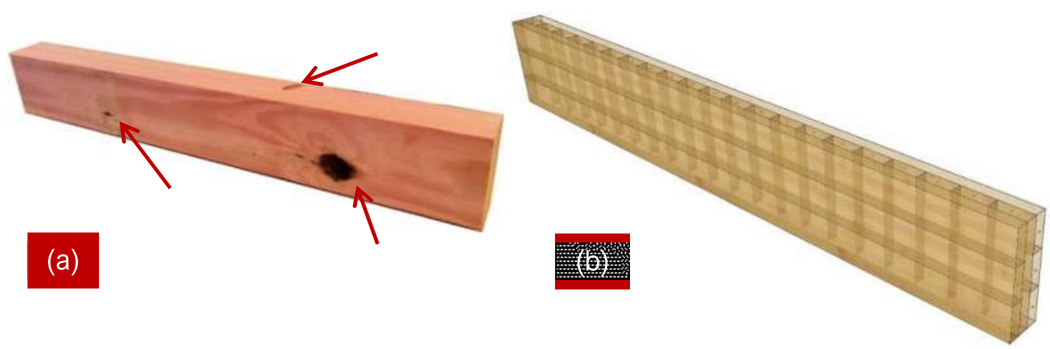


Figure 193: Structural timber beam versus CLT beam; a) Structural timber beam with common defects; b) CLT beam.

The cross-layer configuration of CLT beams reduces the risk of splitting at supports, penetrations, and connections. *Figure 194a* and *193b* compare the additional mechanical fixings required for a circular penetration through GLT versus CLT. *Figure 194c* and *193d* compare the additional mechanical fixings required for a square penetration through GLT versus CLT. CLT beams provide grain to grain support in high compression zones via the transverse layer(s). Refer to *Figure 194e, 193f, 193g* and *193h comparing* the additional mechanical fixings required for load bearing interfaces in higher compression zones. The high-tension capacity in the transverse layers of CLT significantly reduces the risk of splitting in bolt, screw and rivet connections parallel or perpendicular to the grain (Refer to *Figure 194i, 193j, 193k* and *193l*).

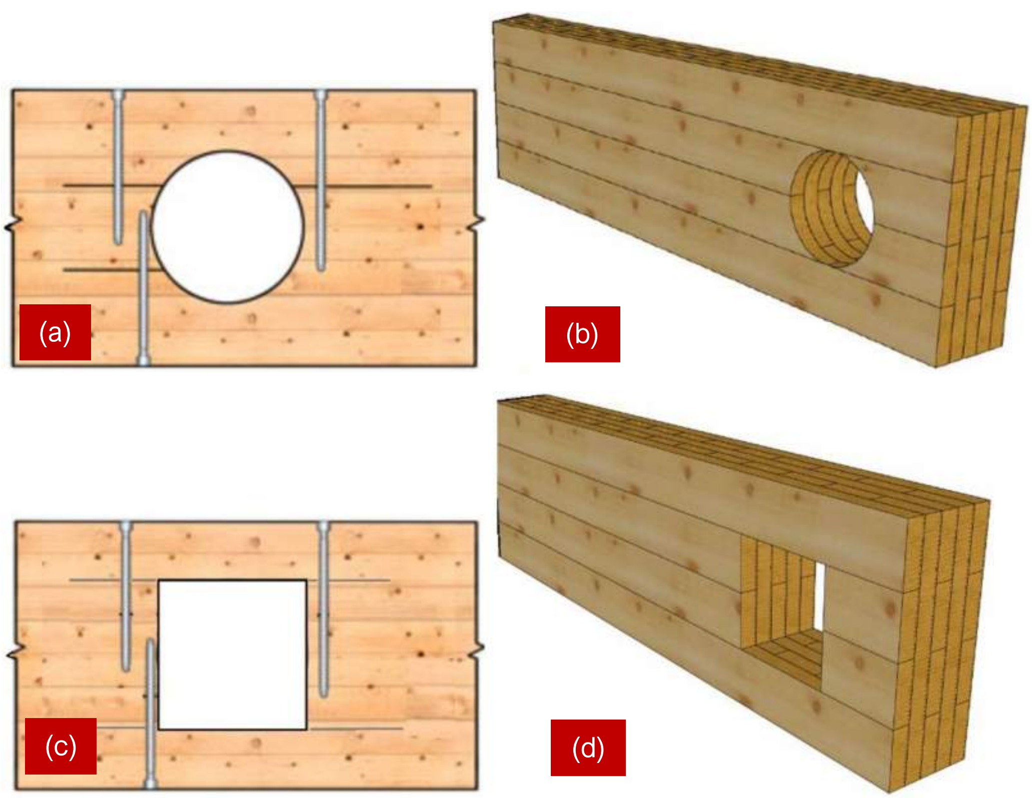


Figure 194: Red Stag CLT beam versus traditional GLT beam configurations; a, b, c, d) Improved reinforcement around openings in Red Stag CLT versus traditional GLT; e, f) Improved reinforcement at notched load interfaces in Red Stag CLT versus traditional GLT; g, h) High compression bearing capacity (grain to grain bearing) in Red Stag CLT versus traditional GLT; i, j, k, l) Improved connection performance parallel or perpendicular to the grain in Red Stag CLT versus traditional GLT.

52.1 Red Stag CLT Portal Beams

Red Stag CLT is a strong, cost-effective structural alternative for portal frame structures. Portal frames are one of the most favoured structural solutions for commercial and industrial buildings whose functions necessitate long spans and open interiors. Red Stag CLT offers designers simplicity, speed and economy in fabrication and erection for portal frame applications.

Red Stag CLT has been tested for portal frame knee connections. The CLT beam to column joint under cycling load has been tested by a third-party certified laboratory to confirm the structural performance in a large-scale application (Refer to *Figure 195*).

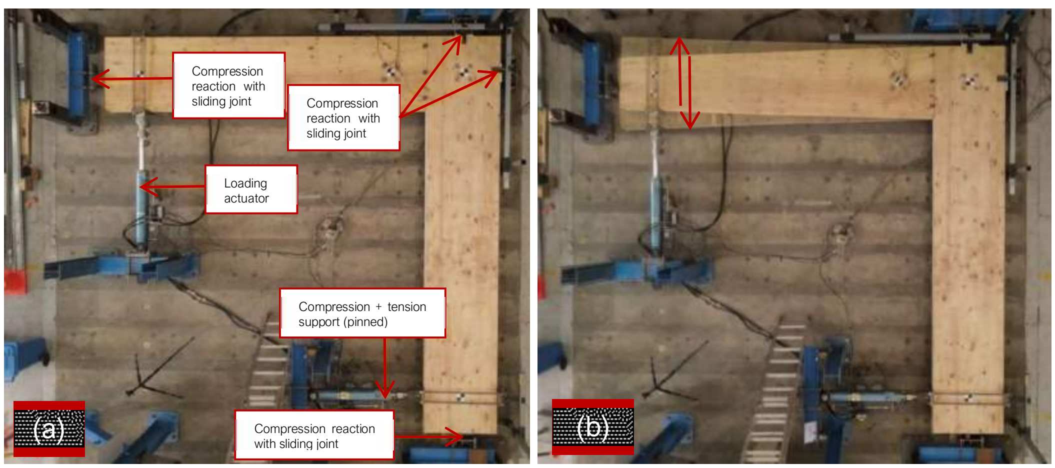


Figure 195: Large scale knee test for portal frame application; a) Red Stag CLT portal frame test set-up; b) Red Stag portal frame under cyclic load.

The experimental testing confirmed that design calculation based on the Timber Design Guide 2007 is conservative when compared to the test results.

An important finding from the testing is that the corner reinforcing screws, which are typically required for GLT/LVL frames, are not required for Red Stag CLT Portal Frames.

The load conditions (test cycling) for the test continued beyond the design properties for the portal frame. Testing concluded with the Red Stag CLT performing more than 2.5 times the bending strength of SG8.

CLT portal frames are an excellent environmentally friendly structural option for replacing commonly used steel portal frames. The environmental benefits of timber portal frames can be further improved by converting steel purlins to Red

Stag CLT or GLT_b (Refer to *Figure 196* and *Figure 197*). The environmental benefit of timber portal frames and purlins, versus the steel and concrete equivalents is presented in *Figure 198*.

According to NS-EN 15804:2012 and BS EN 15804:2012+A2:2019, the core environmental impact indicator for climate change is the Global Warming Potential (GWP). GWP is correlation of sequestered carbon to carbon emissions (kg CO_2-eq). *Figure 198* shows that steel and concrete portal frames have a considerably higher total GWP/m^2 than the timber equivalent.

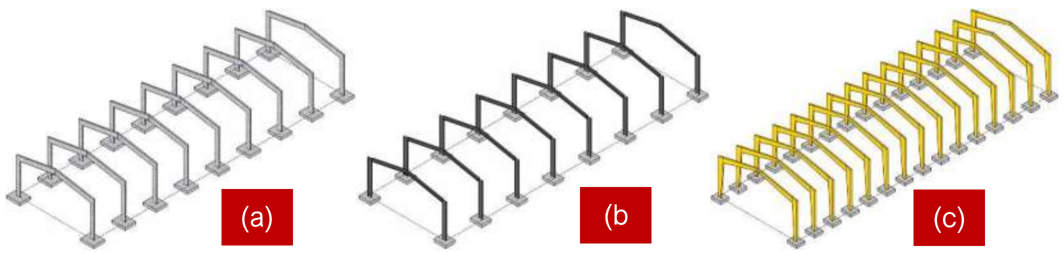


Figure 196: Equivalent representation of portal frame design with steel, concrete and timber; a) Steel portal frame; b) Concrete portal frame; c) Timber portal frame.

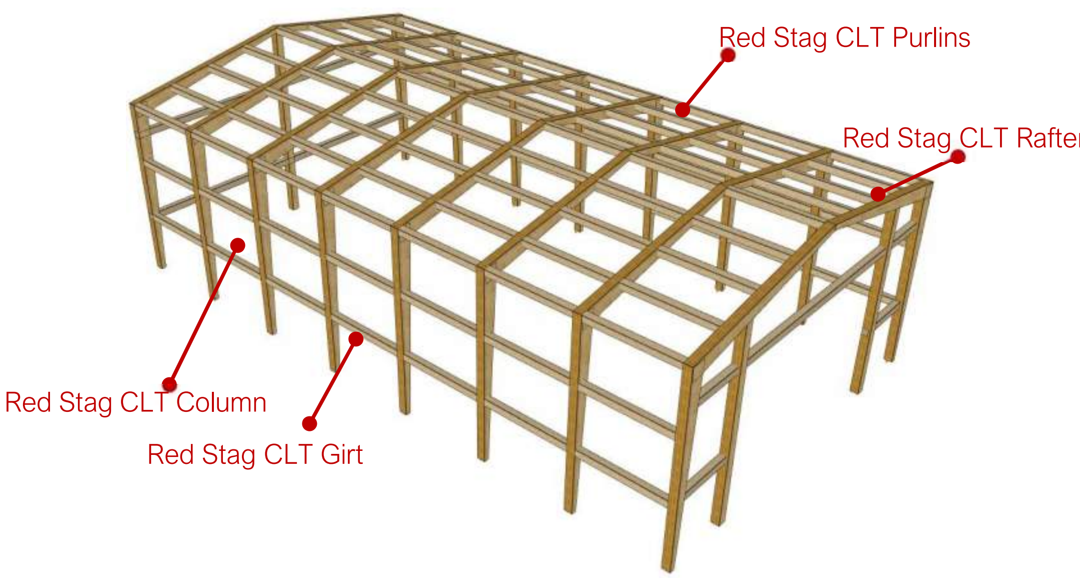


Figure 197: CLT portal frame and CLT purlins.

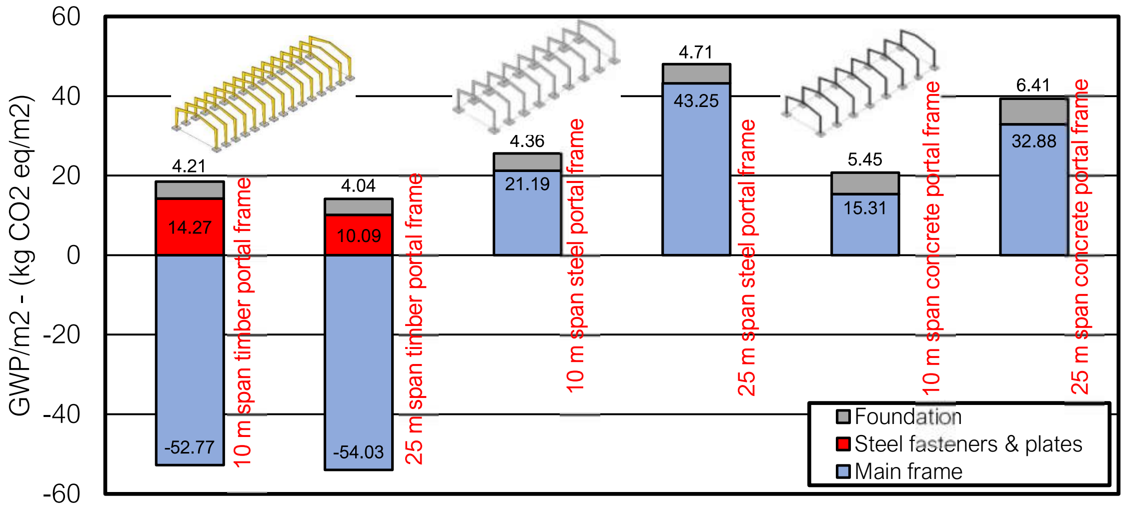


Figure 198: Environmental impact of timber portal frame compared to steel and concrete portal frames.

Depending on engineering design and CNC equipment, the CLT portal frame could have less fibre wastage and fabrication time, making it a more cost-effective alternate to other EWP and steel portal frames (Refer to *Figure 199*).

Figure 199: Fast and efficient CNC processing of Red Stag CLT portal frames; a) Optimisation process of CLT portal frame manufacturing; b) Red Stag CNC equipment; c) Parallel CLT portal frame at Red Stag stacker building; d) Truncated CLT Portal frame.

52.2 Red Stag CLT Lintel Beams

Openings in timber frame walls are typically spanned by horizontal structural members known as lintels. Red Stag CLT is structurally suitable for bridge openings such as windows and doors (More common in wider framing; however, Red Stag is targeting 90 mm alternatives as well) (Refer to *Figure 200*).

Figure 200: Red Stag CLT lintel in a Red Stag Wood Solutions frame; a) Red Stag CLT lintel over a window opening; b) Example of a common Red Stag CLT lintel.

Continuous lintel systems have less deflection under similar load conditions (Refer to *Figure 201*) and provide much larger spans or distance between supports as compared to simply supported lintels. The Red Stag CLT lintel properties are summarised in *Table 59*.

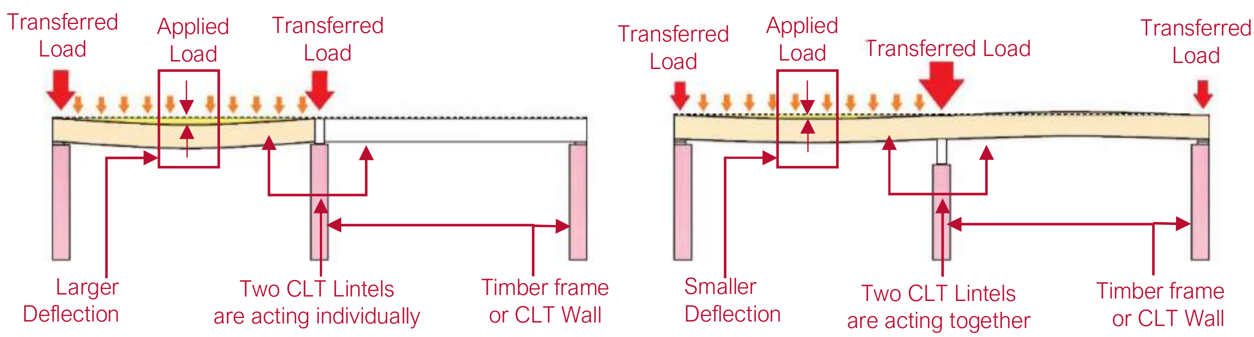
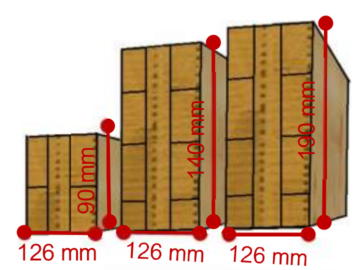


Figure 201: Comparison of deflections between single and double-span CLT lintels to support applied loads.

Table 59: Red Stag CLT Beam Properties [a, b, c, d]

Depth	Width	I (mm⁴)	EI	Z (mm³)	ØMn long	ØMn med	ØMn short	As mm²	ØVn long	ØVn med	ØVn short
90 mm	126 mm	5103000	40824000	113400	1.24 kN.m	1.65 kN.m	2.07 kN.m	5040	10.7 kN	14.3 kN	17.9 kN
140 mm	126 mm	19208000	153664000	274400	3.00 kN.m	4.00 kN.m	5.01 kN.m	7840	16.7 kN	22.3 kN	27.8 kN
190 mm	126 mm	48013000	384104000	505400	5.53 kN.m	7.37 kN.m	9.22 kN.m	10640	22.7 kN	30.2 kN	37.8 kN

[a] MoE of wood planks in longitudinal direction = 8 GPa.
[b] Characteristic of wood planks in longitudinal direction. f_b = 19 MPa and f_s = 3.7 MPa.
[c] Only the capacity of wood plans in longitudinal is consider in the calculation.
[d] Red Stag will verify the calculation by the experimental test with the SCION laboratory.



52.3 Red Stag CLT Beams (and Joists)

Red Stag CLT beams provide an alternative to steel or concrete beams to support floor or roof systems in buildings. *Figure 202* represents a Red Stag floor system build up with CLT beams and CLT flooring. The Red Stag CLT beam properties are summarised in *Table 60*.

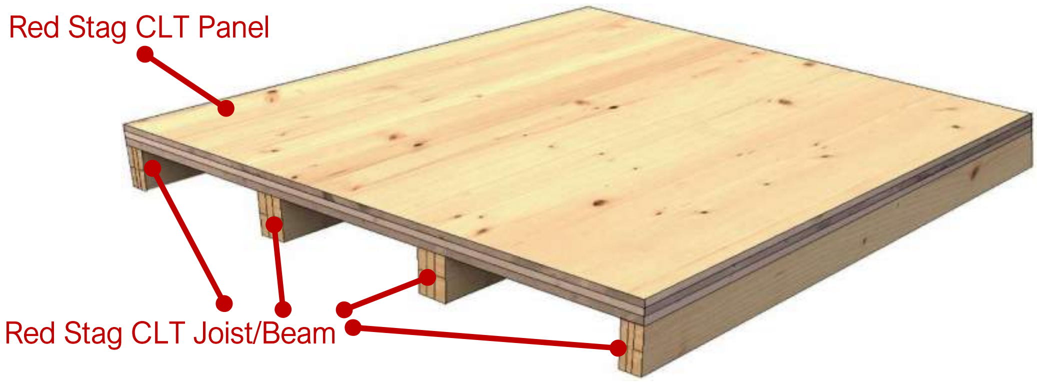
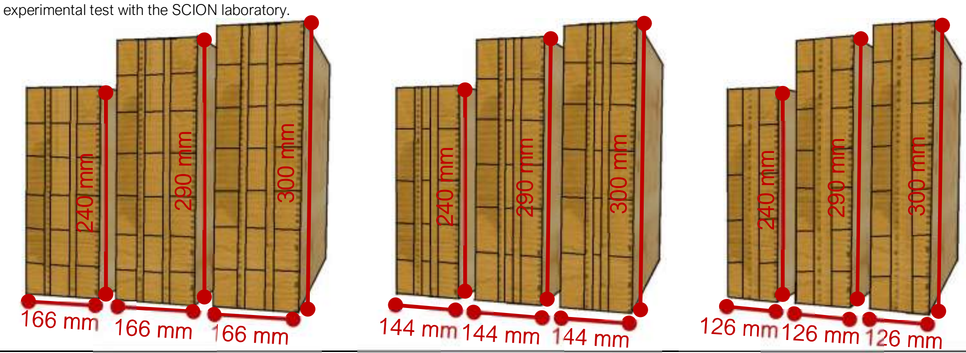


Figure 202: Example of a Red Stag CLT beam and CLT floor system.

Table 60: Red Stag CLT Beam Properties [a, b, c, d]

Depth	Width	I (mm⁴)	EI	Z (mm³)	ØMn long	ØMn med	ØMn short	As mm²	ØVn long	ØVn med	ØVn short
240 mm	126 mm	96768000	774144000	806400	8.83 kN.m	11.77 kN.m	14.71 kN.m	13440	28.6 kN	38.2 kN	47.7 kN
290 mm	126 mm	170723000	1365784000	1177400	12.89 kN.m	17.18 kN.m	21.48 kN.m	16240	34.6 kN	46.1 kN	57.7 kN
300 mm	126 mm	189000000	1512000000	1260000	13.79 kN.m	18.39 kN.m	22.98 kN.m	16800	35.8 kN	47.7 kN	59.7 kN
240 mm	144 mm	119808000	958464000	998400	10.93 kN.m	14.57 kN.m	18.21 kN.m	16640	35.5 kN	47.3 kN	59.1 kN
290 mm	144 mm	211371333	1690970666	1457733	15.95 kN.m	21.27 kN.m	26.59 kN.m	20106	42.9 kN	57.1 kN	71.4 kN
300 mm	144 mm	234000000	1872000000	1560000	17.07 kN.m	22.76 kN.m	28.45 kN.m	20800	44.3 kN	59.1 kN	73.9 kN
240 mm	166 mm	145152000	1161216000	1209600	13.24 kN.m	17.65 kN.m	22.06 kN.m	20160	43.0 kN	57.3 kN	71.6 kN
290 mm	166 mm	256084500	2048676000	1766100	19.33 kN.m	25.77 kN.m	32.21 kN.m	24360	51.9 kN	69.2 kN	86.5 kN
300 mm	166 mm	283500000	2268000000	1890000	20.68 kN.m	27.58 kN.m	34.47 kN.m	25200	53.7 kN	71.6 kN	89.5 kN

[a] MoE of wood planks in longitudinal direction = 8 GPa.
[b] Characteristic of wood planks in longitudinal direction = f_b = 19 MPa and f_s = 3.7 MPa.
[c] Only the capacity of wood plans in longitudinal is consider in the calculation.
[d] Red Stag will verify the calculation by the experimental test with the SCION laboratory.



References

[1] Health Benefits of Wood, An evolving science (online on 2022) Think Wood Website. Website Link: https://www.thinkwood.com/benefits-of-using-wood/wood-and-well-being.

[2] Building sector emissions hit record high, but low-carbon pandemic recovery can help transform sector (online on 2022) UN Report. Website Link: https://www.unep.org/news-and-stories/press-release/building-sector-emissions-hit-record-high-low-carbon-pandemic.

[3] The building and construction sector can reach net zero carbon emissions by 2050 (online on 2022) World Green Building Council Report. Website Link: https://www.worldgbc.org/news-media/WorldGBC-embodied-carbon-report-published.

[4] Chris Bataille (2019) Low and zero emissions in the steel and cement industries," in Green Growth and Sustainable Development Forum, Paris Conference.

[5] Could wooden buildings be a solution to climate change (2019 & online on 2022) BBC FUTURE Report. Website Link: https://www.news.lk/reviews/item/27522-could-wooden-buildings-be-a-solution-to-climate-change.

[6] Forest Stewardship Council (FSC) (online on 2022) Website Link: https://nz.fsc.org/en-nz.

[7] New Zealand Timber Structural Standard (NZS 3603:1993) (2021) Sets out in limit state design format the requirements for methods of design of timber elements of buildings and applies specifically to sawn timber, glue laminated timber, natural round timber and construction (online on 2022) Website Link: https://www.standards.govt.nz/shop/nzs-36031993/

[8] SCION is a New Zealand Crown research institute that specialises in research, science and technology development for the forestry, wood product, wood-derived materials, and other biomaterial sectors.

[9] Henkel laboratory delamination test report based on AS/NZS 1328 delamination test method.

[10] Kayite Symons, Timber, Carbon and the Environment (2020) NZ Wood Design Guides, Chapter 2.1.

[11] FPInnovation CLT Hand Book, FPInnovations is a private Canadian organisation that specialises in the creation of solutions in support of the Canadian forestry sector.

[12] New Zealand Structural Design Actions (AS/NZS 1170.0) (2002) specifies general procedures and criteria for the structural design of a building or structure in limit states format. Covers limit states design, actions, combinations of actions, methods of analysis, robustness and confirmation of design (online on 2022) Website Link: https://www.standards.govt.nz/shop/asnzs-1170-02002/

[13] European Design of Timber Structures, series of European standards (EN) related to construction, Eurocode 5: Design of timber structures (abbreviated EN 1995 or, informally, EC 5) describes how to design buildings and civil engineering works in timber, using the limit state design.

[14] CO_2 Construct (2019) BRANZ, (online on 2022) Website Link: https://www.branz.co.nz/environment-zero-carbon-research/framework/branz-co2nstruct/

[15] TimberFirst is an independent solid timber consultancy providing engineering design, R&D, advanced timber technologies and market development services to the global construction market (online on 2022) Website Link: https://timberfirst.wordpress.com/category/solid-timber-cross-laminated-timber/page/2/.

[16] Robert McCaffrey, Climate change and the cement industry (2002) GCL: Environmental Special Issue.

[17] Andrea Stocchero, Indigenous forestry renewed (2019) Scion Connections, no. Scion Connections, Issue 34, Page 8.

[18] Wood Building - The Future (online on 2022) Website Link: https://wooddays.eu/.

[19] Abaqus FEA is a software suite for finite element analysis and computer-aided engineering, originally released in 1978.

[20] Graham Lowe (2020) Wood, Well-being and Performance: The Human and Organisational Benefits of Wood Buildings, Report for Forestry Innovation

Investment.
[21] Bending formulas with shear and moment diagrams (2007) Design Aid No. 6, American Forest & Paper Association, American wood council.
[22] Greenspec - Crosslam timber / CLT - Performance characteristics (online on 2022) Website Link: https://www.greenspec.co.uk/building-design/crosslam-timber-performance-characteristics/#:~:text=Thermal%20conductivity%20(%CE%BB%20lambanda%20value,element%20to%20a%20higher%20performance.
[23] PÖSCHL, W. (2004): Zuschnitt 14 – Zeitschrift über Holz als Werkstoff und Werke in Holz [Magazine title: Wood as a material and works made of wood], proHolz Austria, Vienna.
[24] Red Stag CLT Floor Passive Fire Details 20211104 (2021).
[25] Red Stag CLT Wall Passive Fire Details 20211104 (2021).
[26] Fire assessment report, Penetrations through Red Stag CLT floor and wall systems (2022) Report Number FAS210260.
[27] Fire assessment report, Fire resistance performance of the loadbearing CLT floors (2021) Report Number FAS210211.
[28] Fire Assessment and span table for three (3) layer Red Stag CLT floors (2021).
[29] Fire Assessment and span table for five (5) layer Red Stag CLT floors (2021).
[30] David Roberts, The many benefits of using wood in place of concrete and steel (2020) VOX. Website Link: https://www.vox.com/energy-and-environment/2020/1/15/21058051/climate-change-building-materials-mass-timber-cross-laminated-clt.
[31] Red Stag Technical Statement Background Information (2022).
[32] Layne Evans, Cross Laminated Timber, Thermal performance and energy efficiency (2013) Sponsored by reThink Wood, American Wood Council, and FPInnovations, Website link: https://continuingeducation.bnpmedia.com/courses/think-wood/cross-laminated-timber/4/#:~:text=The%20commonly%20used%20R%2Dvalue,an%20R%2Dvalue%20of%208.75.
[33] USDA Forest Products Lab Wood Handbook, Chapter 4.
[34] Thermal Performance of Light-Frame Assemblies, Canadian Wood Council.
[35] Heat, Air and Moisture Control Standard, Enclosure, Building enclosure design

for cross-laminated timber construction, Chapter 10, FPInnovation CLT Hand Book, FPInnovations is a private Canadian organisation that specialises in the creation of solutions in support of the Canadian forestry sector.

[36] New Zealand Timber Structural Standard (NZS 3603:1993) (2021) Sets out in limit state design format the requirements for methods of design of timber elements of buildings and applies specifically to sawn timber, glue laminated timber, natural round timber and construction.

[37] New Zealand Structural Design Actions (AS/NZS 1170.0) (2002) specifies general procedures and criteria for the structural design of a building or structure in limit states format. It covers limit states design, actions, combinations of actions, methods of analysis, robustness and confirmation of design.

[38] Section 3, FPInnovation CLT Hand Book, FPInnovations is a private Canadian organisation that specialist in the creation of solutions in support of the Canadian forestry sector.

[39] Bending formulas with shear and moment diagrams (2007) Design Aid No. 6, American Forest & Paper Association, American wood council.

[40] Section 7, European Design of Timber Structures, series of European standards (EN) related to construction, Eurocode 5: Design of timber structures (abbreviated EN 1995 or, informally, EC 5) describes how to design buildings and civil engineering works in timber, using the limit state design.

[41] Section 7, FPInnovation CLT Hand Book, FPInnovations is a private Canadian organisation that specialist in the creation of solutions in support of the Canadian forestry sector.

[42] New Zealand Standard, Methods of Determining the Total Thermal Resistance of Parts of Building (NZS 4214) (2006) Provides methods of determining the thermal resistance of building components and elements consisting of thermally homogeneous layers, in steady-state environmental conditions. (online on 2022) Website Link: https://www.standards.govt.nz/shop/nzs-42142006/

[43] Screws and Connectors for Timber, Carpentry, Structures and Outdoor, Rothoblaas Document. Website Link: https://issuu.com/rothoblaas/docs/screws-and-connectors-for-timber-2021-en?mode=embed.

[44]

[45] Acoustics, Chapter 13.5, NZ Wood Design Guide, May 2020.

Cross-laminated timber manufacturing, Chapter 2, FPInnovation CLT Hand Book, FPInnovations is a private Canadian organisation that specialises in the
[46] creation of solutions in support of the Canadian forestry sector.
Structural design of cross-laminated timber element, Chapter 3, FPInnovation CLT Hand Book, FPInnovations is a private Canadian organisation that specialises in the creation of solutions in support of the Canadian forestry sector.

[47] Mestek, P., H. Kreuzinger, and S.Winter. 2008. Design of cross laminated timber (CLT). Paper presented at the 10th World Conference on Timber Engineering, Juner, 2008, Miyazaki, Japan.

[48] Cross laminated timber as innovative building material. In Prcceedings of CSCE Annual Conference, Quebec, QC. Montreal, QC: Canadian Society for Civil Engineering. CD-ROM.

[49] New Zealand Timber Structural Standard (AS/NZS 1720.1:2022).

Contact Details:

Website: redstag.co.nz

General Enquiries & Quotation Requests: ewp@redstag.co.nz

General Accounts & Finance Team Enquires: accounts@redstag.co.nz

Phone: 0800 RED STG (0800 733 784) Office

+64 7 843 5797