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Utilization of low-grade timber in the construction industry

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ABSTRACT

This study explored the adaptation of the Australian sawn timber industry to evolving market demands, climate change impacts, and variations in harvested wood characteristics. It was driven by a key challenge: the growing misalignment between the increasing demand for high-stiffness timber products and the industry's diminishing ability to supply them, largely due to declining fibre quality from intensively managed plantations. The study aimed to optimize the use of Australian timber resources by reviewing the supply chain of sawn timber products and identifying areas where technological enhancements, process improvements, or new product developments could be initiated. A critical review revealed broad consideration of opportunities for minimising or utilising low-grade timber across the supply chain is currently missing from the literature. The methodology adopted in this study was a combination of literature review, survey and interviews, site visits, and structural modelling. Specifically, the study incorporated detailed structural modelling of representative single-storey and double-storey residential buildings using out-of-grade timber, simulating variable material stiffness and applying probabilistic methods in accordance with AS1720 and ISO 2394 to evaluate structural reliability. In addition to the comprehensive industry review, this study introduces building-scale structural modelling using out-of-grade timber and probabilistic strength comparison against AS1720 and ISO 2394 benchmarks. This engineering-based analysis reveals feasible pathways for the certified use of low-grade timber in residential construction. The research highlighted significant opportunities for employing low-grade timber in residential building construction through an analysis of the mechanical properties of the timber along with building-scale modelling of the structural performance, thereby promoting more comprehensive utilization of the tree. This approach not only adds value to the built environment but also aligns with global efforts to reduce greenhouse gas emissions and enhance profitability across the entire supply chain, from timber growers to end-users. The key findings of this study were that improved data sharing between growers and sawmills could increase fibre quality, custom structural products exist to utilise low-grade timber, existing post-processing technologies can be leveraged to upgrade low-grade timber, out-of-grade timber can be viable in certain residential scenarios, and there is a reluctance in industry to using low-grade timber. Key future initiatives include leveraging findings from previous studies to extend their application into built environments, addressing the mechanical properties shortcomings of materials through innovative technologies, and refining structural design and construction of low-grade timber buildings with advanced modeling. These efforts aim to develop cost-effective, sustainable, and marketable structural solutions for enhancing the viability and environmental footprint of the timber construction industry.

1. Background

The Australian timber processing sector is currently facing significant challenges due to escalating demand and irreversible changes in raw material characteristics. Accelerated global consumption of logs, fueled by decarbonization efforts [1], is pushing demand for low-carbon building materials like timber, which is expected to grow by 3.1 % annually due to urbanisation, decarbonisation, and increased

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housebuilding [2]. Additionally, the bushfire season of 2019/2020 severely impacted the industry, with substantial losses of 19 % and 25 % in plantation timber in Victoria and New South Wales, respectively—effects that will resonate for many years [3].

Despite an increase in harvested volumes from 20 to 30 million m^3 over the past two decades, forecasts predict that log availability will remain flat for the next fifty years [4]. Timber from intensively managed plantations, which often contains a high proportion of juvenile wood by the time of harvest, exhibits different properties from wood produced in natural stands, affecting its suitability for high-stiffness sawn timber products [5,6]. By the time of harvest at around 30 years old, the proportion of juvenile wood in fast-growing pine plantations is often more than 70 % of the log volume [5–8]. Juvenile wood, produced during the early growth stages of a tree, is typically less dense and structurally weaker than mature or latewood.

In Australian timber frame construction, MGP10 (Machine Graded Pine) is the most commonly used structural grade for components such as lintels, top plates, and beams i.e., elements that must withstand significant bending stresses and maintain dimensional stability. Because MGP10 serves as the standard benchmark in timber construction, timber falling short of its material properties is typically classified as 'low-grade'. While juvenile timber and low-grade timber are often correlated, they are not synonymous. Juvenile timber refers to the inner portion of the log, typically formed in the first years of growth, and is characterised by lower density, higher microfibril angle, and reduced mechanical performance. In contrast, low-grade timber is classified based on performance criteria such as stiffness and strength, which can be affected by factors like knots, grain slope or drying defects, regardless of whether the wood is juvenile or mature. Logs with a high proportion of juvenile wood are more likely to yield timber that falls into lower structural grades or fails to meet grading standards altogether. 'Out-of-grade' refers to timber that falls below the minimum structural grade, which in Australia is F4 visually graded timber. There is a growing tension between the increasing demand for high-stiffness timber from the construction sector and the decreasing capacity for mills to produce these products consistently.

The 2019 National Wood Processing Survey by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) sheds light on several aspects of the timber supply chain in Australia [4,9]. This report reveals that most of the 3908,000 m^3 of sawn wood produced in 2016–17 was used in dry structural applications, while a significant amount was also utilized for non-structural purposes such as pallets, fencing, and landscaping. Despite no reports of low-grade timber imports, a substantial value of wood-based panels was imported in 2020–21, totaling 689 million Australian dollars [9]. The total value of timber imports for that year was $5.4 billion, a decrease of 3 % from the previous year, with the bulk of these imports consisting of paper and paperboard [9]. Moreover, the value of exported low- and high-grade wood products was $2.7 billion, reflecting an 18 % decrease from the previous year, largely due to a decline in international prices for woodchip and paper products, which constitute a significant portion of the export volume [9].

Global timber production strategies are primarily designed to address climate change and facilitate wealth creation by increasing the volume of timber, often for non-structural applications. Despite these efforts, concerns about the declining material characteristics, such as stiffness, remain under-discussed in the industry [10–12]. Canuel et al. [12] propose several methods to enhance the value of the wood supply, including improving product quality, increasing the quantity of products and by-products, expanding productive areas, and boosting yield per unit area. These strategies often involve intensive silvicultural practices that may not necessarily enhance wood quality. Countries like New Zealand [11] and Scandinavian [10] nations often adopt monoculture approaches to maximize production efficiency. In contrast, Canada advocates for a diversified approach that aligns with sustainable development principles, focusing on harvesting timber based on specific characteristics to enhance the robustness of forest management strategies against climate change [12–14]. This strategy includes selecting species for their desirable traits and enhancing fibre recovery, with a growing emphasis on diversification for uses like packaging and bioenergy production due to changing market demands. Despite these extensive efforts, challenges remain in improving the overall quality of wood fibre and adapting production to evolving material characteristics, highlighting a critical gap in research and industry practices aimed at balancing quality with quantity.

Recent literature reviews highlight the scarcity of research on the utilization of out-of-grade timber. Cherry et al. [15] critically examined the structural limitations and variability inherent in out-of-grade pine timber, evaluating its potential for use as a load-bearing material in construction. Their study characterised the mechanical deficiencies commonly found in low-grade timber, including knot frequency, grain deviation, and inconsistent strength, and also proposed integration strategies to support its use in modern building systems. Among these, engineered wood products like cross-laminated timber (CLT) were identified as promising platforms to offset variability through lamination and cross-grain reinforcement, thereby enhancing structural reliability. Building on these foundational insights, recent empirical studies have further advanced the structural utilisation of low-grade timber through innovative engineered assemblies. For instance, Gattas et al. [16] introduced controlled lamination processes that enable the formation of panels with predictable stiffness and strength using only two or three out-of-grade boards. This approach effectively mitigates the impact of individual board deficiencies by statistically distributing weaker elements, thereby producing a composite system with uniform mechanical behaviour. Similarly, the Marino et al. [17] investigated structurally optimised floor truss systems fabricated from ungraded or minimally graded hardwood and softwood. Through full-scale testing and computational simulations, the study demonstrates that when used in combination with strategic geometric design and mechanical fasteners, these materials can meet key performance criteria for residential and light-commercial flooring systems. Further reinforcing the viability of low-grade timber, prior work on glued-laminated beams [18] has shown that integrating bonded-in glass fibre-reinforced polymer (GFRP) rods significantly enhances both bending stiffness and ultimate load capacity. This hybridisation technique allows low-strength timber to be used in demanding structural applications by compensating for its material deficiencies with high-performance reinforcement. Such reinforcement schemes, especially when optimised for depth-to-span ratios and service class conditions, offer a scalable strategy for upgrading low-value timber into structurally compliant elements.

Further literature review on juvenile wood yielded limited relevant findings, mainly focusing on tree breeding and selection. Burden and Moore [19] discussed the genetic correlations and the impacts of silviculture on wood properties, particularly in Radiata pine. They explored how silvicultural practices affect the quality of wood, particularly juvenile wood, and its implications for structural wood products. Their findings suggest that juvenile wood typically exhibits properties that could potentially compromise the structural integrity and stability of timber products, such as decreased stiffness and dimensional stability, though it may also lead to a reduction in spiral grain angle and fibre coarseness. They emphasized that enhancing the profitability of timber production hinges on the optimal balance of productivity, cost-efficiency, and the strategic timing of harvests to minimize costs. These reviews underscore a growing interest in harnessing low-quality wood resources, although the direct application of out-of-grade solid timber in residential framing still requires further technical investigation and design standard calibration.

Engineered Wood Products (EWPs) like Cross-Laminated Timber (CLT) are rapidly growing in popularity and demand within the building sector, reflecting broader market trends towards sustainable and innovative construction materials [20]. The demand for natural textile fibres, sustainable packaging, biochemicals, and both thermal and electric

energy is similarly expected to rise significantly in the forthcoming decades. This surge is partly due to the ongoing adaptation of natural forests to climate change, which is anticipated to shift from predominantly coniferous (softwood) to a more diverse range of deciduous (hardwood) species, which are potentially more resilient [21]. Pramreiter et al. [20] note that the timber industry has historically been optimized for homogeneous softwood assortments, but current environmental and market pressures demand a broader range of wood types. In response, three strategic solutions are proposed: (1) enhancing the resource efficiency of products in the industry's decision-making processes, (2) promoting a diverse array of processing technologies, such as integrating sawmilling and stranding processes, and (3) optimizing the efficiency of existing material concepts. Furthermore, emerging research and limited scholarly discourse suggest the potential for new material concepts that leverage low-quality forest resources and develop co-products from existing process streams. A notable example involves analytically designing timber components to conform to specific stress distributions, potentially reducing material usage by up to 20 % [22]. Such innovations do not necessitate altering structural dimensions such as partition walls or ceiling heights, offering practical, resource-efficient solutions in timber design and construction.

In the processing of logs into boards (see Fig. 1), bending stiffness is a critical characteristic that is assessed after seasoning through mechanical or acoustic testing to determine the modulus of elasticity (MOE). Recent studies indicate a decreasing availability of high-stiffness wood, largely due to an increased proportion of juvenile wood, which exhibits greater variability and inferior mechanical properties. Given the substantial variation in structural performance and economic value within a single tree, much of this lower stiffness timber fails to meet the standards of widely used and sought-after machine graded pine (MGP) grades. This variability presents a significant challenge for the construction industry, which is at the forefront of adopting sustainable building practices. As the demand for timber, a key renewable resource, continues to grow, there is an increasing risk of misalignment between supply capabilities and building design requirements, potentially hindering the effective use of forest resources. Thus, optimising the use of available resources and exploring methods to utilise more parts of the tree are essential strategies for improving supply resilience and enhancing construction sustainability.

This study aims to address these challenges by exploring viable strategies for structurally incorporating low-grade timber into the Australian construction sector. The primary objective is to optimise the use of domestic softwood resources by developing cost-effective, compliant, and market-ready solutions that account for both high-grade and underutilised wood. To achieve this, the study adopts a multi-method approach comprising: (1) a comprehensive literature review on low-grade timber utilisation; (2) structured interviews and surveys with engineers, material suppliers, truss manufacturers, and builders to assess industry perceptions and barriers; (3) a detailed case study of a representative softwood mill and plantation operation; and (4) full-scale structural modelling of residential buildings using actual out-of-grade timber data. This integrated methodology addresses a critical engineering knowledge gap by evaluating the structural reliability of out-of-grade timber using probabilistic simulations aligned with ISO 2394 [23] principles. The findings also assess compliance potential under Section A5.2 of the National Construction Code (NCC), proposing pathways for broader acceptance through performance-based design, engineer certification, and CodeMark approval.

2. Current research concerning the utilisation of low-grade timber in the construction industry

This section explores the potential for improving the structural performance and applicability of out-of-grade timber through technological interventions and engineered product development. Building on the insights of King [24], the market-driven approaches alone are insufficient, the focus here is on practical advancements that enhance material performance through classification, treatment, and application-specific design. King [24] highlights the importance of inventory management, physical property assessment, and grouping by material behaviour; however, he concludes that meaningful gains in the utilisation of low-quality timber will come from innovations in processing and manufacturing. In line with this, the following subsections review a range of emerging and established strategies such as composite reinforcement, thermal and mechanical treatment, densification, and panel-based fabrication techniques. These approaches aim to enhance the mechanical properties of low-grade timber and support its integration into structural systems. These strategies are assessed with a focus on their applicability to residential construction settings, and span panel products (e.g., flooring, nail-laminated and stress-laminated timber), reinforced and glued structural members such as glued laminated timber (glulam), carbon fibre-reinforced polymer (CFRP) and glass fibre-reinforced polymer (GFRP)-enhanced beams, truss systems, and modified veneer-based assemblies. The connection between these engineered solutions and the practical requirements of house framing and floor systems is explicitly considered throughout this section. The

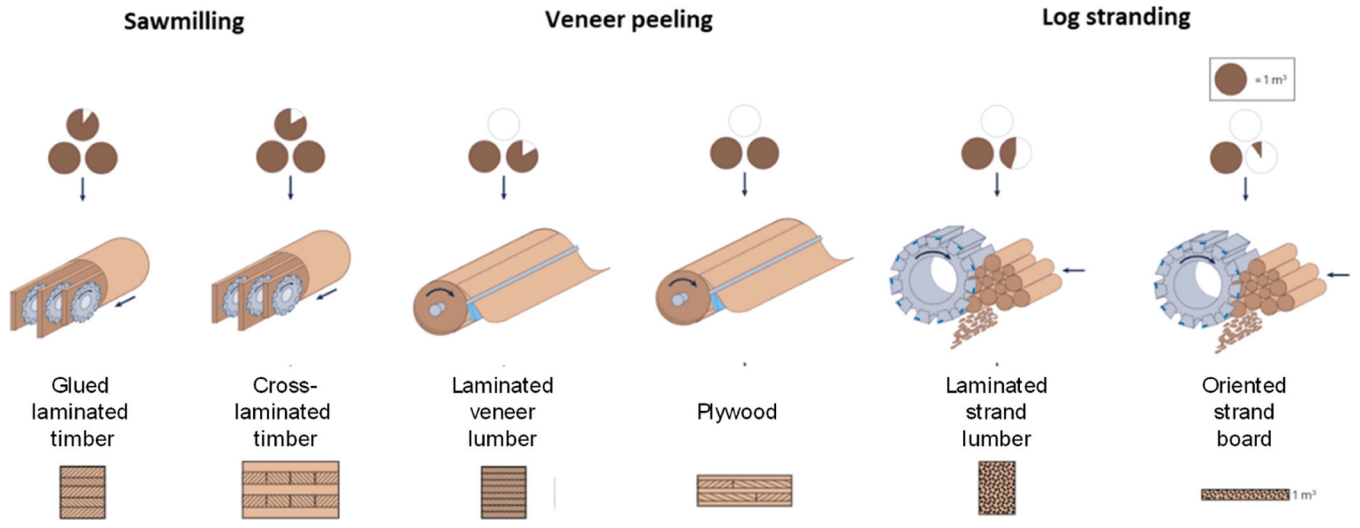


Fig. 1. Resource demand of established engineered wood products. Estimated amount of round wood (without bark) required to produce 1 m^3 of glued laminated timber, cross-laminated timber, laminated veneer lumber, plywood, laminated strand lumber or oriented strand board [20].

literature reviewed was identified through targeted database searches and prioritised based on structural relevance, manufacturing feasibility, and alignment with contemporary design standards.

2.1. Panelling and flooring

2.1.1. CLT production

Cherry et al. [15] reviewed the use of out-of-grade timber in cross-laminated timber (CLT), suggesting that while it can be utilized, extensive research is necessary to fully assess its mechanical properties, gluability, and fire performance. They noted that some timber, despite falling outside standard grade limits, could meet the requirements for use in specific CLT panel layers, especially if lower stiffness is acceptable for non-outer layers, and highlighted the importance of rolling shear stiffness in these applications as shown in Table 1. Gagnon and Popovski [25] found that reducing span/depth ratios in such panels minimally impacts the allowable span. Additionally, they pointed out that the potential layers for out-of-grade timber within CLT could be correlated with their grade characteristics. Rose and Stegemann [26] proposed the innovative use of secondary timber for creating 'cross-laminated secondary timber' (CLST) as a substitute for conventional CLT, though this requires further research for commercial viability. Sigrist and Lehmann [27] demonstrated the feasibility of using non-structural radiata pine as the central layer in CLT, with similar performance to standard panels, provided rough grading is employed. Ma [28] explored the mechanical properties of CLT made with low-value sugar maple and salvaged spruce, showing variable increases in mechanical strength depending on the timber and layup used, with specific layup configurations and their performance benefits.

2.1.2. Hardwood panels

The US Forest Products Laboratory has developed an innovative method for manufacturing solid wall paneling and flooring from small, low-grade hardwood logs [29]. This approach involves breaking down logs directly at the head saw to near-final thickness, rather than using traditional panel-making processes. For drying, panels undergo either conventional kiln drying or press drying, the latter of which reduces width shrinkage by 25 %, contributing to the panels' distinctive appearance. Once dried, the panels are planed to 11.1 mm (7/16 in.) thickness and designed with tongue and groove connections for easy installation using basic carpentry tools as shown in Fig. 2. The finished surface is sanded for smoothness and may receive a natural finish to enhance aesthetic appeal and protection, ensuring a high-quality product with a uniform appearance.

2.2. Reinforcement strategies for low-grade timber for flexural members

The widespread adoption of CFRP and GFRP in the repair and strengthening of civil structures is well-documented [30–33]. More recently, these materials have been incorporated into laminated timber systems to enable structural use of lower-grade wood species [31] (see Fig. 3). Among common reinforcement types, GFRP with E-glass fibres—known for high strength and chemical resistance—offers a favourable balance of performance and cost [32].

Raftery and Harte [34] demonstrated that bonding pultruded GFRP plates to the tension zone of low-grade glulam beams enhanced stiffness by 13 % and ultimate moment capacity by 38 %. Introducing a sacrificial lamination below the FRP plate further increased stiffness by up to 55 %, albeit with limitations due to added section depth. Follow-up studies reported stiffness increases of 11–14 % with 1.4 % GFRP reinforcement in the tension zone, and 22–29 % when reinforcement extended to both faces [18]. Importantly, these studies found that a uniform adhesive could be used across all bonding interfaces, avoiding costlier epoxies [35]. Raftery and Kelly [36] compared the use of basalt FRP (BFRP) and GFRP rods, finding that both yielded similar structural improvements when applied to low-grade glulam at equal reinforcement ratios. BFRP offers potential advantages in fire resistance and environmental exposure, making it promising for specific applications. Meanwhile, recent investigations have examined reinforcement schemes for fast-growing and low-grade timber. Basterra et al. [37] introduced vertical GFRP placement in duo beams to improve aesthetics and fire resistance. This approach achieved up to 12.1 % improvement in bending stiffness (MOE) and 18.4 % in moment capacity (MOR) using only 1.07 % reinforcement [38,39]. These gains are attributed to defect homogenisation and crack-bridging effects. Balmori et al. [40] further verified the strong bond behaviour between GFRP and low-density softwoods using epoxy adhesives.

In addition to FRP systems, metallic reinforcements such as bonded steel bars, perforated plates, and mesh sheets have been explored for flexural enhancement of timber. Studies have shown that embedded or surface-bonded steel can significantly increase stiffness and delay failure [41–43]. While these methods offer high strength, they may introduce corrosion risk and often require mechanical anchorage, making them more suitable for sheltered or hybrid assemblies. Natural fibre reinforcements such as flax, hemp and jute have also attracted attention due to their environmental benefits and cost efficiency. Although their lower modulus and moisture sensitivity currently limit structural application, early studies demonstrate potential for use in non-primary load paths, especially where aesthetics or sustainability are prioritised [44,45]. Together, these findings highlight a broadening array of reinforcement techniques for enhancing low-grade timber performance. The selection of reinforcement type, layout, and bonding method must be aligned with service conditions, target performance, and compliance frameworks.

Table 1
Out-of-grade characteristics potential for layers within CLT [15].

Out-of-grade characteristic	Potential for CLT layers
Low longitudinal stiffness	Transvers layers Central layer
Sloping grain	Transverse layers Central layer
Knots	Top layer under compression Transverse layers Central layer
Shakes, splits, checks, resin and back pockets	Depending on extent and orientation of separation – transverse or central layers Bottom layer
Distortion	All layers – where distortion can be reduced to within acceptable limits through preparation for gluing

2.3. Truss production

Crafford and Wessels [46] investigated the structural viability of juvenile, unseasoned finger-jointed Eucalyptus grandis timber for use in prefabricated roof truss systems. Their work demonstrated that when allowed to dry in situ, green timber performs comparably to South African pine in flexural strength, tensile strength parallel to grain, shear, and compression parallel to grain. Although the 5th percentile values for tensile and compressive strength perpendicular to the grain fell short of the national standards for the lowest structural grade, these properties are typically less critical for nail-plated trusses, where axial loads dominate. The study called for further testing on long-term effects such as checking, shrinkage-induced deformations, and reductions in nail-plate joint capacity under drying and loading conditions. Muhammad et al. [46] highlighted the potential of upgrading lower-grade timber via conversion into laminated veneer lumber (LVL) products for use in trusses. Through veneer reconstitution and controlled bonding, the mechanical properties of the timber can be elevated by up to two strength grades, improving both stiffness and dimensional stability. Section ↱2.6 provides a detailed review of LVL production and its implications for utilising low-grade feedstock in high-performance

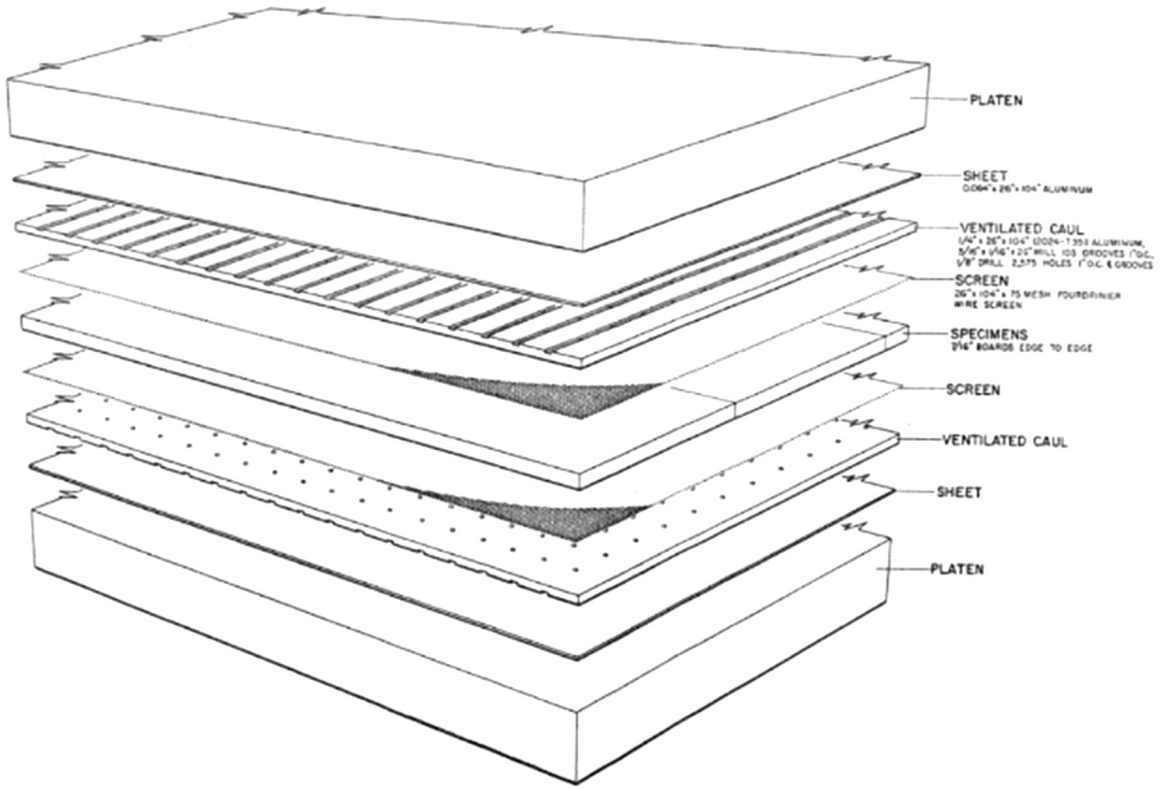


Fig. 2. Detail of ventilated cauls and screens used in press drying [29].

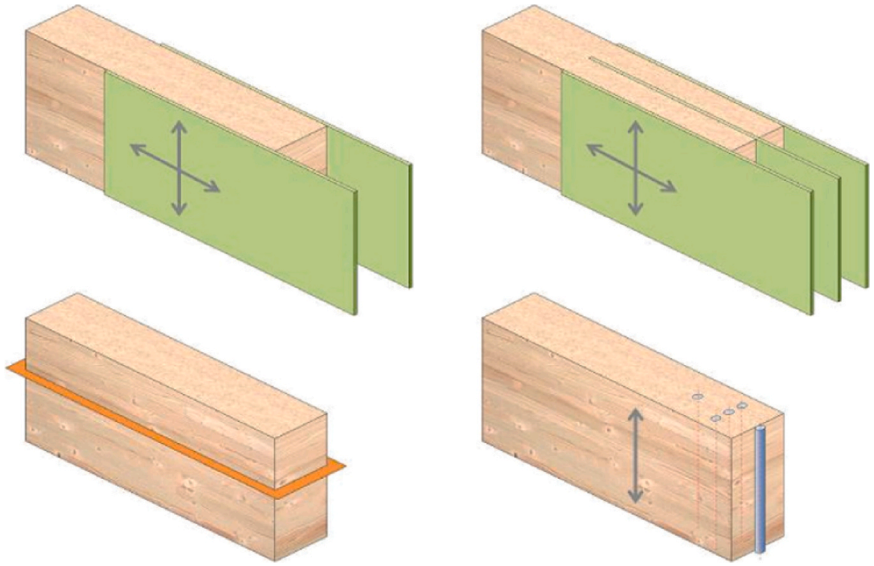


Fig. 3. Schematic diagrams of the reinforcement of wood with FRP [31].

structural applications. Additional studies have explored alternative truss configurations that integrate mechanically graded or composite timber sections to optimise performance while accommodating variability in material quality [47,48]. These include hybrid trusses combining laminated cores with sawn timber chords, as well as the use of tension-only steel elements to relieve stress concentrations in defect-prone timber members [47,48]. Such approaches extend the design flexibility of truss systems and open opportunities for standardising the use of lower-grade or fast-grown plantation timber in structural roof assemblies.

2.4. Timber framing

Wallace [49] investigated laminating and resawing low grade timber into a new product called LamStud to achieve a structural grade stud that meets the Canadian standard (CSA O86). White wood species were assessed including ponderosa pine, lodgepole pine, Engelmann spruce and Douglas fir. The manufacturing of LamStud includes low-grade stud (economy stud) categorisation, assembling/gluing 5-board cants, and resawing and ripping (Fig. 4). The study included establishing visual grading guidelines for the remanufactured studs, developing the gluing and laminating process, performing structural testing of prototypes and

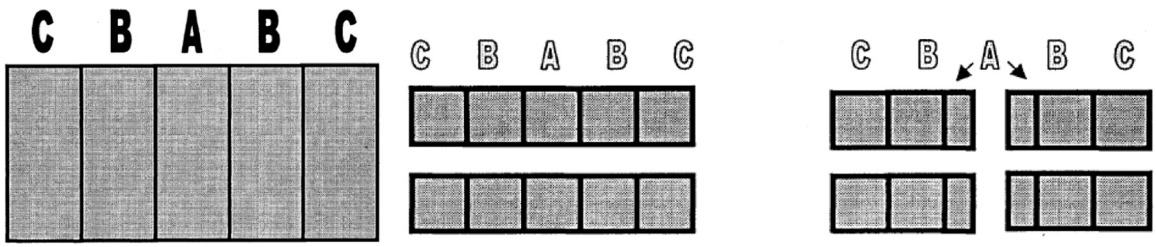


Fig. 4. Layup, re-sawing, ripping of Cants (from left to right) [49].

establishing mechanical properties including MOE, compression strength parallel to the grain, tensile strength and bending strength. Results demonstrated the developed product can meet or exceed the design values for solid sawn timber. Improvement in tensile strength was reported for LamStud reinforced by glass fibre while more research is required to eliminate the delimitation under extreme loads. In addition, the financial analysis demonstrated LamStud has potential for commercialisation.

2.5. Stress-laminated timber

As part of the structured literature review introduced in Section 2, stress-laminated timber (SLT) was examined for its relevance in enhancing the structural viability of both low- and standard-grade timber elements. Stress lamination is a well-established technique that has been used extensively in timber bridge construction for over four decades [50,51]. In this system, timber laminates are drilled and compressed together using high-strength steel rods and outer bearing plates, transferring load through interlaminar friction (Fig. 5).

Freedman and Kermani [51] explored stress lamination as a construction method designed to utilise lower-quality, smaller softwoods from UK forests. Their preliminary study assessed the structural performance of stress-laminated timber decks in arched forms, which comfortably sustained loads of 50 kN at mid-span and withstood over 30 kN in a 4-point bending test. These promising results led to further research involving the construction and testing of nine laboratory-scale arches and two field bridges with spans of 15 m and 20 m. This research [52,53] aimed to fully explore the capabilities of stress-laminated arched timber structures, ultimately facilitating the design and construction of 20 commercial bridges in rural areas that proved to be cost-effective.

The application of stress-laminated timber has since expanded to other structural uses, including roofing. Building on the successful application in timber bridges, the technique was further adapted for the construction of full-scale timber columns using low-grade spruce. Full-scale testing of a 2.4 m column under compression parallel to the grain revealed that stress-laminated columns performed comparably to solid timber and glulam columns [54,55]. Freedman and Kermani [53] observed that prestress losses in stress-laminated columns were effectively controlled and mitigated in the long term by using over-dried hardwood bearing plates, achieving a lamination efficiency factor of 0.84, compared to 0.53 for timber columns connected by self-tapping screws. This factor indicates the effectiveness of maintaining intended friction forces and structural integrity within the structure, crucial for minimising and managing prestress losses for optimal performance and stability.

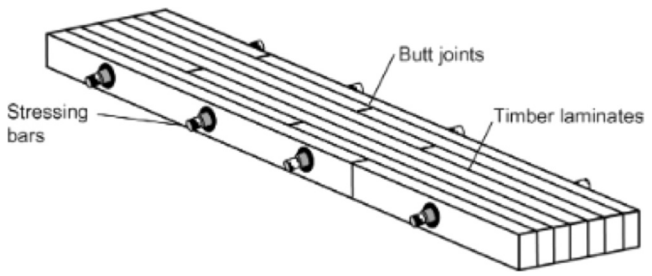


Fig. 5. Stress-laminated timber plate/deck [51].

Moreover, developments in the Australian market have introduced a variety of large screws, which could further support the adoption of stress lamination techniques. According to Derikvand et al. [56], this broad range of available hardware may enable the expansion of stress-laminated timber applications across different structural contexts, potentially increasing both the efficiency and the scope of this innovative construction method within the industry.

Freedman and Kermani [51] explored stress lamination as a cost-effective construction method aimed at utilising low-grade timber. Their research demonstrated promising mechanical behaviour in arched SLT decks made from smaller-dimension softwoods, with mid-span load capacities exceeding 50 kN and four-point bending resistance of over 30 kN. This work laid the foundation for subsequent large-scale investigations into stress-laminated arches, resulting in the construction of nine laboratory-scale arches and two full-scale field bridges [52,53]. These projects demonstrated the feasibility of SLT systems in rural infrastructure, where 20 commercial bridges were ultimately realised with positive cost-performance outcomes. The application of stress lamination has since been extended beyond bridge decks to include structural columns and walls. Fleming and Ramage [57] conducted full-scale testing of 2.4 m stress-laminated columns made with low-grade spruce. The results showed mechanical performance comparable to solid and glulam columns. Fleming [55] further demonstrated that using over-dried hardwood for bearing plates improved prestress retention and reduced lamination slippage, yielding an efficiency factor of 0.84—substantially higher than the 0.53 observed in screw-connected timber columns. This finding reinforces the value of SLT techniques for minimising prestress losses and maintaining structural integrity over time.

To support SLT deployment in the Australian context, Derikvand et al. [56] discussed the availability of advanced timber fasteners such as long screws and threaded rods. These components expand the design flexibility of SLT and enable its use across a broader range of applications, including prefabricated wall panels, columns, and floor plates. Beyond low-grade timber, several international studies have addressed general SLT performance. Ekholm [58] conducted foundational work on long-term load transfer and load distribution in SLT bridge decks. Crocetti et al. [59] provided detailed field-based and numerical assessments of prestress loss mechanisms. More recently, Massaro and Malo [60] presented a comprehensive investigation into the behaviour of SLT bridge decks, focusing on the effects of friction between laminations, butt joint configurations, and pre-stressing rod locations. Their experimental and numerical findings led to practical design recommendations for optimising SLT deck performance. In summary, stress-laminated timber offers a robust, efficient, and scalable method for improving the performance of timber elements, particularly when low-grade material is used. Its continued development and adaptation across contexts such as bridges, walls and columns demonstrate its versatility and potential in both engineered and modular construction systems.

2.6. Press-lam and veneer-based products

The manufacture of veneer-based engineered timber products (e.g., LVL and plywood) has been identified as a potential area of opportunity for poor-quality and small-diameter hardwood. Preliminary studies showed processing these logs into rotary veneers can yield a two to six times higher recovery rate compared to traditional sawn timber processes [61]. Furthermore, adopting spindleless technology can achieve up to 70 % green recovery, which refers to the efficiency of extracting usable material during the peeling process from raw, irregular, truncated cone-shaped billets [62]. The resulting veneers have also been reported to possess suitable mechanical properties for manufacturing LVL or plywood for structural applications [63]. Plywood and LVL products made from poor-quality hardwood veneers have been shown to exceed the mechanical properties of comparable products manufactured from mature plantation softwood [64,65]. Despite the proven potential of juvenile hardwood to be manufactured into high-grade veneer-based structural products, barriers still hinder their commercialisation. These barriers include a lack of comprehensive investigation into their mechanical properties, such as density, modulus of elasticity (MOE), and knot locations, due to the high proportion of natural defects [66].

Gilbert et al. [67] assessed the capacity and reliability of LVL beams manufactured from juvenile hardwood plantation logs through experimental testing and numerical modelling. That study found fabricated LVL beams to be comparable and, in some cases, to have up to 2.5 times higher design bending strength than commercialised LVL products. Additionally, the proposed design capacity factors (load duration, resistance, compression/tension shape, etc.) were 5–12 % lower than those currently adopted in Australia for beams manufactured from mature softwood logs [68]. Moreover, manufacturing high-quality veneer-based products by blending different wood species has proven feasible by utilising low-grade and low-density wood veneers as core layers. For instance, studies have demonstrated that LVL produced from fast-growing plantation species like Melia dubia meets the mechanical and quality requirements set out in IS 14616, an Indian standard that specifies performance criteria for laminated veneer lumber used in structural applications [69], making it suitable for structural applications [70]. Similarly, research on LVL composed of poplar and beech veneers indicates its potential application in window frames due to its favorable mechanical properties [71]. Additionally, investigations into the effect of wood species and the number of layers on laminated veneer properties have shown that varying these parameters can significantly influence the mechanical performance of LVL [72].

A preliminary study conducted by Wang et al. [73] indicated that veneer from low-value red maple logs may be used to manufacture high-quality LVL products by placing veneers with high dynamic MOE values on the outer layers and those with low dynamic MOE values in the core. Similarly, H'ng et al. [74] found that LVL manufactured with low-density hardwood veneer as the core and high-density hardwood veneer as the outer sheeting (11 and 15-ply) achieved the minimum requirements for stress, stiffness, and delamination (<10 %) across various grades, according to the Japanese standard for structural LVL. Further studies have further expanded the understanding of LVL's mechanical properties. Romero and Odenbreit [75] conducted a comprehensive evaluation of the strength and stiffness properties of crossbanded LVL panels made from Scandinavian spruce, providing valuable insights into their mechanical behavior for engineering applications. Xue and Hu [76] analyzed the mechanical properties and reliability of LVL with different assembly patterns using finite element analysis, highlighting the influence of veneer arrangement on performance. Peignon et al. [77] investigated the effect of ply number on the stiffness of poplar LVL, offering an analytical modelling strategy to account for various factors affecting LVL stiffness.

2.7. Glulam

An emerging opportunity for utilising low-grade timber is to manufacture glulam beams. Several studies have investigated how glulam products can be fabricated using lower-quality or non-standard material while still meeting structural performance expectations. Janowiak [78] found that high-performance glulam can be effectively manufactured using lower-quality hardwood timber, specifically for highway-rated bridge structures. This demonstrates that even hardwoods outside the typical grade specifications can still be used for critical infrastructure applications when engineered appropriately. Wang et al. [79] assessed the mechanical properties of 5-ply and 7-ply glulam beams composed of low-grade laminae in the core and high-grade laminae on the outer faces. Their study compared these configurations against conventional E65–F225 grade glulam as specified by EN 14080 [80]. The results showed that bending strength and stiffness were largely comparable, although a reduction of 20 % in tension stiffness and 13 % in compression strength was observed for the low-grade hybrid glulam. These findings indicate that carefully layered glulam incorporating low-grade timber can still provide structural performance within acceptable limits, especially if used in less critical sections of a structure. Lannie [81] evaluated the bonding quality and bending performance of 5-ply glulam manufactured from low-density timber treated with chromated copper arsenate (CCA), a widely used preservative. The fabricated beams were assessed for delamination, shear bond strength, and percentage of timber failure during testing. All indicators met the relevant standard requirements, demonstrating that the bonding performance was satisfactory despite the use of chemically treated, lower-density timber. However, it is important to note that chromated arsenicals such as CCA are classified as hazardous substances. Exposure can pose cancer and other health risks to workers in treatment facilities, and the use of these chemicals has been banned or heavily restricted in several countries due to associated health and environmental concerns. Dziurka et al. [82] explored the manufacture of glulam using wedge-jointed, small-sized timber elements. Despite the non-continuous and more variable nature of the laminae, the resulting 3-layer glulam exhibited mechanical performance closely aligned with that of conventional glulam made with homogeneous, full-length lamellae. Notably, the modulus of elasticity exceeded the threshold defined for GL 32c, the highest strength grade under the European standard EN 14080 [80]. This finding is particularly relevant in regions where resource availability limits access to longer, defect-free timber elements and where engineered solutions using smaller segments can be more sustainable and cost-effective.

In addition to optimised layups and adhesive performance, another promising strategy to increase the utility of low-grade timber in glulam is through the use of fibre-reinforced polymers (FRPs). Multiple studies [18,32–40,83,84] have shown that integrating FRP materials such as carbon, glass, or aramid fibres into glulam significantly enhances flexural capacity, stiffness, and overall load-bearing performance. Reinforcement can be introduced through surface bonding or internal embedding, with various configurations improving both short- and long-term performance. FRP reinforcement is particularly useful when incorporating lower-grade laminae in tension zones, where strength demands are highest. These hybrid systems allow manufacturers to increase the use of lower-value timber without compromising product integrity. A detailed discussion on FRP integration is provided in Section ↱2.2. Overall, the reviewed studies demonstrate that with proper design strategies such as selective lamination, adhesive bonding control, and reinforcement, glulam manufactured from low-grade timber can achieve structural performance levels comparable to conventional products. These approaches enable the effective use of lower-quality materials without compromising strength or durability. This opens viable pathways for using abundant but underutilised timber resources in engineered structural systems.

2.8. Nail-laminated timber

Nail-laminated timber (NLT) is a mass timber product created by mechanically fastening layers of timber boards together using nails, without adhesives or specialised edge-gluing (Fig. 6). The product has been adopted in various structural applications including floor systems, bridge decks, wall panels, and prefabricated modular structures [85–87]. NLT's mechanical lamination process allows the use of timber boards that have not undergone intensive pre-thicknessing, making it a cost-effective alternative to glued laminated timber (GLT) and cross-laminated timber (CLT) [88]. This characteristic is particularly advantageous for incorporating low-grade or low-density timber, either as the sole material or in combination with higher-grade boards, to optimise resource efficiency. NLT also benefits from high load-sharing capacity due to its cross-sectional redundancy and mechanical interconnectivity. Derikvand et al. [89] evaluated the bending performance of both standard NLT and hybrid NLT-concrete (NLTC) floor panels constructed from fibre-managed, low-grade Eucalyptus nitens and Eucalyptus globulus. The NLTC system included screw connectors and a cast-in-place concrete topping to enhance strength and stiffness. The floor panels were subjected to 4-point bending and vibration testing across various span lengths and cross-sectional geometries. Results demonstrated that the NLT and NLTC panels outperformed several commercially available CLT and GLT systems in terms of modulus of elasticity (MOE) and modulus of rupture (MOR). They also met the short-term serviceability limits prescribed for both residential and commercial buildings. However, Derikvand et al. [89] also observed that the structural design of NLT fabricated from plantation eucalypt timber was governed more by serviceability constraints—such as stiffness and deflection—than ultimate strength. A high degree of stiffness variability was attributed to the random lamination of boards with inconsistent properties. To address this, Derikvand et al. [90] developed an optimised lamination strategy using eight side-by-side boards joined in a zigzag pattern with two staggered rows of 3.5 mm × 75 mm nails. This pattern was specifically designed to reduce variability and improve load distribution while maximising the use of low-grade material. The modified panels were subjected to both short- and long-term loading. Results showed improved serviceability performance and a coefficient of variation for MOE under 2.6 %, indicating substantial improvement in stiffness consistency. These findings underscore NLT's suitability for utilising underperforming timber stocks, particularly in modular floor and wall systems. As NLT construction does not rely on adhesives or precision milling, it offers flexibility for incorporating a wider range of timber grades, including those from plantation thinning, salvage timber, or fibre-managed forests. Continued research into joint patterns, fastener types, and hybrid materials such as concrete toppings or fibre-reinforced inserts could further enhance the viability of NLT as a structural solution in both local and international contexts.

2.9. Microwave treatment and densification

Researchers at the University of Maryland, USA, have developed a technology that transforms wood into a high-strength material, named "Superwood," by partially removing its lignin and hemicellulose and then densifying it [92]. This process enables the use of plantation-grown timber to produce a material with properties comparable to steel. The benefits of this new material include a superior strength-to-weight ratio, enhanced fire resistance, and greater sustainability within the forestry and wood products sectors. It also reduces dependency on steel, leading to decreased CO_2 emissions from steel production, and lowers water and energy consumption, potentially reducing kiln-drying schedules [92, 93]. Despite its potential, several manufacturing challenges need addressing to scale up production effectively. These challenges include the high usage of costly and environmentally harmful pulping chemicals, significant energy and water requirements, limitations related to the size and species of timber, and high operational and capital costs.

In summary, while Sections 2.1 to 2.9 present a range of strategies for utilising low-grade timber, including visual and mechanical grading adaptations, reinforcement methods, hybridisation with engineered products, and modified panel assemblies, each approach has inherent limitations and unresolved challenges. Several options, such as FRP reinforcement or adhesive bonding, show technical promise but face scalability, cost, and certification barriers under current regulatory pathways. Similarly, laminated and hybrid systems (e.g., NLT, nail-laminated composites) offer opportunities for value-adding low-quality resources but lack standardised design guidelines and long-term performance data, particularly under Australian climate and service conditions. Furthermore, international studies often rely on temperate species and supply chains that differ significantly from Australian hardwood and plantation softwood contexts, limiting direct applicability. There remains a notable gap in holistic frameworks that align mechanical performance, durability, sustainability, and code compliance. These gaps highlight the need for integrative performance-based design methods, probabilistic reliability modelling, and pathway-specific certification mechanisms to enable broader and safe adoption of lower-grade timber in structural applications. The remainder of this study aims to address these issues through original simulation, reliability assessment, and practical implementation scenarios.

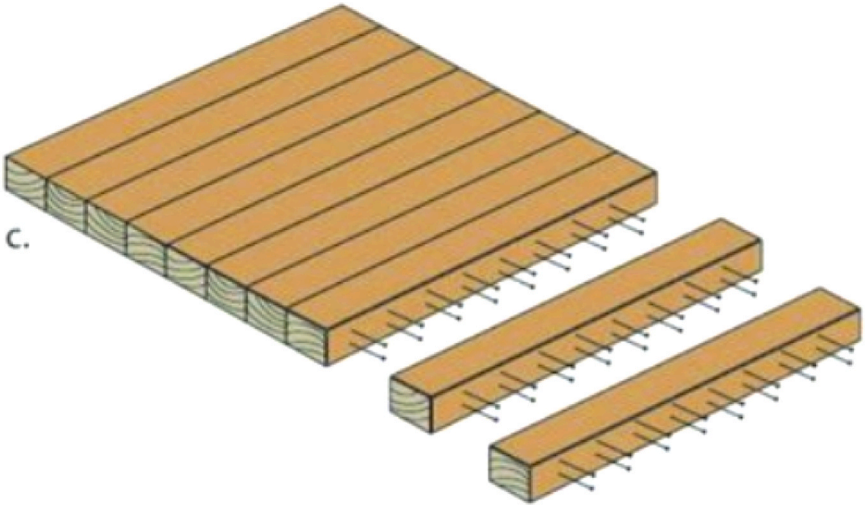


Fig. 6. Nail-laminated timber [91].

3. Timber product specification requirements

Johansson et al. [94] conducted interviews with end-users and building contractors regarding their experiences and perceptions of timber products, specifically focusing on wall studs. The findings revealed a significant knowledge gap among end-users about timber mechanical properties, while contractors expressed dissatisfaction primarily due to excessive warping of timber, including issues like crook and twist. These deformations are major concerns for builders, often leading to substantial material wastage of 30–40 %. The forestry sector identifies defects such as lack of straightness and the presence of branches, while the sawmill industry prioritizes high-quality raw materials characterized by knot-free wood, even annual rings, minimal tapering, a high percentage of heartwood, and straight fibers. Building upon this, Woxblom [95] proposed more stringent acceptance limits for wall studs compared to current grading rules by interviewing contractors and aligning their requirements with wall specifications. Field tests conducted by carpenters indicated the reasonability of these proposed limits. However, achieving these standards is not always feasible, as processes like sawing strategy and drying are employed to minimize distortion. Consequently, timber studs can still be excluded from the high-grade category due to distortion, resulting in their classification within low-grade timber populations. To maintain timber's competitiveness as a building material, the forest and sawmill industry should prioritize the production of products that meet the preferences and specifications of end-users [95]. Additionally, plasterboard manufacturers allow tolerances of 4, 5, and 6 mm on underlying timber framing, depending on the desired finish quality. The grading and supply of consistent timber framing products are critical to achieving optimal results during plasterboard installation and finishing processes. Issues such as cupping can cause air leakage in exterior wall assemblies and complicate the fitting of other wood components. A study on the distortion of fast-grown Sitka spruce, dried to 12 % moisture content, highlighted that twist is a major factor leading to timber degrade, with a significant percentage of timber failing to meet the warp limits required for both General and Special Structural grades [96].

Recent literature reinforces the need for product development approaches that consider both technical grading and user-perceived value. Mark-Herbert et al. [97] examined value communication in multi-storey timber construction and stressed the role of clear specification, predictable performance, and stakeholder collaboration in supporting material acceptance. Their findings suggest that technical properties alone are insufficient to ensure product marketability. User satisfaction also depends on confidence in reliability, dimensional stability, and ease of installation. Further, a 2024 report by the Tasmanian Forestry Hub [98] highlighted the performance requirements demanded of timber products in commercial developments. The study, involving 30 stakeholders across 6 timber-inspired commercial buildings, underscored the importance of aligning timber product characteristics with market, regulatory, and client-imposed performance requirements. The findings emphasize the need for the timber industry to adapt to evolving expectations and standards to remain competitive.

3.1. Stress groups and stress grades

The process of structural grading in Australia involves categorising timber into stress grades based on their structural properties, with the aim of achieving consistency within each group [99]. However, due to the natural variation in timber properties, there is still a significant range of properties within each group and some overlap in properties between different groups

The process of structural grading in Australia involves categorizing timber into stress grades based on their structural properties, aiming for consistency within each group. However, due to the natural variation in timber properties, there remains a significant range of properties within each group and some overlap in properties between different groups [100,101].

In addition to Australian grading standards (AS/NZS 1748 [99], AS 2082 [102]), international grading frameworks such as the American National Standard for Structural Glued Laminated Timber (ANSI 117–2020) have introduced updated performance criteria and specification protocols for softwood species. ANSI 117 [103] emphasises manufacturing tolerances, strength classification, and adhesive requirements, reflecting the growing importance of consistent product certification in international timber markets. Referencing such standards offers valuable benchmarking for Australian grading practices in a global context [103].

3.1.1. Visual stress-grading

This method involves trained graders examining timber to assess characteristics and size, assigning structural grades based on more than 20 different features like knots, resin pockets, and grain. Each species' wood strength is tested to assign a strength group, and these structural grades are linked to a stress grade (F-grade) using standard tables [104] [105].

3.1.2. Machine stress-grading

Machine stress-grading uses machines to measure timber stiffness, assigning stress grades based on the stiffness-strength correlation. This method is more objective and efficient than visual grading but still shows overlap between grades. Quality control ensures reliability, and grade stamps indicate the grade for marketing and distribution [99, 106].

3.1.3. Machine proof-grading

Machine proof-grading tests each timber piece with a high load; pieces that pass without damage qualify for the stress grade. This method is less common but used for certain Australian hardwoods and treated timber. It can also grade utility poles and structural assemblies for high reliability [107].

3.2. Mechanical properties of minimum structural grade timber around the world

Table 2 summarises the review of minimum structural grade timber for different countries. The EU's C14 grade [108] generally has the highest strength properties' requirement among the timber grades listed, including the highest bending strength and compressive strength parallel to grain. Australia's F4 grade [109] follows closely behind in bending strength, while China's TB11 grade [110] ranks well in tensile strength parallel to grain. The USA's Northern White Cedar Stud [111] consistently allows for the implementation of structural timber with lower strength properties compared to the other grades.

3.3. Alternative product certification pathways

Provision A5.2 of the Australian National Construction Code (NCC) [113] outlines the minimum level of acceptable evidence required to demonstrate that a building 'material, product, form of construction or design' meets the specific requirements of the National Construction Code (NCC) shown in Table 3. Builders and certifiers are obliged to reject products that do not provide this evidence of conformity. This is particularly relevant for construction materials that do not conform to the standard grading system as outlined in Australian standards (grading system) discussed in section ↱3.1.

Considering the varied methods for utilising lower-grade and customised grade timber, obtaining a CodeMark Certificate of Conformity is the most robust approach to gaining market acceptance. However, there are alternative possibilities outlined in A5.2 (1) (d–f) that may be considered for early adoption, such as in specific projects or applications. Typically, this would involve prototype testing, followed by production series testing to determine statistically reliable characteristic

Table 2
Review of minimum structural grade timber for different countries.

Country / Region	Standard	Minimum grade	Strength properties (MPa)	Stiffness properties (MPa)						
			f_b	$f_{t,\parallel}$	$f_{t,\perp}$	$f_{c,\parallel}$	$f_{c,\perp}$	f_s	$E_{Avg,\parallel}$	G_{Avg}
Australia	AS 1720.1 [109]	F4 (Visual grade)	12	HW 7 SW 5.8	NA	8.6	NA	1.3	6100	410
		MGP 10 (mechanical grade)	14–17	6.1–7.7	0.5	16–18	NA	2.3–2.6	10,000	670
China	GB 55005 [110]	TB11	11	8	NA	10	2.1	1.3	7000	NA
EU	EN 338 [108]	C14 (Softwood from bending test)	14	8	0.4	16	2	3	7000	440
		T8 (Softwood from tension test)	13.5	8	0.4	16	2	2.8	7000	440
		D18(hardwood from bending test)	18	11	0.6	18	4.8	3.5	9500	590
USA	NDS [111]	Northern White Cedar Stud (Visual grade)	2.9	1.7	NA	2.1	2.6	0.8	4100	NA
Canada	CSA O86–19 [112]	No.3 Stud (Visual grade)	4.5	2	NA	5.2	3.5	1.3	6500	NA

f_b Bending strength, $f_{t,\parallel}$ Tension parallel to grain, $f_{t,\perp}$ Tension perpendicular to grain, $f_{c,\parallel}$ Compression parallel to grain, $f_{c,\perp}$ Compression perpendicular to grain, f_s Shear in beam, $E_{Avg,\parallel}$ Average modulus of elasticity parallel to grain, G_{Avg} Mean shear modulus, HW hardwood, SW softwood (Note: Some standards refer to the 5th percentile mechanical properties, while others refer to the average values.)

values. Independent engineering assessment of the results would also be necessary.

4. Industry perceptions and stakeholder survey results

As part of this study, an in-depth exploratory investigation was undertaken to understand the attitudes, perceptions, and concerns of construction industry professionals regarding the structural application of low-grade timber in Australia. The methodology adopted for this investigation was qualitative in nature, based on semi-structured interviews guided by a carefully developed questionnaire. The design of this questionnaire was carried out collaboratively by the academic research team and representatives from key industry stakeholders, including timber manufacturers, engineers, and builders. This collaborative approach ensured that the questions addressed both technical and practical dimensions relevant to the real-world deployment of low-grade timber products. The questionnaire covered a range of themes including material performance expectations, structural design preferences, compliance requirements, supply consistency, cost-benefit considerations, and perceived risks associated with deviating from standard timber grades. The participants were purposively selected through recommendations by the project's industry partners to ensure relevance, experience, and professional diversity. Respondents included senior structural engineers, architectural designers, truss manufacturers, timber supply chain managers, volume home builders, and property developers. These participants collectively represented a cross-section of stakeholders involved in timber specification, design implementation, regulatory compliance, and product delivery.

Each interview was conducted one-on-one by a senior structural engineer on the academic team, either via phone or video conference, and was structured to follow the questionnaire framework while allowing scope for open-ended responses and elaboration on context-specific issues. This approach enabled the capture of detailed, case-based insights that reflected current market conditions, design practices, and institutional resistance or openness to new materials. The interviews were not intended to produce a statistically generalizable dataset, but rather to explore nuanced perspectives that can inform future technical research and implementation strategies. In particular, interviewees were encouraged to discuss past project experiences where timber grading constraints impacted design outcomes, or where they had considered or rejected low-grade or alternative timber products for structural applications. Recurring themes across interviews included uncertainty about the long-term durability and reliability of low-grade timber, limited access to structural design tools calibrated for such materials, a lack of third-party certification or CodeMark approvals, and confusion regarding the implications of performance-based compliance pathways under the National Construction Code. At the same time, there was broad recognition of the growing demand for timber products, the need for better utilisation of plantation resources, and interest in engineered wood systems that could improve consistency and performance. To support transparency and reproducibility, the complete interview guide is provided in Appendix A, and a consolidated summary of the main insights, grouped by theme, is presented in Table 4 of this manuscript. These findings have informed the development of the research framework, ensuring that the technical investigation and proposed material strategies are grounded in practical industry expectations and constraints.

5. Case study of Australian sawn timber production

A descriptive industry case study was explored to provide a specific example of Australian sawn timber production to complement the broader and more general findings from the ABARES data. The mill had been reporting a trend of increasing proportions of low-grade and out-of-grade timber, which has direct implications for the structural timber supply chain in Australia. The diminishing proportion of logs meeting MGP10 grade, despite increasing harvesting volumes, reflects the growing prevalence of juvenile wood and processing limitations that hinder recovery of structural-grade material. The site chosen was a softwood mill, operated by a typical Australian sawlog processor. The case was informed by a site visit to both the plantation and the mill, as well as discussions with representatives from both entities.

It was observed that the estates managed by the local forest plantation management company are grown for 25–30 years, with the duration depending on the growth rate, volume achieved, and client specifications, extending from plantation sites to harvesting sites. A more detailed inspection was carried out at the sawlog processor's mill, where a group discussion was facilitated between the research team and the mill staff. Initiated at the log merchandiser, the tour encompassed various manufacturing steps including kiln-drying and the dry mill and concluded with a visit to the glulam mill.

A visual summary of the sawn timber production process is shown in Fig. 7. The process is split into the three broad stages of 'Plantation,' 'Sawmill,' and 'Construction.' At the mill, the arrangement between the two entities is a volume supply agreement. This involves an agreed-upon volume of logs being harvested that have met the required age and geometry parameters. No pre-harvest assessment of density or elastic modulus is used to inform the value of the logs or prices charged to the

Table 3
Overview of the acceptable forms of evidence required to demonstrate NCC building requirements [113].

NCC	EVIDENCE	DESCRIPTION	APPLICATION	EXAMPLE
A5.2 (1) (a)	CodeMark Certificate of Conformity	A certificate issued under the Australian Building Codes Board CodeMark scheme by a JAS-ANZ accredited third party body certifying compliance to the NCC	*New and innovative building products and systems*, that don't have a reference Standard	Timber preservation not meeting AS 1604
A5.2 (1) (b)	Certificate of Accreditation	Certificate issued by a State or Territory accreditation authority, e.g., Victoria's Building Regulations Advisory Committee	Products or systems *applicable to a particular region*	NA
A5.2 (1) (c)	Certification	Certificates issued by a certification body experienced in the field of application and JAS-ANZ accredited	Confirming the product's performance or properties meet the specific product standard	Stress grades, compliance to product standards (i.e. EWPAA, GLTAA)
A5.2 (1) (d)	Testing Report	A report issued by an Accredited Testing Laboratory	New report or modifications to an existing test report	Acoustic or fire test report
A5.2 (1) (e)	Qualified Person	A certificate or report from a professional engineer or appropriately qualified person	Certifies compliance with Standards, specifications, or other publications	Span Tables Str. Design/ Software Evaluation report WoodSolutions Guide
A5.2 (1) (f)	Other forms of evidence	Other forms of evidence that is not covered above	First-party (company issued) document or prototype that demonstrates compliance	Product Technical Statement

Table 4
Key findings from structured interviews.

Aspect	Key findings
Structural grade	All participants agreed that the minimum structural grade suitable for construction is F4 according to Australian Standards 1720 (no other performance or code mark solutions were highlighted).
Timber availability and grades	Availability of timber grades varies; consistent supply advantageous. Different grades used in wall, floor and truss components.
Timber grades used	Roof trusses, floor trusses and wall frames employ F5, MGP10, MGP12, MGP15 and F27 grades.
Lower-Grade Consideration	Lower-grade timber considered for non-load bearing walls and web material in trusses, depending on design requirements and software.
Optimisation opportunities	Potential for optimising truss and frame designs for cost reduction without compromising integrity.
Software tools	Commonly used programs for truss analysis and design: MiTek 20/20, Pryda. Adjustments made to meet structural and cost requirements.
Use of larger lower-grade sections	Consideration of using larger sections of lower-grade timber for comparable outcomes, assessing cost-performance trade-offs.
Engineered wood products (EWPs)	Consideration of laminated veneer lumber (LVL) or glued laminated timber (glulam) for improved properties and strength at higher cost.
Incorporating lower-grade timber	Lower-grade timber (lower than F4) use in specific truss or wall frame sections without compromising overall performance.
Stud suitability	Stiffness primary criterion for stud suitability in truss manufacturing, other factors like straightness and stability also significant.
Timber characteristics importance	Straightness crucial for wall frames, aids in reducing bending effects in trusses. Shrinkage and swelling considerations in trusses.
Utilisation of lower-stiffness timber	Complexity in design and operation, willingness to replace some truss components with lower-grade timber depends on performance and cost.
Troublesome defects	Irregular-sized timber, stock management and availability issues identified as troublesome. Various defects in final product noted.
Acceptance of repaired timber with defects	Acceptance of repaired timber (by filling Knots and Cracks with epoxy Resins, reinforcing with steel and FRP, heat and Moisture Treatment, sanding minor warping; and cutting and Patching) depends on structural performance, cost and feasibility of repair process.
Need for further exploration and solutions	Findings highlight the need for further exploration and solutions to overcome barriers in using low-grade timber in the industry.

mill. The absence of pre-harvest density or MOE assessment also exacerbates this issue, as mills are unable to proactively sort for higher-grade output, thus highlighting a critical gap in optimising low-grade timber within domestic construction pipelines. Within the plantation stage of the sawn timber production process, there was also a projected decrease in fiber quality (predominantly stiffness). This has been identified by the mill, with smaller proportions of the processed logs achieving the minimum requirements for MGP10 structural grade [109]. As a result, more timber is diverted to non-structural markets, reducing availability for truss and framing applications and prompting the need for engineered solutions to revalue low-grade outputs. The construction stage of the sawn timber production process includes all the post-production customers (e.g., truss manufacturers, builders, and homeowners).

The next stage involved identifying opportunities for improvement within the production process with an aim to decrease the proportion of low-grade or out-of-grade timber produced. The opportunities for improved production processes were categorized by their relative time and cost investment: 'Low-hanging fruit,' 'Mid-term with medium setup time or cost,' and 'Long-term with large setup time or cost,' represented visually in Fig. 7 with the colors red, yellow, and blue, respectively.

5.1. Low-hanging fruit

There were opportunities with relatively low upfront time or cost investments identified across all 3 stages of the sawn timber production process. Within the plantation stage, data sharing and matching between sawlog processor and forest plantation management could allow for a clearer understanding of the change in fibre quality over time and across the Forest plantation. This could benefit both parties as harvesting could be informed by the exact products being demanded by the market to implement appropriate improvement strategies. The opportunities identified within the sawmill stage were centred around process optimisation. Understanding the variability and correlation between early material property measurements already in use (e.g. diameter, density, acoustic etc.) and the final product quality, along with an effective application of those measurements could allow for a lower proportion of lower-value boards being produced (at great expense considering the energy requirements of the drying kilns). Additionally, equipment that can handle the currently rejected larger butt diameter

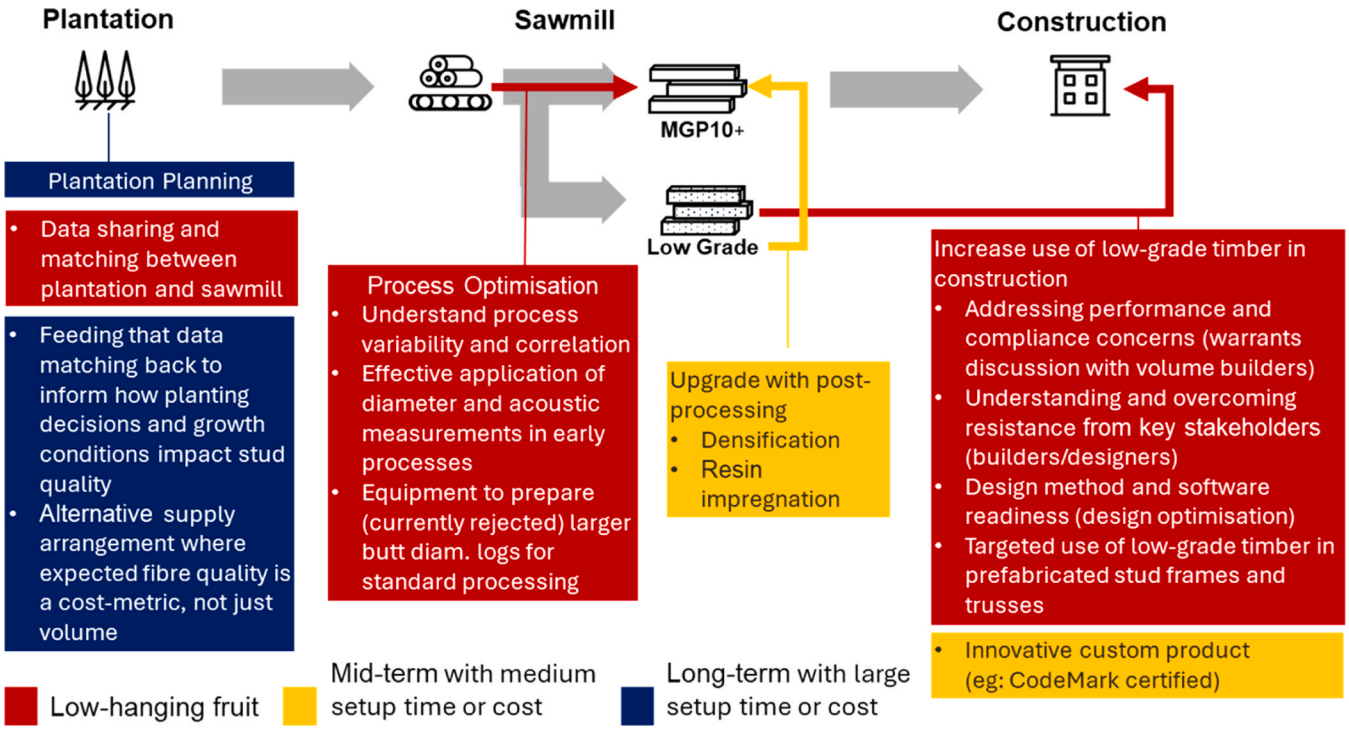


Fig. 7. Opportunities of Australian sawn timber production.

logs and prepare them for standard processing would provide more higher-value fibres for the mill. The opportunities identified in the third stage are focused on increasing the use of low-grade timber in construction. These opportunities include addressing performance and compliance concerns, overcoming resistance from builders and designers, and design software readiness. Targeted use of low-grade timber in prefabricated stud frames and trusses was also identified as an opportunity to increase the use of low-grade timber in construction.

5.2. *Mid-term with medium setup time or cost*

Mid-term opportunities, with moderate setup time and cost, are primarily focused on the sawmill and construction stages of the production process. Key to these opportunities is enhancing the value of low-grade timber through innovative post-processing technologies such as resin impregnation and densification. These methods effectively upgrade previously low-grade fiber to meet or even surpass the minimum MGP10 grade standards. Resin impregnation, extensively documented in the literature, involves infusing resins into wood to improve its mechanical strength, moisture resistance, and durability, raising its quality to that of higher-grade materials.

Additionally, utilizing the CodeMark certification [114] process for custom product development provides a robust pathway to add value to low-grade timber products. This certification is crucial for gaining market acceptance for new building products or innovations without a historical usage record. Obtaining a CodeMark Certificate [114] of Conformity is a significant step towards market acceptance for customized timber grades and innovative designs, such as deeper stud configurations for 7- or 8-star energy ratings, user-specific grades, densified timber, and non-standard cross sections. The process typically involves prototype testing, followed by series testing to establish reliable characteristic values, with an independent engineering assessment for compliance verification. (Fig. 8)

Furthermore, ongoing research and development are essential to refine microwave treatment processes, including the design and manufacture of a pilot plant for new materials enhanced through microwave intensity variations, partial delignification, and thermomechanical

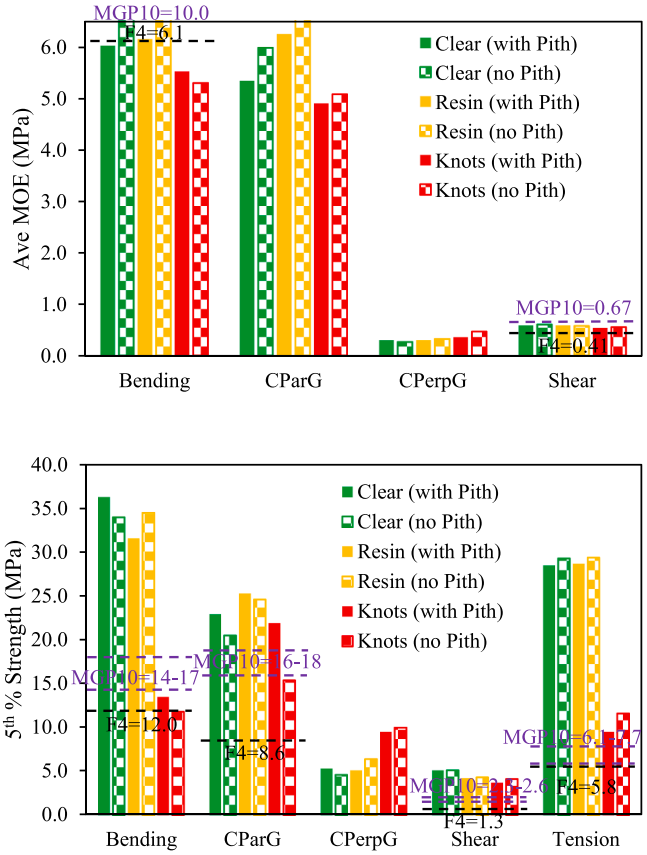


Fig. 8. Mechanical properties of out-of-grade timber at the case study of sawlog processor [115]. CParG: compression parallel to grain; CPerpG: compression perpendicular to grain.

treatments. Establishing baseline data for designing a semi-commercial plant is crucial, as is conducting an economic assessment of these technologies to outline commercialization steps. Such strategic enhancements are expected to significantly boost the market viability of lower-grade timber, aligning product offerings with industry standards and consumer expectations, and driving innovation in the construction materials market.

5.3. Long-term with large setup time or cost

The identified long-term opportunities focus primarily on the plantation phase of the production process, enriched by comprehensive data sharing between forest plantation management and sawmill. Forst management has amassed an extensive dataset over the past 40 years, which includes management practices, measurements of diameter at breast height, total height, and detailed plantation resource assessments. In the more recent years, they have integrated resistograph density measurements to better understand wood density variations across different trees. Meanwhile, the sawlog processor has collected a substantial array of data starting at the log merchandiser—where harvested logs are categorized based on volume, diameter, and initial quality into 46 different bins—and extending to the green mills, where logs undergo acoustic grading. Further details are recorded as logs are processed, including data on recovery rates, acoustic grading which encompasses grade, modulus of elasticity (MOE), density, and volume metrics. Leveraging this rich dataset, the proposed opportunities include enhanced data matching initiatives between two entities that could significantly influence planting decisions and growth conditions to optimize stud quality. An improved understanding of these variables would enable the prediction and enhancement of log quality, informing strategic decisions that align with market demands and production capabilities. Moreover, alternative supply arrangements could be established where the expected fiber quality forms a high-value cost metric. This approach diverges from traditional agreements predominantly focused on volume, thus offering a more nuanced understanding of material value that can influence procurement strategies. Such long-term strategies would provide mutual benefits by facilitating the selection and prioritization of timber varieties—specific species or taxa—that yield superior fiber quality. By focusing on high-quality fiber, a pricing model could be developed that attracts a premium, reflecting the enhanced market value of the final sawn products. This would not only meet but potentially exceed the needs of designers, builders, and end users by ensuring a consistent supply of high-grade timber. Additionally, these strategies could lead to a reduction in the production of low-grade timber, which currently constitutes up to 25 % of production from logs of indeterminate quality, thus enhancing overall efficiency and sustainability within the timber industry.

6. Structural performance assessment of residential buildings using out-of-grade timber: A simulation-based study

Building on the case study's identification of increased use of low-grade timber as a short-term, cost-effective strategy to reduce material waste and embodied carbon, this section presents a structured investigation using numerical modelling and probabilistic strength analysis of out-of-grade timber members in residential structures. The analysis aims to assess the structural feasibility and compliance of these materials within the framework of AS/NZS 1720.1 [109] and the National Construction Code (NCC) [113]. A key reference for this investigation is the experimental study by Cherry et al. [115], which evaluated the mechanical properties of out-of-grade timber sourced from the same case study sawlog processor. Fig. 13 presents the comparative mechanical performance between visually clear specimens and those with common defects such as resin pockets and knots. These results are benchmarked against the minimum performance requirements for F4 grade timber in accordance with AS/NZS 1720.1 [109]. The study confirmed that while most strength parameters, including tensile strength parallel to grain, shear strength, and compressive strength, meet or exceed the F4 threshold, the primary limitation of out-of-grade studs lies in their average Modulus of Elasticity (MOE) in the longitudinal direction. This property is especially critical in meeting deflection and serviceability limits for load-bearing walls. Notably, the average MOE of these members is comparable to the lower bound defined for Northern White Cedar studs in the U.S. National Design Specification (NDS), suggesting opportunities for parallel applications in other international design contexts. To evaluate how this MOE limitation could influence overall structural performance, further numerical simulation and reliability-based analysis were conducted, as described in the following sections.

6.1. Materials and methods

To this end, two representative residential house designs—provided by a national volume builder—were selected for structural simulation. These include a single-storey house (Fig. 9) and a two-storey house (Fig. 10). The original specification used 90 × 35 mm MGP10 (F5 equivalent) studs for the single-storey house and 90 × 45 mm studs for the double-storey house. Stud spacing was set at 600 mm centres for all non-load-critical walls, with 450 mm spacing adopted at the ground floor of the double-storey design to account for increased vertical loading. All lintels, load-bearing double and triple studs, and corner junctions remained as originally specified. Applied loads included a dead load of 0.9 kPa for the tiled roof and 0.4 kPa for the upper-level floor structure. Live loads were modelled in accordance with AS/NZS 1170.1: a roof live load of 0.25 kPa and an internal floor live load of 1.5 kPa were assumed. Wind actions were assigned according to AS/NZS 1170.2 with internal pressure coefficients derived from typical suburban terrain exposure conditions. Structural simulations were conducted using ETABS v20.3, which enabled detailed finite element modelling of wall panels, floors, and roof systems for whole 3D model of the building. While AS1720.3 provides a simplified 1D stud analysis model for assessing rotational stiffness, this approach is not accurate as it ignores top plate lateral deflection and overestimates stud fixity to the top and bottom plates. Instead, a 3D modelling approach was adopted here, capturing realistic boundary flexibility and lateral deflection, thereby reflecting real-world behaviour more accurately. Timber wall framing was modelled using vertical frame elements, incorporating member stiffness variations based on a probabilistic Monte Carlo distribution of MOE derived from Cherry et al. [115]. For boundary conditions, rotational degrees of freedom at the bottom of the studs were fixed while flexural degrees of freedom were released, resulting in the studs behaving as simple connections at both the top and bottom. Nonlinear load combinations were applied as per AS/NZS 1170.0 [116], including combinations for strength (ULS) and serviceability (SLS) limit states. Creep deformation effects under sustained load were included by applying a creep factor of 2.0, as appropriate for service class one and long-term loading durations. The results of the simulation allowed for the identification of peak axial and bending demands in wall studs, as well as horizontal displacements, inter-storey drifts, and floor deflections. A Monte Carlo–type probabilistic analysis was undertaken to simulate variability in material properties and determine the probability of strength exceedance for each critical component. The resulting statistical distributions were used to calculate reliability indices, enabling assessment of compliance with the target performance levels defined in the NCC and AS/NZS 1720.1 [109]. While this approach aligns conceptually with the probabilistic framework outlined in AS 5104 [117], strict compliance with that standard would require executing a very large number of ETABS models with systematically varied load intensities to comprehensively evaluate reliability. The methodology adopted here provides a practical yet robust estimate of probability of failure within the constraints of the current study.

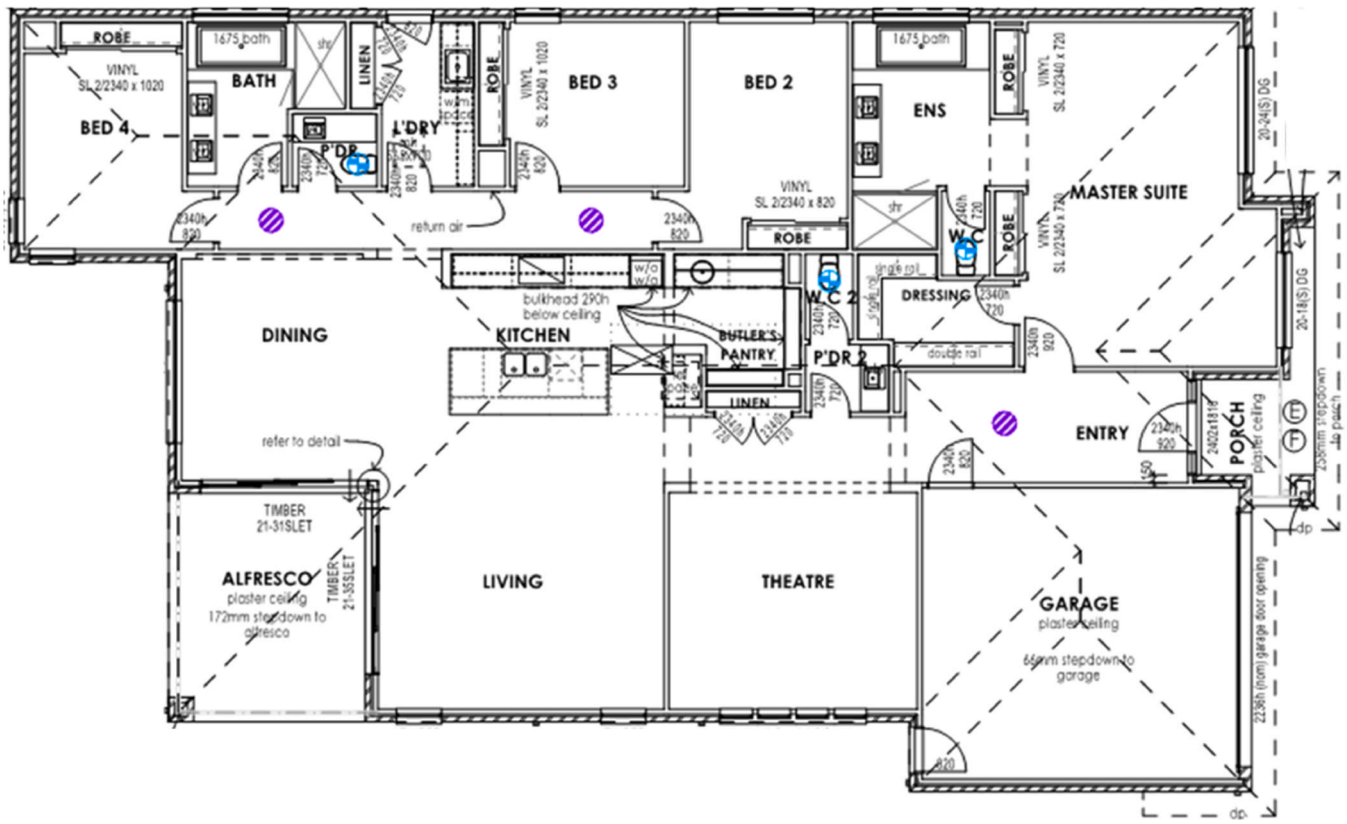


Fig. 9. The single storey architectural floor plan.

6.2. Structural modelling and categorisation of results

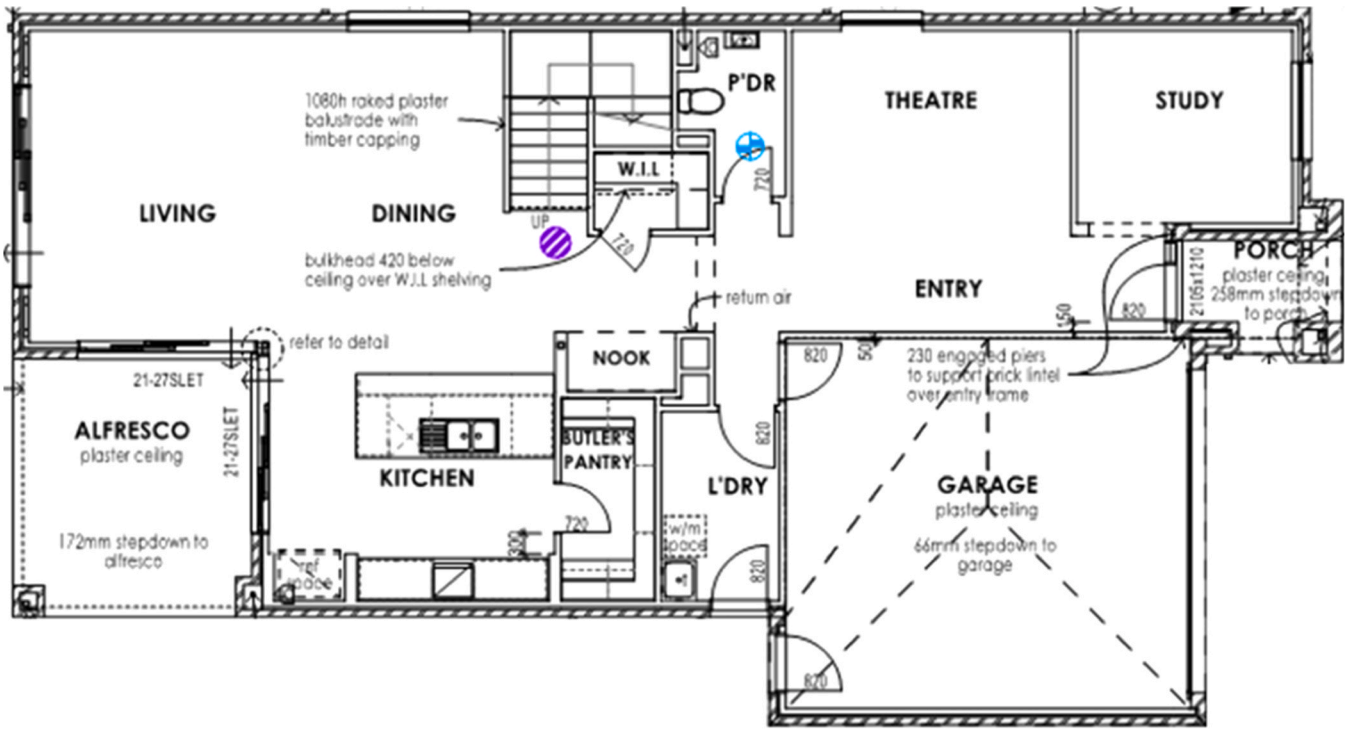
Fig. 11 depicts the 3D analytical model of the consolidated buildings constructed in ETABS, capturing the structural component detail. To simulate strap bracing, link elements with appropriate stiffness and nonlinear behaviour were combined with non-linear static analysis to ensure an accurate representation of behaviour under various loading conditions. Additionally, shell elements were implemented for modelling roof truss diaphragms and floor joists, contributing to the global lateral stiffness and load transfer mechanisms, improving the accuracy of the structural simulation. The simulation results were systematically categorised and illustrated according to Fig. 12. This categorisation framework enhances clarity in interpreting component-specific performance under applied loading. Specifically, the results for the one-storey building and the upper storey of the two-storey buildings are represented by the label 'STUD1', indicating the maximum internal forces experienced by the studs in these sections. Conversely, the lower storey of the two-storey building is represented by 'STUD2', capturing the maximum internal forces in those studs. Furthermore, the analysis extends to include the maximum internal force demands in other critical wall framing components: 'TOP' refers to the top plates, 'BTM' to the bottom plates, and 'NAG' to the noggings. This classification scheme provides a structured basis for comparing the imposed demands with the probabilistic strength capacities derived from experimental data.

6.3. Evaluation of characteristic stresses and modelling limitations

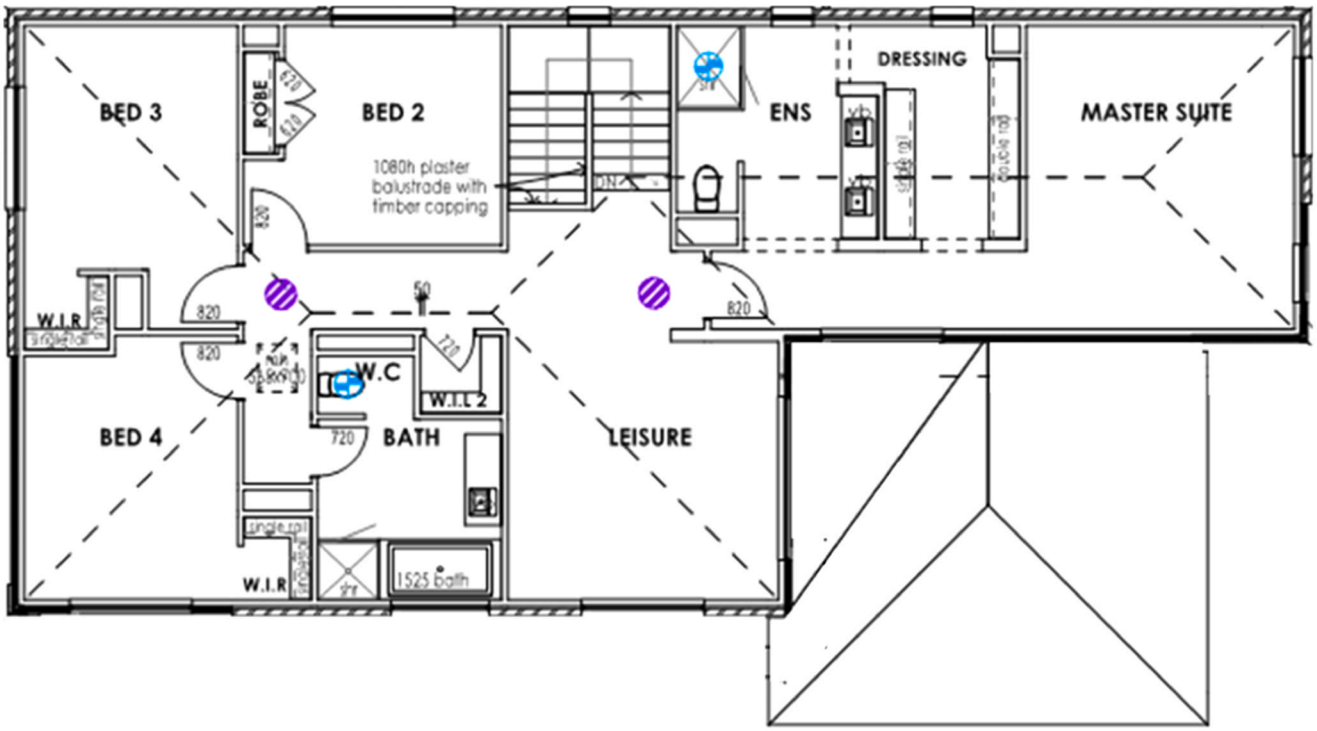
Fig. 13 illustrates the characteristic stresses corresponding to different actions for the categorised elements shown in Fig. 12. Characteristic strength values for F4 and MGP10 are also presented, allowing a comparison of the imposed actions against common strength grades in the Australian market. These characteristic values were derived from probabilistic analysis at the 5 % fractile level, following ISO 2394 [23] recommendations for structural reliability. For instance, the characteristic tensile force (f_t) in the bottom plate of the 1-storey build and upper level of the 2-storey building is around 2 MPa, which is considerably lower than F4 grade characteristic strength of 5.8 MPa. This indicates a potential margin for safely substituting lower-grade timber in such locations. However, it was observed that some internal forces approached or slightly exceeded the MGP10 strength threshold. This apparent exceedance can be partly attributed to limitations in the simplified modelling approach, which may not fully capture true load distribution and interaction effects within the structure. Specifically, the shell elements employed in the model are unable to represent the localised effects of roof trusses, floor joists, and concentrated nodal loads accurately. Furthermore, to conservatively simulate wind uplift forces, support conditions were defined between studs—representing precise nailing points of bottom plates. While appropriate for lateral loads, this assumption over-constrains the model for vertical gravity loading, where bottom plates in reality are supported by a continuous elastic base such as a concrete slab. Due to the associated modelling complexity, this elastic support condition was not incorporated into the current study. Nonetheless, the stress results provide a valuable first-order estimate of structural demand relative to material capacity and help identify critical locations requiring further refinement in future work.

6.4. Probabilistic comparison of strength and internal stresses

Figs. 14–17 demonstrate the probability density of imposed actions (derived from the current study) compared against the mechanical properties of out-of-grade timber collected from the production line, as reported in Cherry et al. [115]. These comparisons were conducted for various internal forces (compressive, tensile, shear, and bending). Three timber types were assessed: clear timber (red), timber with resin (green), and timber containing knots (purple). Each data point on the graphs represents a laboratory test result, with normal distributions fitted

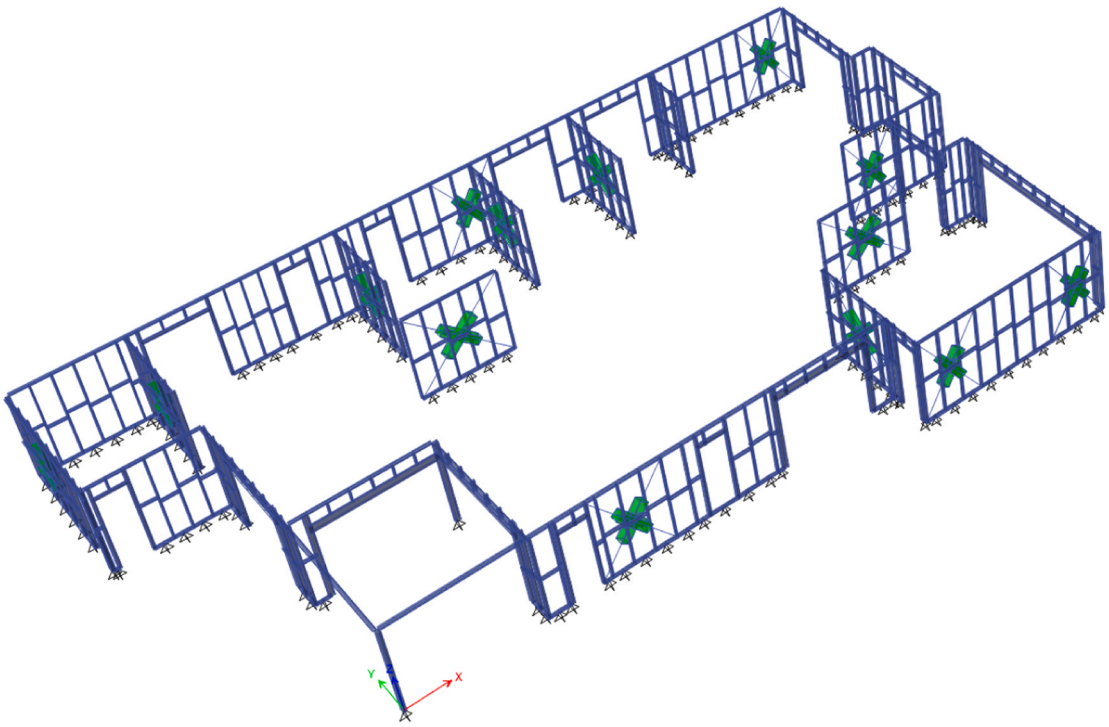


a) Ground floor plan

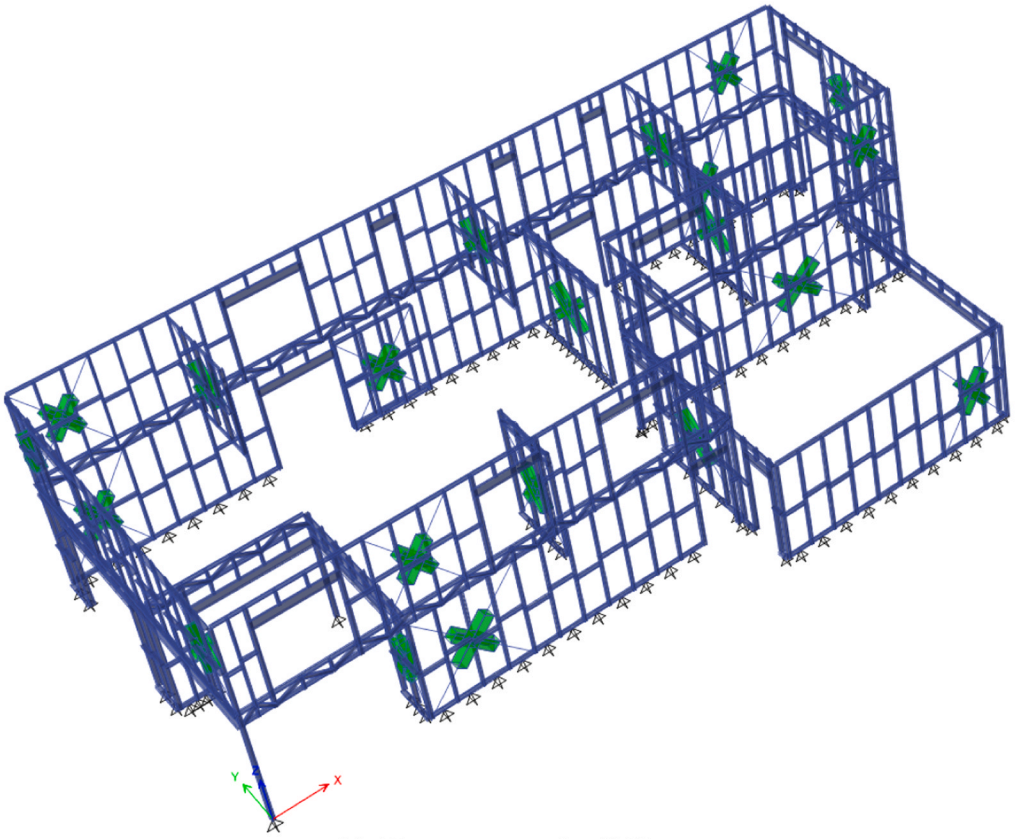


b) First floor plan

Fig. 10. The 2-storey architectural floor plans.



a) One-storey building



b) Two-storey building

Fig. 11. Three-dimensional analytical model of considered buildings.

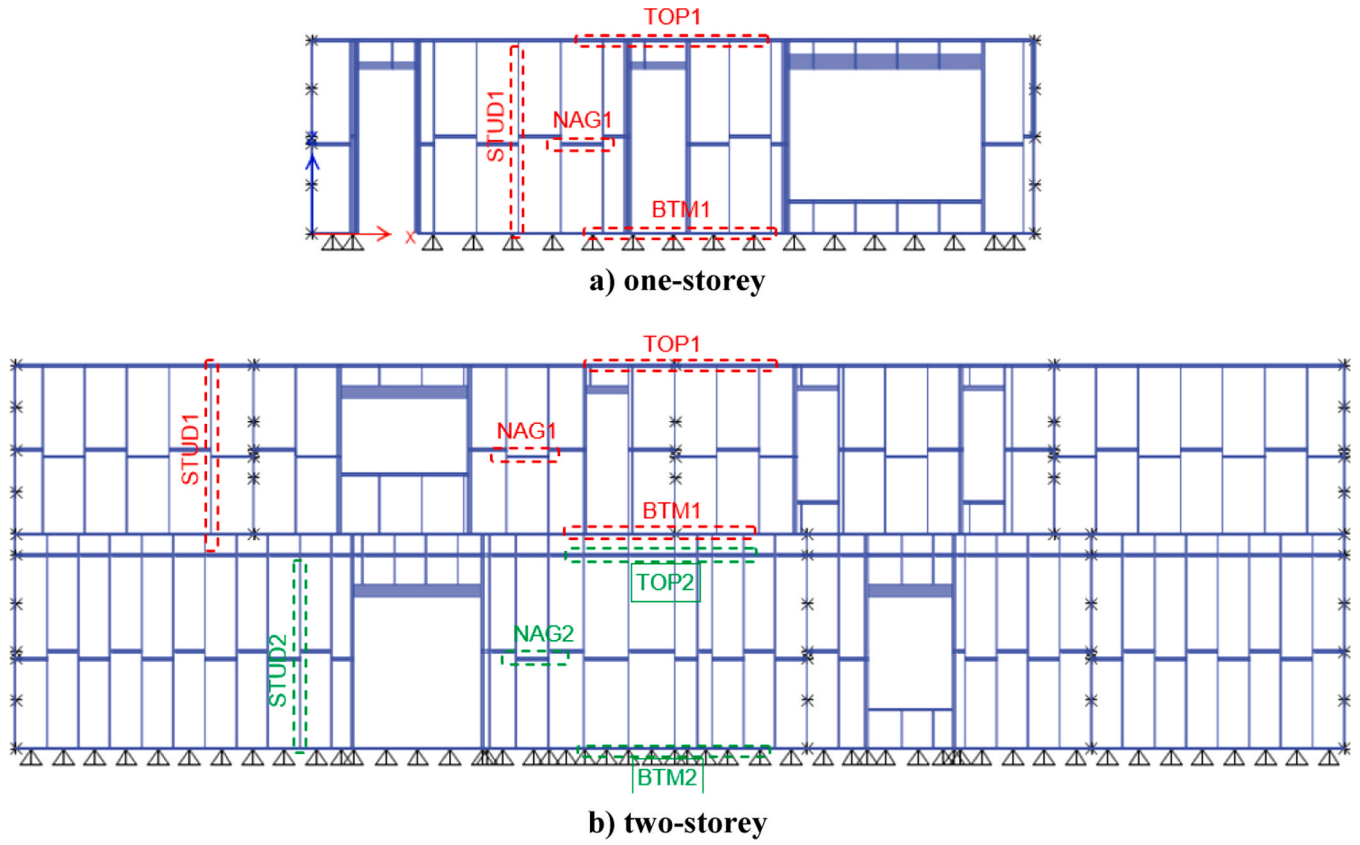


Fig. 12. Framing elevations of 3D model. categorising convention for outcomes. STUD1: studs in the 1-storey building and the upper storey of the 2-storey buildings; STUD2: studs in the lower storey of the 2-storey building; TOP: maximum internal forces in the top plate; BTM: maximum internal forces in the bottom plate; NAG: maximum internal forces experienced by the noggings.

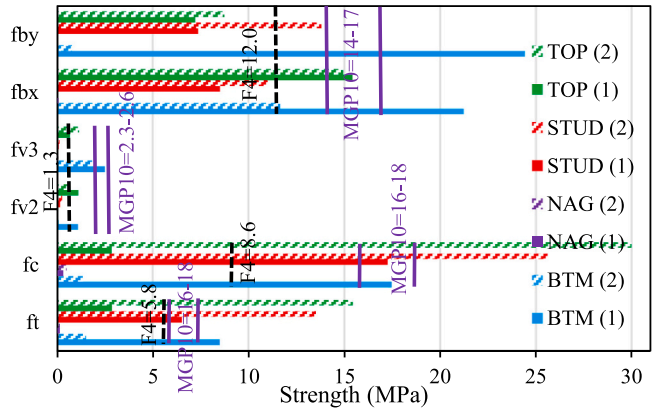


Fig. 13. Characteristic stress vs F4 and MGP10 strength for different elements. STUD1: studs in 1-storey building and the upper storey of the 2-storey buildings; STUD2: studs in the lower storey of the 2-storey building; similarly, TOP: maximum internal forces in the top plate; BTM: maximum internal forces in the bottom plate; NAG: maximum internal forces experienced by the noggings. f_{by} : bending stress around strong axis, f_{bx} : bending stress around weak axis, f_{v3} : shear stress corresponding to f_{by}, f_{v2} : shear stress corresponding to f_{bx}, f_c : compressive stress, f_t : tensile stress.

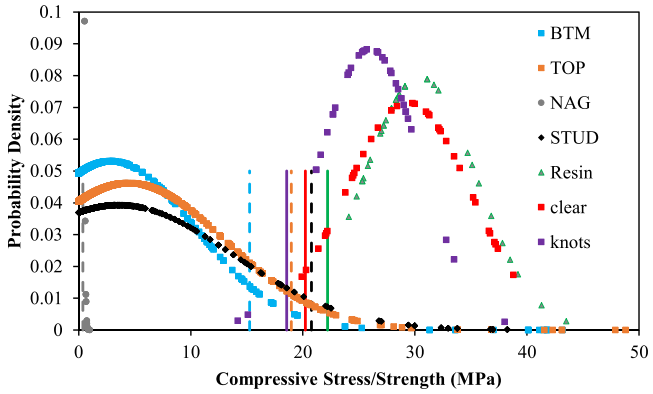


Fig. 14. Probability density of compressive stress and timber out-of-grade strength (vertical solid and dash lines represent characteristic strength and stress, respectively). Clear: clear timber (red); Resin: timber with resin (green); Knots: timber containing knots (purple); TOP: top plate; BTM: bottom plate; NAG: nogging.

across the population to determine 5th percentile characteristic values. Vertical solid lines represent characteristic strength; dashed lines represent characteristic internal forces experienced by building components. In these figures, the structural elements—bottom and top plates, studs, and noggings—are analysed separately. Characteristic stresses and strengths were calculated based on a 5 % probability of failure, in accordance with ISO 2394 [23]. This probabilistic framework aligns with the NCC's performance-based provisions, which accept that 5 % of structural members may fall below nominal strength thresholds provided overall reliability is achieved.

6.5. *Interpretation of results and application feasibility*

Upon examination, the internal loads for noggings were found to be minimal, suggesting high potential for substituting standard-grade material with out-of-grade timber in these components. In fact, AS1684.1

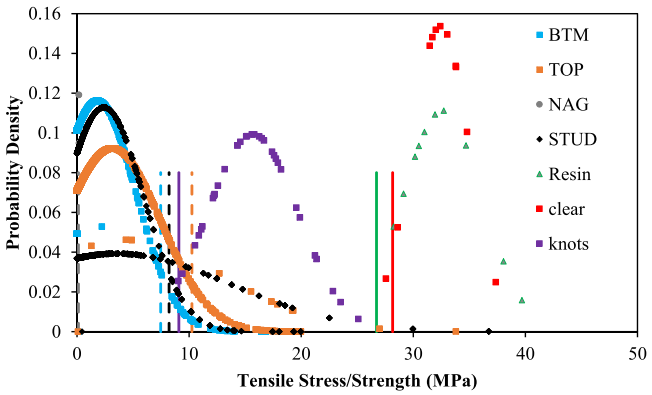


Fig. 15. Probability density of tensile stress and timber out-of-grade strength (vertical solid and dash lines represent characteristic strength and stress, respectively). Clear: clear timber (red); Resin: timber with resin (green); Knots: timber containing knots (purple); TOP: top plate; BTM: bottom plate; NAG: nogging.

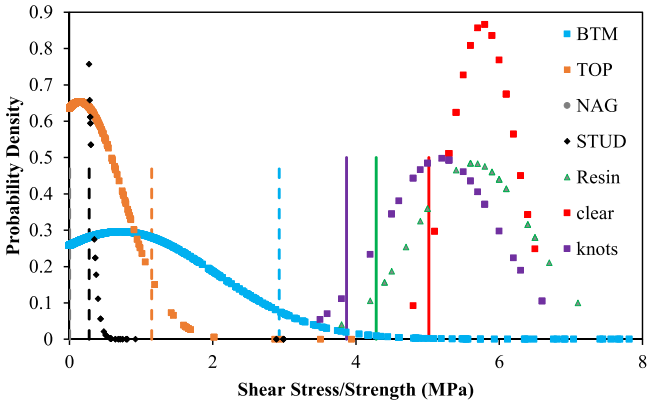


Fig. 16. Probability density of shear stress and timber out-of-grade strength (vertical solid and dash lines represent characteristic strength and stress, respectively). Clear: clear timber (red); Resin: timber with resin (green); Knots: timber containing knots (purple); TOP: top plate; BTM: bottom plate; NAG: nogging.

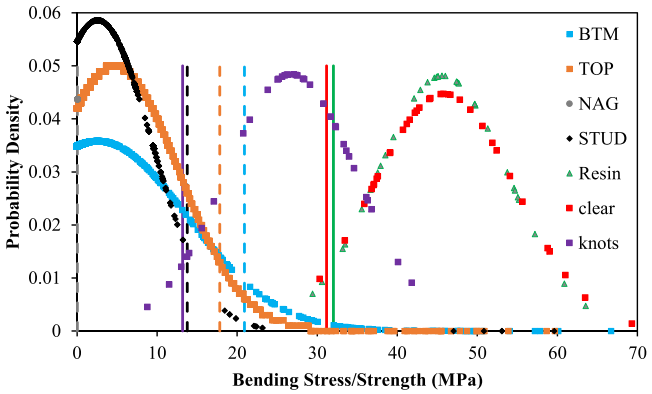


Fig. 17. Probability density of bending stress and timber out-of-grade strength (vertical solid and dash lines represent characteristic strength and stress, respectively). Clear: clear timber (red); Resin: timber with resin (green); Knots: timber containing knots (purple); TOP: top plate; BTM: bottom plate; NAG: nogging.

Section 6.2.1.5 does not require noggings to be of structural grade, and the findings here are consistent with this requirement. Tensile, shear, and bending demands across all studied members remained below the characteristic strength of even defect-bearing timber types (resinous and knotted), indicating safe utilisation margins. For example, bottom and top plates (BTM and TOP) and studs generally displayed stress levels well within the range of tested material capacities for each timber category. However, compressive forces (Fig. 14) presented more nuanced outcomes. In several cases—particularly in studs and, to a lesser extent, top plates—the applied compressive stresses approached or exceeded the lower-bound characteristic strength values, suggesting potential failure risk. This observation underscores the need for selective application of low-grade timber and/or reinforcement strategies in compression-critical members.

6.6. *Engineering implications and future recommendations*

In summary, this case study demonstrates that out-of-grade timber, when assessed through prototype testing and reliability modelling, can meet the performance-based compliance requirements outlined in Section A5.2 of the NCC [113]. This method bypasses the need for traditional stress grading and allows for regulatory acceptance through mechanisms such as CodeMark certification or documented engineering assessments. Several methodological innovations differentiate this work from prior studies:

Comprehensive 3D ETABS modelling of typical low-rise residential buildings using real-world production data from a sawmill.

Monte Carlo-based probabilistic evaluation of internal stresses matched against statistical timber strength distributions aligned with ISO 2394 [23]

Demonstration of safe use for noggings, plates, and selected stud members using out-of-grade timber

Further studies are recommended to extend this methodology to more complex configurations, validate load-sharing interactions through experimental testing, and identify additional opportunities for cost-effective and sustainable material substitution in residential timber construction.

7. Conclusion

This study investigated strategies to optimise the use of Australian timber resources, addressing the growing disconnect between the construction sector's demand for high-stiffness timber and the industry's declining capacity to supply such material. A key focus was the structural potential of low-grade and out-of-grade timber, which has been underutilised due to concerns about mechanical performance, lack of certification pathways, and limited industry confidence. The study began by reviewing the Australian sawn timber supply chain and global production strategies. The analysis revealed that current methods focus more on quantity than quality and frequently neglect how reductions in fibre properties, especially stiffness, affect structural performance. This foundational review highlighted the absence of systemic interventions that address the growing proportion of juvenile and low-grade timber in plantation-grown resources.

To understand practical barriers to adoption, structured interviews and surveys were conducted with engineers, suppliers, builders, and developers. These revealed persistent resistance to the use of non-standard timber products, driven by limited performance data, procurement uncertainty, and a lack of flexible design tools. Nevertheless, growing material demand and supply shortages are prompting increased interest in novel solutions. A real-world case study of an Australian softwood mill provided insight into how procurement practices and quality assessments currently operate in the industry. The findings underscored that fibre characteristics, such as density and modulus of elasticity, are not typically considered in pricing or supply contracts, despite their impact on structural performance. The study identified opportunities to increase resource efficiency through improved data sharing, better alignment between growers and processors, and post-processing technologies capable of enhancing the structural properties

of low-grade timber.

The central engineering contribution involved full-scale structural simulations of one- and two-storey residential buildings using out-of-grade timber. These simulations incorporated probabilistic variability in mechanical properties and applied AS/NZS 1170 load combinations and ISO 2394 design principles. The results showed that many framing members, particularly noggings, plates, and non-load-critical studs, operate under internal forces significantly below the characteristic strength of even low-grade timber. This supports the feasibility of substituting standard-grade timber with out-of-grade material in selected components, provided deflection, joint detailing, and system effects are carefully considered. Importantly, the modelling demonstrated that out-of-grade timber can meet performance-based compliance criteria under Section A5.2 of the National Construction Code (NCC), given appropriate testing and reliability-based assessment. This opens a regulatory pathway through CodeMark certification or site-specific engineer approval, providing an alternative to conventional stress grading systems. By integrating literature analysis, industry consultation, field observations, and advanced structural modelling, this study proposes a scalable framework for incorporating low-grade timber into residential construction. This approach aligns with decarbonisation goals, waste reduction targets, and the need for greater supply chain resilience. Future work should focus on refining prototype design tools, expanding testing datasets, and establishing certification protocols to facilitate broader adoption of these strategies in practice.

CRediT authorship contribution statement

Belleville Benoit: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Wen Li:** Writing – original draft, Methodology, Investigation, Formal analysis. **Chiniforush Alireza:** Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Echo Wang:** Writing – original draft, Formal analysis. **Tuan Ngo:** Supervision, Resources, Project administration, Funding acquisition. **Richard Nero:** Writing – original draft, Formal analysis.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Alireza A. Chiniforush reports financial support was provided by Building 4.0 CRC. Alireza A. Chiniforush reports a relationship with Commonwealth of Australia that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Questionnaire for Utilisation of Low-Grade Timber in Roof/Floor Truss or Wall Frame Construction

Have you considered using lower-grade or out-of-grade timber as roof/floor truss or wall frame components?

If so, where do you think they would be best suited?
If so, and decided not to use it, what are the reasons?

Have you identified obvious areas of over-engineering in truss and frame design that would provide an opportunity for optimisation around timber grade?

Do you think stiffness is the most appropriate way to determine the suitability of a stud for truss manufacturing? Would straightness, dimensional stability, and absence of specific defects be more appropriate in some cases? Please name any other criteria that you would consider.

Would you consider larger section sizes of lower-grade timber to achieve the same outcome?

Would you consider using EWPs such as LVL or glulam instead of stud if properties are equivalent? Would you choose this product for improved dimensional stability and strength for a higher price?

Are you required to use a certain minimum grade for the timber used in your product(s)?

If so, what is the minimum useful grade?

Is this a major obstacle for procurement?

Are all truss components the same timber grade? If yes, what barriers (e.g. equipment, warehousing, programming, education, risk reduction etc.) need to be addressed or overcome to use multiple grades within a truss and/or frame?

What are the timber grades currently used for:
roof truss
floor truss
wall frames?

Is there an opportunity to utilise some lower-grade timber in specific parts of the roof/floor truss or wall frame without compromising or limiting the overall performance of the truss?

If so, would a mix of different (lower) grade timber components complicate the manufacturing process and/or increase construction errors?

What are the lowest strength and stiffness properties that would be appropriate to apply to any component of the truss (if the standards allow)?

How important are the straightness, shrinkage and swelling characteristics of the timber components? Please quantify each of these characteristics, where possible.

How much would further complexity to design/manufacturing/operation be imposed if timber with the same quality to MGP10 with a lower stiffness is utilised in truss manufacturing? Is there any room in truss manufacturing to use such a product?

What software do you use for truss analysis and design? Do you always follow the program recommendations, or do you opt for alternatives such as more economical solutions that still meet the structural performance requirements?

How much price reduction (percentage) will motivate you to consider replacing some of roof/floor truss components with lower-grade timber?

How much price reduction (percentage) will motivate you to consider replacing some of wall frame components with lower-grade timber?

What is the most troublesome defect of your process?

What is the most troublesome defect of your product?

What cost in waste does your company experience due to these troublesome defects (e.g. waste timber, extra labour, extra processing time, recalls/rework)?

Would you be willing to accept timber that had these defects reinforced or ‘repaired’ if the structural performance and/or processing ability was improved?

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