Construction and Building Materials 537 (2026) 147207

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

A critical analysis of using fibre-managed *Eucalyptus globulus* for engineered wood products

William Leggate [a,b], Benoit P. Gilbert [a,b,*], Robert L. McGavin [a,b], Tim Woods [c]

[a] Queensland Department of Primary Industries, Horticulture and Forestry Science, Salisbury Research Facility, Salisbury, QLD 4107, Australia
[b] School of Engineering and Built Environment, Griffith University, Gold Coast Campus, QLD 4222, Australia
[c] IndustryEdge Pty Ltd., Geelong West, VIC 3218, Australia

ARTICLE INFO

Keywords:
E. globulus
Engineered wood products
Laminated veneer lumber
Glued laminated timber
Fibre-managed timber

ABSTRACT

This paper provides an assessment of the suitability of *Eucalyptus globulus* (*E. globulus*) plantations originally established for woodchip and pulp production (i.e., fibre-managed), as a resource for manufacturing engineered wood products (EWPs), particularly laminated veneer lumber (LVL) and glued laminated timber (GLT), within the Australian and international contexts. It first outlines the current wood products market and the potential role of fibre-managed *E. globulus* within it. The discussion then examines methods, opportunities, and technical challenges associated with utilising this resource to meet present and future market demands. The paper finally identifies research priorities required to enable broader and more effective use of *E. globulus* in EWPs. Evidence from Europe and Australia demonstrates the capacity to produce sawn timber and veneers with high mechanical performance, and to manufacture GLT and LVL from fibre-managed *E. globulus* with structural properties comparable to, or exceeding, widely adopted commercial alternatives. For GLT, however, adhesive systems and finger-jointing techniques require further optimisation, particularly for higher-density boards. For LVL production, spindleless lathe technology has proven effective for rotary peeling small logs into veneers, with recovery up to six times higher than if the logs were converted into sawn timber products. Recent investigations using 15- to 19-year-old fibre-managed *E. globulus* from Victoria, Australia, proved that high-grade LVL with high stiffness (characteristic modulus of elasticity up to 20,000 MPa) and high strength (characteristic edge bending strength up to 120 MPa), meeting the requirements for future market demands, can be manufactured. To attract scale investment in GLT and LVL production from fibre-managed *E. globulus*, further work on tree selection, processing and manufacturing optimisation, leading to large-scale commercial trials, and addressing business environment barriers will be needed. Fibre-managed *E. globulus* plantations in Australia and internationally represent a strategically important yet underutilised forest resource capable of helping meet rising global demand for structural wood products.

1. Introduction

Global demand for wood products is rising sharply, with most projections indicating increases of 40–80% by 2050, and some suggesting demand could even quadruple during this timeframe [1–4]. This surge in demand is driven by major societal megatrends, including population growth, rapid urbanisation, decarbonisation efforts, and rising demand for housing and commercial construction. Wood is increasingly favoured over alternative materials due to its recognised sustainability, environmental advantages, and performance benefits [5–8].

Against this backdrop, many countries, including Australia, are expected to face significant shortfalls in domestic wood supply under current forest production and conversion systems [3,9,10]. Forecasts suggest that by 2050, Australia's domestic softwood timber production may meet only around 60% of national demand [9]. Put simply, global society must produce substantially more wood products to satisfy rising needs, particularly for construction materials in the built environment.

Several strategies have been proposed to address this wood supply challenge. A long-term option is to expand tree planting to increase future forest resource availability [11]. However, because many log types suitable for structural applications require extended growth cycles in some regions, before reaching harvestable size and quality, new

* Corresponding author at: School of Engineering and Built Environment, Gold Coast Campus, Griffith University, QLD 4222, Australia.
E-mail address: b.gilbert@griffith.edu.au (B.P. Gilbert).

https://doi.org/10.1016/j.conbuildmat.2026.147207
Received 26 February 2026; Received in revised form 8 June 2026; Accepted 22 June 2026
Available online 25 June 2026

plantations established today may not contribute meaningfully to structural wood product supply until well into the future [12,13]. Moreover, plantation expansion in many regions is increasingly constrained by competition for suitable land from agriculture and urban development, coupled with persistent concerns about the economic viability of new plantations, which continues to limit investor confidence [12–14].

For countries such as Australia, increasing reliance on imported wood products represents another potential strategy. However, this approach carries several disadvantages. Given that global demand for wood is rising sharply, it is risky to assume that future supplies can be reliably sourced from other nations. Dependence on imports also exposes domestic markets to supply chain delays, geopolitical instability, volatility and currency fluctuations [15,16]. Moreover, reliance on imported timber is less beneficial for national employment and broader economic development compared to investing in local timber processing industries that utilise domestic resources [17,18]. There are also ongoing concerns about verifying sources of origin and ensuring independent certification for some imported wood products [19].

In the shorter term, the likely best options to increase wood supply include both improving the efficiency of forest resource processing and recovery, and repurposing timber resources not traditionally grown for structural applications. Engineered wood products (EWPs) are suitable for both options, representing practical and scalable solutions to the rising demand for structural wood products. Unlike traditional sawn timber, they often enable higher log recovery, can utilise small dimension wood feedstocks and lower-grade timber, and represent value-added products [19–22]. Their manufacturing processes also deliver structural products with improved reliable performance, reducing the variabilities in strength, stiffness, and dimensional stability [19–22]. By combining resource efficiency with improved structural properties, EWPs can expand the usable portion of forest resources and ensure that engineered solutions meet both market expectations and sustainability goals [19,20,22,23].

In Australia, *Eucalyptus globulus* (*E. globulus*), native to southeastern Australia and commonly known as southern blue gum or Tasmanian blue gum, is the second most commercially important plantation species after radiata pine (*Pinus radiata*) by area planted, with approximately 324, 000 ha established [24–26]. Also, internationally, around 2.3 million hectares of *E. globulus* plantations exist, making it one of the most widely distributed eucalypt species in the world, with plantings across Europe, Africa, USA, South America, and China [27–29]. Historically, these plantations have been managed primarily for pulp and paper production (i.e. fibre-managed), grown in short rotations (< 15 years) without thinning or pruning [29]. Recognition of the existence of this resource, mostly favourable wood fibre properties of *E. globulus,* combined with projected wood supply shortages, has stimulated growing interest in its commercial potential for EWPs, principally for laminated veneer lumber (LVL) and glued laminated timber (GLT) [30]. Generally, at harvest, higher quality logs would be diverted into the manufacture of EWPs, representing higher financial returns to growers, while lower quality logs would be chipped for pulpwood purposes.

LVL and GLT are two common EWPs that enhance structural performance and resource use efficiency. LVL is produced by bonding thin rotary veneers with durable adhesives under heat and pressure, with all veneers usually oriented in the same grain direction, yielding members that are typically stronger, straighter, and more uniform than sawn timber. It is widely used in applications such as I-joist flanges, wall frames, roof and floor structures where dimensional consistency and high strength-to-weight ratios are critical [31,32]. LVL is also regularly used in other applications such as furniture, packaging and concrete formwork. GLT, in contrast, is manufactured by bonding layers of sawn timber with durable adhesives, allowing for long, straight, or curved members. Its ability to form arches and complex shapes provides architects and engineers with significant design flexibility, while its strength makes it suitable for beams, columns, posts, trusses, bridges, and long-span roofs. GLT also offers aesthetic appeal when left exposed, combining mechanical efficiency with architectural expression [32–34].

Among the range of EWP options, LVL and GLT have been prioritised for utilisation of the *E. globulus* plantation resource in Australia. This prioritisation reflects their strong alignment with rising demand for structural EWPs, their established acceptance and use within the Australian and international building supply chain, opportunities to replace imports and the likely technical suitability of *E. globulus* fibre properties for these product types. In addition, the anticipated availability of investment capital, manufacturing technologies, and production capacity at appropriate scales means LVL and GLT present lower technical and market risks compared to many other EWP alternatives [19]. Research has been performed to some extent to manufacture other types of EWPs from young plantation eucalyptus species, included CLT [35–39], particleboards [40–42], strand/flake-based products [43–45] or Medium Density Fibreboard (MDF) [41,46–50]. For the reasons explained above, these papers are outside the scope of this study".

This paper provides a critical analysis to inform future research and support investment in EWP manufacturing, focusing on LVL and GLT derived from *E. globulus* plantations in the Australian market context. Specifically, it aims to: (1) examine current and future markets for structural LVL and GLT, focussing globally and on Australia where this paper originates; (2) evaluate techniques, challenges, and opportunities for using fibre-managed *E. globulus* plantations to support global EWP market development; and (3) propose directions for future research to support the use of *E. globulus* EWPs. While the focus is on *E. globulus*, relevant insights from studies on other eucalyptus species, including *Eucalyptus nitens* (*E. nitens*), are also considered. Additionally, research has been undertaken on hybrid EWPs that combines hardwood species, such as *E. globulus*, with softwood species in their manufacture, in order to enhance the mechanical properties of softwood [51–60]. While such products are of interest for applications that do not require the full strength and stiffness offered by purely hardwood structural products, hybrid EWPs incorporating *E. globulus* fall outside the scope of this review paper.

2. Review methodology

A structured literature search was conducted to identify studies on the use of *E. globulus* and other plantation-grown hardwoods in EWPs, with emphasis on GLT and LVL. Searches covered major databases including Google Scholar, Scopus, Web of Science, and ScienceDirect. Search terms included: "*Eucalyptus globulus*," "plantation hardwoods," "engineered wood products," "glued laminated timber," "laminated veneer lumber," "wood product markets," "wood properties," "wood quality," "fibre managed timber," "manufacturing," "processing," "sawing," "drying," "gluing," and "mechanical properties," used singly or in combination.

The inclusion criteria included (1) source types: journal and conference articles; reports; reference books and other information sources published in English between 1960 and 2025, however earlier studies were also considered if highly relevant (2) data sources: forest product statistics from the Australian Bureau of Agricultural Resource Economics and Sciences (ABARES) and the Forest and Wood Products Association of Australia (FWPA) (3) scope: studies addressing the processing and utilisation of *E. globulus* and other plantation hardwoods for EWPs, with a focus on GLT and LVL. Studies were excluded if (1) they were focused on softwoods, hybrid-species EWPs or non-relevant products (e.g. pulpwood) (2) they had major methodological/data limitations (3) full text was inaccessible.

3. Market context for structural EWPs

The global market for structural EWPs, particularly LVL and GLT, has expanded substantially over recent decades [19,23,61–68]. This growth aligns with broader shifts toward sustainable construction, including the emergence of mid-rise to tall timber buildings, in which EWPs are increasingly promoted as credible alternatives to sawn timber, steel and concrete [19,69,70]. As mentioned earlier, LVL and GLT are now widely used across residential, commercial, infrastructural, and recreational applications in both global and Australian contexts [19]. Their appeal stems from the decreasing availability of large dimension sawn timbers (particularly hardwoods with high mechanical properties), their high strength-to-weight ratios, dimensional stability, straightness, uniformity, and compatibility with prefabricated and digitally enabled construction systems [19,21,71,72]. Advances in off-site manufacturing, digital design technologies, and policy frameworks encouraging low-carbon building materials have further accelerated their adoption [69,70,73].

Recent market assessments estimate the global LVL sector at around USD 5.5billion, equivalent to approximately 5.3 Mm^3 of annual production [74,75]. Long-term forecasts diverge considerably, with projections ranging from USD 6.9 billion by 2033 to USD 15.3 billion by 2035 [75,76] reflecting steady demand for LVL across construction and industrial applications. North America, Europe and Asia-Pacific account for more than 85% of total LVL consumption [77].

The global GLT market was valued at USD 7.44 billion in 2023 (approximately 7 Mm^3) and is projected to grow at around 5% annually through to 2030 [78–80]. Europe, North America and the Asia-Pacific regions again dominate consumption [79–81]. Across both global and Australian markets, supply remains dominated by softwood-based products, highlighting a significant opportunity for sustainably sourced hardwood alternatives with superior mechanical properties [19]. Australian commercial hardwood timbers, including plantation species, often exhibit superior strength and stiffness compared with common softwoods like *Pinus radiata* (radiata pine) [20,82–84]. However, factors such as stem form, resource uniformity, and inherent wood variability also influence their practical use relative to softwoods.

Focussing on Australia, Australia's structural EWP market, while comparatively small, is strategically significant. IndustryEdge [19] identified substantial commercial opportunities to manufacture LVL and GLT from Australian hardwood plantation resources to meet rising domestic demand and reduce reliance on imports. LVL and GLT together comprise approximately 85% of the Australian structural EWP market (excluding particleboards), which continues to experience strong growth. Annual consumption is conservatively estimated at 280, 000 m^3 (AUD 398.9 M) for LVL and 79,000 m^3 (AUD 165.1 M) for GLT, yet domestic production capacity remains insufficient, resulting in heavy dependence on imports, especially for LVL [19]. Currently, with only one domestic manufacturer, Australian LVL production meets only about half of minimum national demand, with imports totalling an estimated 156,400 m^3 in 2023–2024. This reliance exposes the sector to supply chain disruptions, price volatility, and currency fluctuations, and raises concerns regarding species verification, legality, certification, and sustainability of some imported products [19,85].

IndustryEdge [19] also identified strong potential in Australia for producing higher structural grades of LVL and GLT than the ones commonly produced, i.e., manufacturing products not currently available in sufficient volumes from either domestic or imported softwoods. High-strength and high-stiffness hardwood LVL and GLT can directly compete with steel in a range of applications [19]. The fibre properties of *E. globulus* (discussed in subsequent sections) indicate strong potential to produce LVL and GLT with mechanical performance equal to or exceeding softwood alternatives, addressing domestic supply constraints while positioning Australia as a potential exporter of high-grade hardwood EWPs. The interest in plantation-grown hardwoods such as *E. globulus* for high-grade structural applications has also recently intensified due to reduced access to native hardwood resources, including the cessation of native forest harvesting in Victoria [86,87].

Out of the potential markets for new EWPs manufactured from *E. globulus*, IndustryEdge [19] identified substantial market opportunities, reflecting a strong demand across the Australian construction sector, for LVL in structural grades commonly referred to as LVL13 (i.e., a LVL with a Modulus of Elasticity (MOE) of 13,000 MPa) and above. Commonly used LVL grades in Australia mainly are referred to and include LVL10 (MOE of 10,000 MPa), LVL13 and LVL15 (MOE of 15, 000 MPa), selected according to application requirements ranging from moderate-strength wall studs to wide-span beams requiring higher stiffness and minimal deflection. IndustryEdge [19] noted that LVL manufactured entirely from *E. globulus* could substantially reduce import dependence and strengthen domestic supply chains.

Additionally, in terms of the growing market for LVLs, recent research into the Australian timber frame and truss sector has documented significant growth in LVL use [88]. This trend reflects not only LVL's increasingly competitive pricing relative to sawn timber but also its perceived performance advantages, including superior straightness and uniformity. Some builders now specify wall frames constructed exclusively from LVL. The rising competitiveness of steel framing has further highlighted the limitations of sawn timber, as steel's uniformity and generally defect-free nature expose quality problems and variability in traditional sawn timber products. LVL, offering characteristics more comparable to steel, is increasingly viewed as a preferred timber-based alternative [88].

The outlook for GLT differs from that of LVL. While current production capacity in Australia is sufficient to meet baseline demand, shortages of suitable fibre constrain the availability of higher structural grades [19]. This constraint is most pronounced for GL17 and GL18 grades (the highest GLT grades recognised in Australia under Australian standard AS 1720.1 [89] with MOE values of 16,700 and 18,500 MPa, respectively), which relies heavily on hardwood feedstock. The reduction in native hardwood supply has significantly limited domestic production of such grades and increased reliance on imported hardwoods, especially from Indonesia. Despite these constraints, demand for GL17–18 remains strong. Although the domestic market for GL18 is relatively modest, estimated at 10,000–12,000 m^3 annually, it is strategically important [19]. High structural-grade GLT can reduce import dependence and complement LVL and other EWPs. Hardwood GLT is also preferred for appearance-grade applications. IndustryEdge [19] recommended that GLT production from plantation *E. globulus* focus on GL17 and GL18 grades rather than lower grades such as GL13 in AS 1720.1 [89], which would compete directly with abundant softwood products. GL17 and GL18 are expected to be used primarily in wide-span beams (including exposed applications), flooring systems, and mass-timber projects alongside cross-laminated timber (CLT) for instance.

Although the broader context underscores strong market demand for GLT and LVL, particularly highlighting the opportunities for *E. globulus* plantations in Australia, these prospects can only be realised if technical feasibility is established. In particular, it must be demonstrated that GLT and LVL can be successfully and commercially manufactured from fibre-managed *E. globulus* plantations. This is discussed in the following sections.

4. Challenges and approaches in processing *E. globulus* to manufacture GLT and LVL

This section reviews the processing, recovery and drying challenges and approaches for *E. globulus* to produce either sawn timber boards or rotary veneers, i.e. to produce the raw material feedstocks for GLT and LVL, respectively. Lessons learnt from processing other plantation eucalyptus logs are also covered.

4.1. General description of wood properties and characteristics

E. globulus timber ranges from pale straw to brown in colour, frequently with blue, green, or grey tinges. Regrowth material may display pinkish hues. Sapwood is generally lighter than heartwood, though the boundary is not always distinct [90]. The grain is often interlocked, with a medium and relatively even texture. Growth rings are prominent in end sections. The wood is described as having moderate durability; it is not termite resistant, and untreated sapwood is susceptible to Lyctid borer attack [90]. Although classified as hard, the timber is relatively easy to work, fix, and dress. It exhibits very high tangential and radial shrinkage and high unit movement [90]. The wood physical properties of mature *E. globulus* trees are summarised in Table 1 and are compared with the common commercial softwood radiata pine (*P. radiata*), illustrating its superior density, hardness, and mechanical properties [90–92]. Fundamental properties of *E. globulus* vary with age, silviculture, genetics, and site; younger, plantation-grown material differs from mature trees from native forests. Younger plantation trees can generally be expected to have lower density and mechanical properties at a very young age [93].

E.globulus is more challenging to process and dry than radiata pine, as well as many other common commercial softwoods and native hardwoods. Growth-stress related board splitting, distortion, and also drying defects such as collapse and internal checking are more likely [96–101]. These issues are discussed in the following sections.

4.2. Sawn timber boards

4.2.1. Growth stresses

Growth stresses and tension wood, defined by "abnormal wood produced by hardwoods as a reaction to bending stresses within the tree stem" [96] and characterised by high peripheral tensile stresses commonly occurs in *E. globulus*. Growth stresses are influenced by a combination of factors, including tree age, growth rate, tree size, tree form, genetics, environmental conditions and silvicultural practices, however the formation of tension wood – particularly in response to mechanical stimuli such as tree bending or leaning – is a significant contributor to these stresses [96,102,103]. These growth stresses have been perceived by the industry to be a major constraint when sawing plantation-grown eucalyptus [97,98]. It is believed that growth stresses principally pose problems when sawing small diameter trees as opposed to larger ones [97]. According to Washusen [96], "growth stress release in small diameter logs has a major adverse effect on sawing accuracy, board distortion and board end-splitting". Washusen [96] also mentioned that tension wood in thinned and pruned *E. globulus* stands is minor. However, in unthinned *E. globulus* young plantation stands, as would be the case for plantations established for pulpwood, tension wood and growth stresses are common [101].

Tension wood does not only affect sawing, but it also makes drying difficult (see next sub section). When analysing the effect of growth strain (measured as per Nicholson [104]) on back-sawn 10-year-old unpruned *E. globulus* boards from sites near Mt Gambier, Australia, Yang, et al. [99] found that increasing growth stress and decreasing log diameter had a direct negative effect on the percentage of excessively distorted sawn boards.

Table 1
Wood properties of E. globulus in comparison with P. radiata.

	E. globulus (mature) [90,92]	*P. radiata* [91,92]
Tangential Shrinkage[a]	14.4%	5.0%
Radial Shrinkage[b]	6.9%	3.0%
Unit movement tangential[c]	0.39%	0.27%
Unit movement radial[d]	0.26%	0.20%
Strength group seasoned[e]	SD2	SD6
Stress grade seasoned[f]	F14 – F34	F5-F14
Density seasoned[g]	900 kg/m^3 [92] - 970 kg/m^3 [90]	500 kg/m^3 [92] - 550 kg/m^3 [91]
MOR seasoned[h]	146	81
MOE seasoned[i]	20	10
Hardness seasoned[j]	12	3.3

These definitions are sourced from [90–92]:
[a] change in tangential dimensions from unseasoned to 12% moisture content
[b] change in radial dimensions from unseasoned to 12% moisture content
[c] percentage change in tangential dimension for each 1% change in moisture content
[d] percentage change in radial dimension for each 1% change in moisture content
[e] in accordance with AS2878 [94] where SD1 is the highest and SD8 the lowest
[f] a stress grade is defined in AS 1720 [95] as the classification of timber for structural purposes by means of either visual or machine grading. The stress grade indicates the basic working stresses and stiffnesses to be used for structural design purposes. Measured in MPa.
[g] based on moisture content of 12%. Plantation *E. globulus* harvested at 15–20-year-old would have lower density, with average density of 720 kg/m^3 found in [84].
[h] a measure of the maximum stress which can timber can momentarily sustain when loaded slowly and continuously as a beam Measured in MPa.
[i] this property is of importance in determining the deflection of a beam under load; the greater the stiffness, the less the deflection. Measured in GPa.
[j] refers to the Janka hardness test and is a measure of timber's resistance to indentation.

4.2.2. Processing and recoveries

4.2.2.1. Sawing pattern and recoveries. Innes, et al. [105] mentioned that sawing equipment adapted to *E. globulus* is needed to optimise recovery rate. Quarter-sawing, as shown in Fig. 1, is not prescribed in the literature as a good strategy to process small diameter logs (less than small end diameter (SED) of 40 cm) [97], but better suited to larger diameter logs. Additionally, Washusen [96] (referring to a study performed on 28 m^3 of large diameter (approximately 47 cm in diameter) unpruned *E. globulus* logs and to the study on 32 year-old thinned *E. globulus* logs in Washusen, et al. [106]) mentioned that the mills used the quarter-sawing strategy shown in Fig. 1 and similar recoveries calculated as the ratio of the volume of the dried boards to the volume of the green logs (approximately 29% total recovery and 12% select grade and better recovery), to what is expected for Victorian native forest ash (typically *E. regnans* and *E. delagatensis*) were encountered.

For small diameter logs, Washusen [96] recommends back-sawing, as shown in Fig. 2, and referred to the studies by Washusen, et al. [107] and Washusen, et al. [108] on pruned 22-year-old *E. nitens*. In these studies, back-sawing allowed recovering between 30% and 40% of the log volume into sawn boards, when compared to 25% to 30% for quarter-sawn. However, a higher percentage of "select" and "standard" boards, between 4% and 18% of the total log volume, were recovered from the quarter-sawn logs against 1% to 13% for the back-sawn logs. Another disadvantage of back-sawing was pointed out by de Fégely [97] who mentioned that quarter-sawing can permit better recovery for collapse prone species, as occurring with *E. globulus* [109], during reconditioning. Also, when compared to back-sawing, quarter-sawing resulted in a reduction in internal and surface checking in *E. nitens* [105,107,108]. However, Washusen [96] argued that little surface checking will occur for back-sawn logs if the boards are dried with care. On the plus side, when looking at processing fast-growing *Eucalyptus regnans*, Waugh, et al. [110] found that drying back-sawn boards "required low temperatures, high humidity and low air flow in the early drying stages" and that back-sawing strategies have "the potential to provide both higher sawlog yields from the forest and higher mill-door values than traditional quarter-sawing practices". When studying sawn boards from 17-year-old (Small End Diameter Under Bark (SEDUB) < 45 cm) pruned and thinned *E. globulus* logs, Brennan, et al. [111] stated that "cutting logs into short lengths and using a back-sawing cutting pattern assisted in reducing the amount of bow and spring".

Gilbert, et al. [84] back-sawed twenty 15-years-old and twenty 19 years-old *E. globulus* logs from Victoria, Australia, of Diameter at Breast Height Over Bark (DBHOB) ranging from 17 cm to 31.8 cm. No log splitting was observed. An average of 42% of the logs was recovered into green (unseasoned) boards. The net board recovery, reflecting the

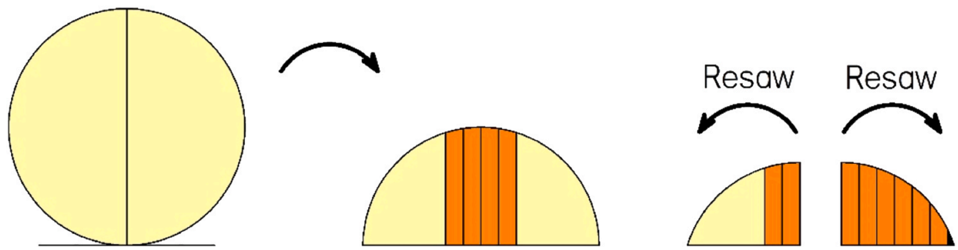

Fig. 1. Quarter-sawing strategy suitable to logs of SED greater than 40 cm (adapted from [96]).

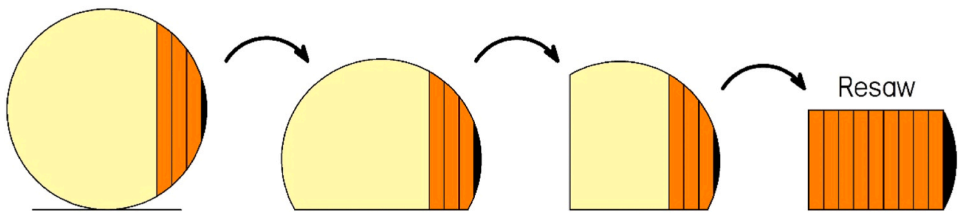

Fig. 2. Back-sawing strategy suitable to logs of SED less than 40 cm (adapted from [96]).

recovery from logs to finished GLT products, was estimated at 12%.

An unpublished trial from the green triangle region of Australia (forest region spanning the southern border of South Australia and Victoria) processed 54 m^3 of *E. globulus* logs using a Hew saw 250. Bow in flitches was encountered immediately. Small diameter logs seemed to process better than larger ones [112].

In general, the literature reports sawn board recoveries as would be expected from other hardwood resources [84,113–115]. Recovery, and product quality and value, improved as the diameter of the logs increased since thinning [106,114].

4.2.2.2. Recommended sawing equipment. Washusen [96] and de Fégely [97] prescribed the use of twin-saws, as opposed to single saws, when processing small diameter eucalyptus. Twin-saw systems release growth stresses more symmetrically, which result in centre cants with limited warping. However, Washusen [96] outlined that twin-saws have more limitations on the maximum log diameter which can be processed compared to single saws. Splitting ahead of saws is also an issue that has emerged frequently in trials and Washusen [96] recommends to further "release growth stresses uniformly from around the log". To do so, the author suggests to use chipper canters which practically remove wood simultaneously from all sides of the logs. Washusen [96] added that if the logs "can be back-sawn with multi-saw systems, growth stress release is controlled better, sawing accuracy improved, board width increased and higher recoveries obtained, in comparison to quarter--sawing". The author further recommended the elimination of end-dogging in the sawing process as it contributes to preventing log end splitting. Additionally, for improved recovery, Washusen [96] noted that the use of "a line-bar to single saw log break-down systems, coupled with multi-saws in down-stream processing, will help reduce the thickness and width variation".

The saw-dry-rip [117] and tangential processing methods (Fig. 3) have been investigated by Franke, et al. [116] on 20-year-old *E. globulus* logs from Portugal. In the saw-dry-rip method, wide flitches are first cut and dried. As the flitches are wide, it reduces warping during drying and as "the flitch dries the growth stresses are largely relieved due to slippage of the wood cells relative to one another while the piece holds it shape" [117]. The flitches are then cut into boards and further dried. Before final drying, the saw-dry-rip method exhibited superior board recovery than the tangential method, with the production of boards showing nearly half less bow and spring distortion.

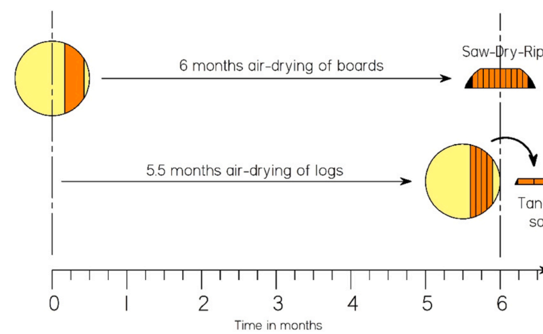

Fig. 3. Saw-dry-rip and tangential processing technique used by Franke, et al. [116].

4.2.3. Drying

Tension wood does not only affect the processing of logs but also the quality of the boards recovered after drying. Washusen [96] noted that "tension wood is extremely unstable during drying and has very high transverse and longitudinal shrinkage". *E. globulus* is known to be susceptible to drying stresses leading to "collapse, case hardening, honeycomb, checking and cupping" [100]. Washusen [96] advocated that "internal checking is not a serious problem in plantation-grown *E. globulus* provided that logs with high levels of tension wood are avoided (where possible) and appropriate sawing strategies are applied".

Neumann, et al. [118] found that checking will reduce in 30- to 40-year-old *E. globulus* sawn timber if the initial drying temperature of the kiln is kept as low as possible, preferably below 30 °C. Regular high humidity treatment also helped reducing honeycomb. However, Chafe, et al. [119] found that pre-steaming radially sawn boards cut from 40-year-old *E. globulus* logs provided little reduction in internal checking, a result different from Neumann, et al. [118]. Bekele [120,121] studied different drying methods for young plantation *E. globulus* boards from Ethiopia, consisting of air, one high (between 40 °C and 65 °C) and one low (between 22.5 °C and 35 °C) temperature kiln drying regimes. The temperature increased as the boards dried. The selected trees had an average SEDUB of 15.2 cm. For kiln drying, while taking longer, 840 h instead of 520.5 h, low temperature drying resulted in less, but still comparable, geometric imperfections (bow, twist and cupping) and internal checking. In comparison, higher degradations were observed for air drying over 14 months. In all cases and after planing, the authors claimed that mainly utility boards according to the former Australian standard AS 2796 [122] were produced.

Washusen, et al. [101] compared two different drying regimes on conventionally back-sawn 40 mm thick boards from 15-year-old unpruned and unthinned plantation *E. globulus* logs, harvested from the Murray darling basin, Australia. In the first drying regime, the boards were air dried to 26.5% moisture content (MC) and then kiln dried, whereas, in the second drying regime, the boards were kiln dried directly from green. The dry bulb temperature increased from 30 °C to 80 °C for the latter schedule. Results showed that "drying degrade in the form of either surface checking, internal checking or distortion and splitting or combination of these defects was severe and led to serious degrade under both drying regimes." Low recovery (less than 2%) of Select grade or better was achieved. Tension wood accounted for some of the drying defect.

Hansmann, et al. [100] reported that collapse can occur during air drying, and controlled drying is important. The authors used vacuum drying with high-frequency energy (400 W @ 13.6 MHz) to dry a limited number of "quality" *E. globulus* boards, i.e., without cracks, cell collapse, warp, or obvious discoloration. The authors claimed that there was reduced cell collapse with this drying method, but no benchmarking to other drying methods was performed. Still on vacuum drying, Franke, et al. [116] compared different drying techniques on timber from 20-year-old *E. globulus* logs from Portugal. Vacuum drying took place after air-drying, with a schedule for European oak, and performed better than conventional kiln drying.

Brennan, et al. [111] kiln dried 28 mm to 50 mm thick *E. globulus* boards, with the drying conditions increasing as the MC decreased. The authors found that some of the thicker boards (50 mm) collapsed after drying, with the collapse being recovered with an 8-hour steam recondition. Bow and spring of flitches were not found to be an issue when drying. Overall, after dressing, collapse and surface checking were not observed. In a literature review, Washusen [96] also found that "substantial reduction in visible internal checking in *E. nitens* is possible with good drying practices and it can be largely eliminated by sawing thin-section boards" (less than 25 mm thick). "Sawing thin section back-sawn and quarter-sawn boards < 25 mm thickness will improve drying results if boards are dried carefully above fibre saturation point and a steam reconditioning treatment applied at a mean moisture content of 15%". Washusen [96] also pointed out that "the defects in dried boards appear as high shrinkage, surface and internal checking and distortion in the form of spring, bow (that may not be present after sawing), cupping and twist". Boards up to 43 mm thick can be achieved with good results.

Gilbert, et al. [84] processed 15-year-old and 19-year-old fibre-managed plantation *E. globulus* logs from Victoria, Australia with the nominal 25 mm thick boards loaded with concrete blocks, wrapped under a hessian mesh and stored under cover to air dry for a period of about 6 months until they reached a moisture content of around 18% to 20%. Finally, the boards were kiln dried to a target moisture content of 12%. No steam reconditioning was undertaken to recover collapse. Planing was efficient in removing collapse developed during drying, as well as large spring and cup imperfections.

4.2.4. *Sawn timber board grades and mechanical properties*

McGavin, et al. [123] assessed the processing and utilisation options of 8–9-year-old sub-tropical and tropical eucalypt plantation thinnings, all sourced from Queensland and Northern New South Wales. While *E. globulus* was not looked at in the study, the outcomes of unpruned plantation logs apply to the *E. globulus* fibre-managed resource. Results showed that visual grading was not a good indicator of the actual mechanical properties of the boards. While more than 50% of the boards failed to meet a structural F-grade in the former Australian standard AS 2082 (2000) when visually graded, destructive four-point bending testing showed significantly higher F-grade recoveries. Fig. 4 shows the difference between visual grading and actual grade, based on MOR tested values, of Gympie messmate boards. The characteristic properties of the F-grades in AS1720.1 are also given in the figure for information. The authors suggested that the difference between visual grading and structural testing was because "the visual grading standard was prepared for a native forest hardwood resource in mind and implies that this standard is not appropriate for the grading of plantation-grown sawn structural material".

A similar finding to McGavin, et al. [123] was previously encountered by Yang, et al. [124] who studied the mechanical properties of boards recovered from three *E. globulus* plantation stands in Tasmania. The stands were 19-, 21- and 33-year-old, with average DBHOB ranging from 27.8 cm (19-year-old trees) to 41.1 cm (33-year-old trees). While not explicitly mentioned in the paper, the text suggests that the trees were extracted from fibre-managed plantations. Recovered sawn boards were first visually graded for structural purposes to former AS 2082

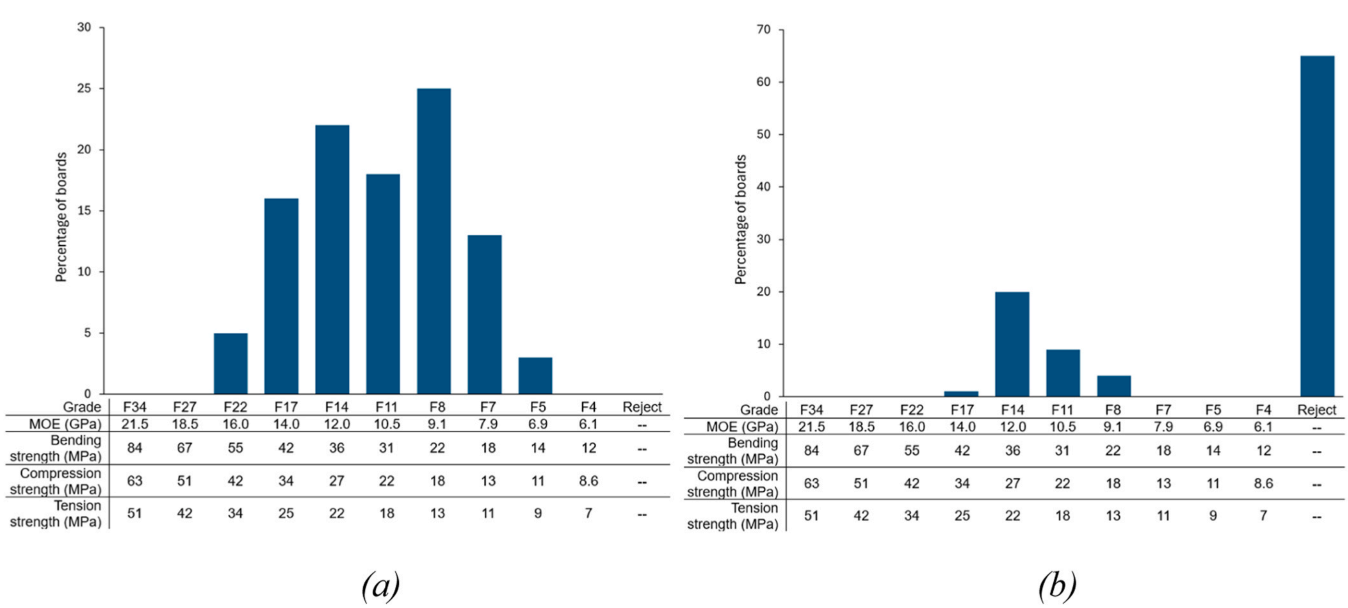

Fig. 4. F-Grade recovery of Gympie messmate (Eucalyptus cloeziana) plantation thinning boards adapted from McGavin, et al. [123] and showing the characteristic properties of the F-grades in AS1720.1, (a) actual MOR values from destructive testing and (b) visual grading.

[125] and then destructively tested in bending. Visual grading led to 31% to 58% of the boards being graded as “reject”. The remaining boards had visual grades ranging from F14 to F27 [89], with the higher grades more commonly found in older stands. For the younger stands, boards were mainly rejected due to the presence of pith or heart material. From the destructive test results, all boards combined would lead to F4 grade. Only considering the boards from the outer heartwood would result in a F8 grade. In comparison, the average bending MOR and MOE of 63.4 MPa and 15,326 MPa, respectively, of the tested boards correspond to a F17 grade. These values reflect the large variability in the mechanical properties of the resource and provide indications on a sizeable presence of high F-grades, presumably not fully captured by the visual structural grading. Additionally, the authors noted that all boards were intentionally loaded with the defects located at the tension side, i.e., at the most detrimental location, resulting in the calculated grades and bending MOR to be conservative.

Pangh, et al. [35] also found that structural visual grading was inappropriate for fibre-managed *E. nitens* and *E. globulus* boards, but not to the same extent as McGavin, et al. [123] and Yang, et al. [124].

The potential inadequacy of the structural visual grading system in AS 2082 [126] for plantation-grown boards may be overcame by the new visual grading system, named MEF, proposed by Fdez-Golfin, et al. [127]. The authors characterised 452 boards of *E. globulus* cut from four different Spanish plantations, and while not explicitly mentioned, the plantations were likely fibre-managed and the logs carefully selected [96]. The new grading system, better suited to the resource, resulted in characteristic bending values of 18,430 MPa for the MOE and 47.9 MPa for the MOR. These values are greater than the characteristic values of a F17 structural grade [89].

Studies, looking at *E. globulus* or *E. nitens*, plantations, “high feature” (also referred to as “utility” or “merch” grade) boards were principally recovered if the plantations were not thinned and pruned [105,108,111, 114,128]. Therefore, it would be challenging to manufacture appearance structural products from fibre-managed *E. globulus* plantations due to the high presence of visual features.

Further regarding the mechanical properties of *E. globulus* boards, Derikvand, et al. [115] converted 26-year-old *E. globulus* fibre-managed plantation logs from Tasmania and determined correlations between the bending properties (MOE and MOR) and visual characteristics, such as strength reduction factors. The logs had an average SEDUB of 403 mm. The slope of grain, amount of clear wood and total number of knots in the loading zone were found as the parameters influencing the MOR and MOE values the most. Average bending MOE and MOR of 11,800 MPa and 49.5 MPa, respectively, were encountered, values close to the characteristic values of a F14 structural grade [89]. Some correlations were found between log MOE and board MOE ($R^2 = 0.534$), but not between log MOE and board MOR ($R^2 = 0.104$). Artificial neural network was used to predict MOE and MOR based on measured parameters.

Lara-Bocanegra, et al. [129] selected 300 Spanish-grown plantation *E. globulus* boards, visually graded to a D40 minimum strength in UNE 56546 [130]. Boards were only selected from the heartwood of the logs. No indication was given if the plantations were managed for structural or pulpwood purposes. 183 boards were tested in four-point bending and reached an average bending MOE and MOR of 18,108 MPa and 91.4 MPa, respectively, with a characteristic bending MOR value of 53.1 MPa, i.e. corresponding to a F27 structural grade in AS 1720.1 [89]. Similar to Derikvand, et al. [115], results showed no correlation between the density of the boards and bending MOR. However, a correlation existed between bending MOE and MOR, with the authors proposing to grade the boards based on the MOE value.

Franke, et al. [116] tested boards sawn from 20-year-old *E. globulus* logs from Portugal, with no information on the silviculture regime applied to the trees. However, according to Washusen [96], *E. globulus* trees in Europe are carefully selected from fibre-managed plantations. Results showed average bending MOE and MOR, tensile strength parallel to grain (performed on small dog bone samples), compression strength parallel to grain, shear strength and bending MOE of 24, 000 MPa, 115.4 MPa, 115.6 MPa, 83.2 MPa and 15.4 MPa, respectively. Such average values correspond to the characteristic values of a F34 grade, the highest structural F grade in the AS 1720.1 [89].

In a very recent study by Gilbert, et al. [84] on 15-year-old and 19-year-old fibre-managed plantation *E. globulus* from Victoria, Australia, 20% of the boards had high acoustic MOE (measured through a non-destructive acoustic/vibration method, providing MOE typically 10–15% higher than static MOE) and density values greater than 21, 000 MPa and 850 kg/m^3, respectively. The high MOE *E. globulus* boards reached tensile strength greater than 100 MPa. Compressive strengths were up to 70 MPa and the bending strength of the boards ranged between 40 MPa and 180 MPa. The average shear strength was 12.4 MPa. Correlation equations were established between the strength, density and knot-to-area ratio. Fig. 5 shows the acoustic MOE distribution of the boards recovered from the 15-year-old and 19-year-old plantations in Gilbert, et al. [84].

4.3. Veneers

4.3.1. Processing and recoveries

The Queensland Department of Primary Industries, Australia, has investigated for the last decade the opportunity to use spindleless lathe technology and maximise the recovery of small diameter logs into rotary veneers [131–135]. A spindleless lathe is shown in Fig. 6. Australian plantation *E. globulus* has been included as part of the studies [132, 134–136]. This technology, commonly used in South-East Asia, China and Vietnam, is emerging in Australia. Contrary to traditional spindled lathes, which use spindles or ‘chucks’ to hold the logs on the ends and rotate it against the blade, spindleless lathes have rollers which apply pressure to the periphery of the logs, resulting in 20–50 mm diameter peeler cores, as opposed to 110 mm and above for traditional spindled lathes [137]. This technology is therefore well adapted for small diameter logs and high recovery of the log volume into veneers. To illustrate, for trees having average DBHOB between 20 cm and 37 cm, green recovery rates (calculated as ratio of the volume of the recovered green veneers to the billet volume) ranges between 68% and 84% and net recovery rates (calculated as the ratio of the volume of the saleable trimmed veneers to the billet volume) between 48% and 58% [132,135]. For 13–16-year-old *E. globulus* of average DBHOB of 30.6 cm and harvested from three sites in Victoria, net recoveries were between 49% and 52% [132,135]. These numbers are superior to the recovery (calculated as the ratio of the volume of the dried back-sawn boards to the volume of the green logs) of about 30% in Washusen, et al. [108] for average DBHOB between 36 cm and 41 cm plantation *E. nitens*. In McGavin, et al. [131] the recovery using spindleless lathe technology was up to six times

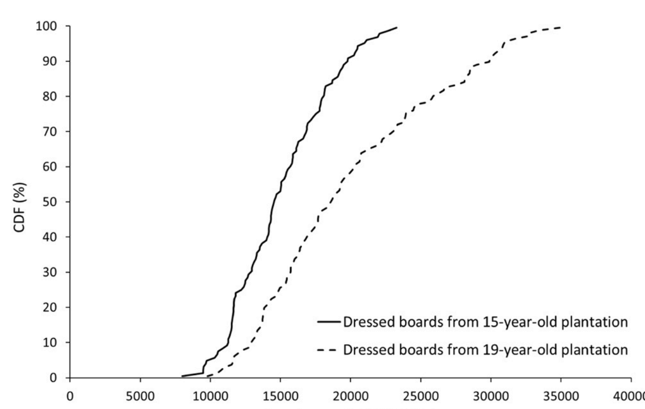

Fig. 5. Acoustic MOE distributions of the boards recovered from two plantations in Gilbert, et al. [84].

Fig. 6. Example of a spindleless lathe.

higher than what would be recovered from the same resource if it was converted into sawn timber products.

For further comparison, when peeling with spindleless lathe technology 7.5-year-old to 19-year-old African Mahogany logs, McGavin, et al. [138] found net recovery ranging between 42% to 57%. This compares to a recovery for sawn graded boards extracted from trees of the same site between 16% to 30%. The trees selected had DBHOB between 25 cm and 36 cm, depending on the site.

Gilbert, et al. [84] performed a comprehensive recent study on rotary peeling 15-year-old and 19-year-old fibre-managed plantation *E. globulus* logs from Victoria, Australia. The gross veneer recovery was around 50% and the net veneer recovery ranged from 43% to 46%, aligned with industry expectations.

Peeling results in higher recovery rates versus sawing and peeling also allows a higher proportion of the desired high density/stiffness wood at the periphery of the logs to be recovered. This benefit provides more opportunities for manufacturers to produce different and a higher proportion of higher grades through different construction strategies.

In addition to significant recovery gains, rotary veneer processing is reported to largely overcome the problematic drying problems that can exist with sawn timber processing [139], particularly with plantation-grown hardwoods such as *E. globulus*. McGavin et al. studies [132,134] successfully dried rotary veneers sourced from a range of plantation hardwood species including *E. globulus* veneers to a target moisture content of 5%, using a conventional jet box drier operating at temperatures between 160 °C to 190 °C. Gilbert, et al. [84] dried rotary veneers from 15-year-old and 19-year-old fibre-managed plantation *E. globulus* logs from Victoria, Australia, using a conventional jet box veneer drying system without issues.

4.3.2. Veneer grades and mechanical properties

Farrell, et al. [140] assessed the possibility of using 16- to 26-year-old fibre-managed *E. nitens* and pruned 33-year-old *E. globulus* logs for the manufacture of plywood and LVL, with a focus on *E. nitens*. For the *E. nitens*, no veneers met a visual appearance grade higher than D in the former Australian standard AS/NZS 2269.0 [141] and between 50% to 60% did not meet a visual grade at all. For the *E. globulus* veneers, the majority of the veneers (96%) were visual grade D. Similarly and more recently, McGavin, et al. [134] studied the grade recovery of veneers peeled from plantations established from various purposes, including (1) 10- to 16-year-old spotted gum, Gympie messmate and red mahogany sawn timber plantations, (2) 11- to 16-year-old Dunn's white gum and *E. globulus* fibre-managed plantations and (3) 20- to 22-year-old *E. nitens* fibre-managed plantation. Results showed that D-grade veneers as assessed in AS/NZS 2269.0 [142] dominated, with less than 1% classified as A-grade veneers for all investigated plantations. For *E. globulus* and *E. nitens*, D-grade veneers represented 84.3% and 67.7%, respectively, of the peeled veneers. Even for 16-year-old thinned and pruned *E. globulus* plantations in McGavin, et al. [135], D-grade veneers represented nearly 81% of the trial, with no veneers meeting the requirements for A-grade. The above results indicate that visual appearance veneer-based structural products are unlikely to emerge from fibre-managed plantations alone, although the majority of structural LVL markets are less demanding on aesthetic characteristics meaning that D-grade veneers are likely suitable. Gilbert, et al. [84] also found that visual D-grade veneers [142] dominated the feedstock of *E. globulus* veneers, limiting the manufacturing of appearance veneered-based products. On average 17% to 23% of veneers, failed to meet the visual grade requirements of AS/NZS 2269.0 [142] and may have limited use in the manufacturing process of LVL structural products.

In terms of the mechanical properties of veneers, MOE between 8,000 MPa and 15,000 MPa, 16,000 MPa and 22,000 MPa, and 22,000 MPa and 32,000 MPa were recovered by Farrell, et al. [140] from fibre-managed 16-year-old *E. nitens*, 26-year-old *E. nitens* and 33-year-old *E. globulus*, respectively. The authors considered "that young unpruned *E. nitens* has low usefulness for higher value veneer and ply production". In McGavin, et al. [136] and for 13–16-year-old *E. globulus* logs, with an average DBHOB of 30.6 cm, resulted in an average MOE of the veneers of 15,896 MPa, with a CoV of 30.8%. In Gilbert, et al. [84], the average MOE for the peeled veneers was equal to 15,690 MPa and 20,119 MPa for the 15-year-old and 19-year-old *E. globulus*, respectively. The 19-year-old logs provided veneers with an MOE about 26% higher on average than the 15-year-old logs. The acoustic MOE (determined through an acoustic/vibration method such as used in industry with Metriguard equipment for instance) distribution of the veneers peeled in Gilbert, et al. [84] are shown in Fig. 7. The high MOE of the veneers recovered in the above studies would result in high mechanical properties of manufactured veneer-based products (see Section 5.2), indicating that if face grade veneers are not required, fibre-managed logs can be used in the manufacture of valuable veneer-based structural products.

4.4. Synthesis

E. globulus plantation logs established for pulpwood purposes are commonly harvested 15 years after planting [143]. If during harvest, selected logs are diverted for sawing, they will be of relatively small diameter (typically DBHOB less than 30–35 cm) for which back-sawing is recommended. While the literature mentions that growth stresses are common in *E. globulus* and logs with tension wood should be avoided, it

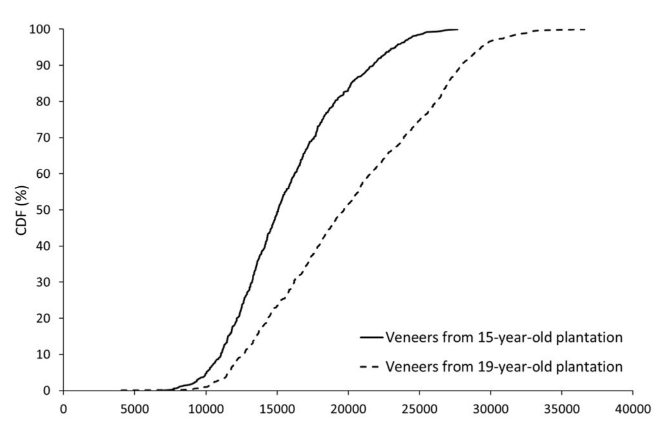

Fig. 7. Acoustic MOE distributions of the veneers recovered from two plantations in Gilbert, et al. [84].

does not provide a methodology to predict the level of tension wood present in a log. Tension wood cannot generally be predicted with visual observations. While growth stresses are linked to drying collapses, and high levels of geometric imperfections, such imperfections can be removed after planing the dried boards to their final cross-sectional dimensions. However, from the authors' experience, thicker green boards than the one typically sawn for other hardwood species may need to be sawn to satisfactory overcome these imperfections. This will nevertheless negatively impact green-off-saw recovery rates and drying time.

Current visual structural grading systems for hardwoods do not reliably predict the mechanical performance of sawn boards from fibre-managed plantation logs and are therefore not recommended. A European visual grading system developed for fibre-managed *E. globulus* merits validation for use in Australia and other regions.

Peeling the logs into rotary veneers with spindleless lathe technology significantly improves the recovery of the logs when compared to sawing, providing a more efficient use of the resource. The drying challenges are largely overcome with veneer processing, and higher volumes of final products can be yielded from the same resources compared to sawn timber processes. It also allows for better recovery of the desired high density/stiffness wood at the periphery of the logs.

Manufacturing appearance structural products from fibre-managed *E. globulus* plantations sawn boards and veneers would be challenging due to the high presence of visual features. Additionally, the structural visual grading for hardwood boards was found to be inappropriate for the resources, predicting low structural grade recoveries. However, the literature clearly indicated that boards with high stiffness and strength are recovered from fibre-managed *E. globulus* plantations, with a large variability in the mechanical properties. This variability can be reduced in GLT manufacturing by removing the strength reduction characteristics (such as knots), increasing the mechanical properties of the boards to produce higher grade EWPs [84]. Veneers with high MOE were also recovered in the literature, indicating that high grade LVLs can potentially be manufactured.

5. Challenges and opportunities in manufacturing *E. globulus* structural GLT and LVL

This section reviews research on the manufacture of *E. globulus* GLT and LVL, with emphasis on the mechanical properties of the structural products and the challenges encountered in manufacturing, especially in gluing. Regarding LVL, published mechanical properties on *E. globulus* LVL and adhesives used to bond *E. globulus* veneers are scarce. Nevertheless, various studies can relate to the scope of this review and investigated either producing *E. globulus* plywood or using eucalyptus logs to manufacture veneer-based products. Consequently, Section 5.2 on LVL first reviews studies looking at either *E. globulus* plywood or other eucalyptus LVL. Second, the mechanical properties of *E. globulus* LVL and of various adhesives used to bond *E. globulus* veneers are discussed.

It is important to note that the literature commonly reports two types of mechanical properties: average values and characteristic values. Characteristic values represent the design properties on which structural grades are based in international design standards. They are calculated with a confidence level of 75%. For strength, characteristic values correspond to the 5th-percentile test results (i.e., the fifth-lowest result out of 100 tests). These values are therefore significantly lower than the average strength values. However, for stiffness, the characteristic MOE is taken as the mean test value. Owing to the confidence level applied, the characteristic MOE is slightly lower than, but still close to, the average MOE [144,145]. Consequently, it is appropriate in this paper to compare published average MOE values with structural-grade characteristic MOE values. In contrast, care must be taken when comparing average tested strength values with characteristic strength values assigned to structural grades.

5.1. GLT

5.1.1. Mechanical properties

Until recently, studies on *E. globulus* GLT have been scarce and were mainly performed in Europe. All studies agreed that high strength and high stiffness GLT can be obtained from *E. globulus* boards. Martins, et al. [52] manufactured non-finger jointed, 5-layer, *E. globulus* GLT beams from *E. globulus* grown in Portugal. The beams were 120 mm deep and 92 mm wide. While no indication was given on the silviculture regime, the trees were likely carefully selected from unthinned and unpruned plantations [96]. The seven tested *E. globulus* GLT reached an average apparent bending MOE and MOR of 22,341 MPa and 114.9 MPa, respectively. The MOE corresponds to the highest structural grade (GL18) in AS 1720.1 [89]. Lara-Bocanegra, et al. [129] in a study undertaken on Spanish-grown *E. globulus* looked at the mechanical properties of 2-layer finger jointed GLT beams, manufactured with 1-component polyurethane (PUR) and D40 or above graded boards [130]. The small GLT beams reached an average and characteristic bending MOR of 61.3 MPa and 45.2 MPa, respectively, i.e., also corresponding to a GL18 structural grade [89].

As a part of the recent study by Gilbert, et al. [84] on 15-year-old and 19-year-old fibre-managed plantation *E. globulus* from Victoria, Australia, the potential for producing GLT was investigated. Simulations based on the mechanical properties of the boards indicated that high GLT grades in the AS 1720.1 [89], can be achieved from the investigated plantation resources in terms of characteristic MOE as long as the correct construction strategies are adopted. The simulations indicated that if all the boards shown in Fig. 5 were used in the manufacturing, it would result with GLT beams with a characteristic MOE of 17,455 MPa (GL17). However, manufacturing two products, one with the 40% denser boards and one with the remaining boards, would result in products with a characteristic MOE of 21,036 MPa (14% greater than GL18 requirement) and 13,435 (GL13), respectively. The simulations also indicated that the bending strength may be the limiting factor to achieve the targeted grades. Four 209 mm deep and 65 mm wide GLT were also manufactured from the resources. A manufactured GLT beam is shown in Fig. 8. The test results indicated that based on MOE (from four-point bending tests), the manufactured GLT beams achieved a GL18 grade and meet the targeted markets discussed in Section 3. However, the characteristic bending strengths of the GLT was low due to the beams prematurely failing at the finger joints. This resulted from challenges encountered in the manufacturing and the difficulty in finger jointing *E. globulus* boards as discussed later in Section 5.1.3. However, other studies in the literature, referred to above, have reported that higher bending strength can be achieved for the type of GLT beams tested.

5.1.2. Commercial Manufacturing Trial

As part of the study by Gilbert, et al. [84], GLT beam manufacturing was also undertaken at a commercial facility in Australia to provide commercial feedback on the suitability of the resource to be handled in

Fig. 8. Example of a GLT beam manufactured and tested in Gilbert, et al. [84].

an industrial setting. Key findings from this commercial trial were:

- The commercial facility considered fibre-managed plantation *E. globulus* to be well suited to produce GLT beams. They also believed that lower-grade material containing strength reducing characteristics could be removed during processing allowing the manufacture of high stiffness and high strength GLT lamellas.
- To remove geometric imperfections encountered in *E. globulus* boards, especially cupping which would impact the manufacturing of the finger joints, the boards can be planed before being finger jointed. This potential additional manufacturing step was not deemed to considerably impact the production operation but would increase wastage. However, if the boards need to be planed before finger jointing and also accommodate for potential thickness variations, thicker boards than normal would need to be delivered by the mill.
- No challenges were reported in planing the lamellas, glue spreading, pressing and final planing of the GLT beams.
- Due to the high level of distortions present in the *E. globulus* boards, the resource was deemed less suitable for automation and high-speed production of larger scale GLT plants but is a better fit for more manual small-scale GLT operations.
- The commercial facility mentioned that GL18 beams should be the target for the *E. globulus* GLT as hardwood beams of lower grade are too heavy to install in the residential market without lifting equipment.
- The commercial facility believed that a *E. globulus* GL18 is a viable product and could be sold readily.

5.1.3. Finger jointing

Producing strong finger joints is important to manufacture useable GLT out of shorter boards. Lara-Bocanegra, et al. [146] in a study on Spanish-grown *E. globulus* investigated the strength of finger-jointed *E. globulus* boards, with the boards solely being selected from the heartwood of the trees and with a “radial annual ring orientation”. It was not mentioned if the boards were sawn from trees planted for structural or pulpwood purpose, but as mentioned earlier, the trees were likely carefully selected from fibre-managed plantations [96]. The joints were glued with 1-component PUR (Purbond HB S 109), with the applied amount of glue not specified. The fingers were orientated vertically and glued immediately after being cut. 10 mm and 15 mm long finger joints were investigated with end pressure ranging from 4 MPa to 20 MPa. Recommendations in EN 14080 [147] and EN 15497 [148] on finger geometry limitations were followed. The 15 mm long fingers provided superior better mechanical performance. End pressure was found not to be critical in enhancing the strength, while a small variation in the tip width of the 15 mm long fingers allowed increasing the joint strength. 58% of the joints failed in the glue, i.e., representing a Mode I failure type in Appendix D of the AS 5068 [149]. Modes III and IV [149], i.e., desired failure mode in standards, consisting of combined failure at the finger roots and wood failure, were only encountered for the boards with the lowest MOE (between 14,000 MPa and 20,000 MPa). Despite the predominant failure mode in the glue, the finger jointed boards reached on average up to 80% of the strength of the non-finger jointed boards, with high average bending MOR up to 87 MPa. This corresponded to characteristic bending MOR ranging from 49.9 MPa (10 mm joints and worst tested configuration) to 76.2 MPa (15 mm joints and best tested configuration). Such results would still allow high grade GLT beams to be manufactured, but the joints would however not meet the requirement for bond durability in international standards, such as the AS 5068 [149].

When manufacturing GLT from *E. globulus* in Spain, Lara-Bocanegra, et al. [129] used the optimum finger configuration and pressure from the work mentioned in the above paragraph using either 1-component PUR (Loctite HB S309 Purebond) or Melamine-Urea-Formaldehyde (MUF) (GripPro Design Adhesive A002). Relative to the solid boards, the bending strength of the finger jointed boards were 6% to 9% lower with the PUR adhesive and equal to with the MUF adhesive.

González-Prieto, et al. [150] in another study on *E. globulus* from Spain, analysed the possibility of finger jointing green and dry *E. globulus* clear wood. 10 mm finger joints were glued under a pressure of 7 MPa and 12.5 MPa for the green and dry boards, respectively, with 1-component PUR (Jowapur 686.60). The green finger jointed boards resulted in equal performance, in terms of bending stiffness and strength, to the control non finger jointed boards. However, the dry finger jointed boards showed a bending strength 23% lower than the control samples. Yet, the green finger jointed boards had a higher average density and more density variability within the group than the dry and control boards which may have influenced the results. A mix failure mode occurring both in the wood and glueline was observed.

The recent study by Gilbert, et al. [84] on 15-year-old and 19-year--old fibre-managed plantation *E. globulus* from Victoria, Australia also reinforced the previous findings that the finger-jointing of *E. globulus* sawn timber is challenging. *E. globulus* samples were finger-jointed with 10 mm long finger joints using both PUR and RF adhesives under a pressure of 8 MPa. The PUR was applied on one side of a joint and at an average spread rate of 575 g per square metre (gsm). The RF was applied on both sides of a joint and at an average spread rate of 615 gsm per glueline. All samples failed the bond durability requirements in AS 5068 [149] with low wood failure percentages being recorded for both PUR and RF.

5.1.4. Gluing

International standards, such AS/NZS 1328.1 [151] and EN 14080 [147], require that the glueline between boards pass a “integrity” or durability test to be commercialised. In this regard, López-Suevos, et al. [152] investigated the use of hydroxymethylated resorcinol (HMR) and novolak-based HMR (n-HMR) primers to bond the *E. globulus* boards together, with n-HMR having longer pot life and less waiting period than HMR before applying the glue. GLT samples were manufactured with and without primer, and with either 1-component PUR (Jowpur 686.60) or MUF (Kauramin glue 683 with Kauramin hardener 688). Control samples were also bonded with resorcinol-phenol-formaldehyde (Aerodux 185 with HRP 155 hardener) with no primer. The samples were 6-layer and boards primed with n-HMR were either planed or not. The bond between boards were evaluated for service class 3 following Method A in now EN 14080 [147], i.e., equivalent to Method A in AS/NZS 1328.1 [151]. With longer press time (5 h), only using PUR with no primer was shown to be effective preventing delamination (2.3% delamination). Delamination significantly increased when the press time was reduced to 2.25 h (19.4% delamination). However, for the same press time of 2.25 h, the use of the HMR primer with PUR, resulted in a 0.6% delamination. Without primer, MUF didn’t perform well (24.1% delamination), while its use with HMR reduced the delamination to 3.1%. The reference samples with resorcinol-phenol-formaldehyde did not perform well, with 19.6% delamination. Even when boards that were not planed prior to bonding, the use of n-HMR was efficient in preventing delamination.

Franke, et al. [116] glued *E. globulus* boards from Portugal with 1-component PUR, with or without primer. Similar to López-Suevos, et al. [152], results showed that the use of prolonged curing time in the press and primer significantly improved adhesion. However, the samples did not pass the minimum delamination criteria in the European standard. Martins, et al. [52] also reported contradictory results to López-Suevos, et al. [152] when using single component PUR adhesives (either Purbond HB S709 with PR 3105 primer or Jowapur 686.60) in the manufacture of 5-layer *E. globulus* GLT. When tested following Method A in EN 14080 [147], the samples showed inadequate performance, despite the samples being pressed longer (7 h) than in López-Suevos, et al. [152] and with the same adhesive.

Suleimana, et al. [153] investigated the gluing of *E. globulus* boards from Portugal using MUF (AkzoNobel MUF 1247/2526). No details were provided on the resource, apart from the species, and the gluing process, apart that it was done in an industrial facility. Only block shear tests were performed, and results showed failure in the wood. No durability assessment of the gluelines was undertaken.

The recent study by Gilbert, et al. [84] on 15-year-old and 19-year--old fibre-managed plantation *E. globulus* from Victoria, Australia showed that successfully gluing higher density boards (>800–850 kg/m^3) of *E. globulus* for structural GLT is challenging. However, lower density boards were able to be glued without significant problems using PUR (Jowat 681.60) and RF (4:1 ratio of resin (950.82) to hardener (950.85), also manufactured by Jowat adhesives). The adhesive spread rates used in this study followed the adhesive manufacturer's recommendations for boards that were planed prior to gluing. For these boards, the PUR adhesive was applied at 180 gsm per glueline on one surface, while the RF adhesive was applied at 360 gsm per glueline across both surfaces. For boards that were face-milled or sanded after planing, the required spread rates increased. In these cases, the PUR adhesive was applied at 250 gsm, and the RF adhesive at 450 gsm. In summary, RF performed better than PUR and was recommended for the manufacturing of *E. globulus* GLT. Planing the boards before gluing was found not to be adequate for lamellas of density greater than 800–850 kg/m^3, and while face milling produced some improvements, was still unsuccessful in achieving sufficient glueline integrity to pass the requirements in AS/NZS 1328.1 [151]. Sanding post-planing produced reductions in measured delamination values for both adhesive types with the RF adhesive passing the glueline integrity requirements. This surface preparation method was recommended however the authors stated that it needs to be further confirmed on a higher number of samples.

5.2. Laminated veneer lumber

5.2.1. Mechanical properties

Gilbert et al. [154,155] developed a new methodology to predict the strength and characteristic values of LVL beams and columns based on the properties of the individual veneers. The methodology was verified and applied to LVL manufactured from rotary peeled veneers from 13- to 16-year-old *E. globulus* logs harvested from fibre-managed plantations in Victoria. The strength of individual veneers was first measured and found to be strongly correlated to the veneer MOE and the presence of knots [156,157]. Then, using the expected MOE distribution of the veneers entering the mill (obtained from McGavin, et al. [136]), the known mechanical properties of the veneers and the validated numerical model, the authors found that for a 300 mm deep reference LVL: (1) if veneers were segregated in the mill in terms of MOE, the characteristic bending MOR ranged from 52.2 MPa (equivalent to F17 for sawn timber [89]) for the lowest MOE veneers to 75.0 MPa (equivalent to F27 for sawn timber [89]) for the highest MOE veneers, (2) if no veneer segregation was performed, a characteristic MOR of 64.3 MPa (equivalent to F22 for sawn timber [89]) was expected. For 300 mm deep LVL columns, characteristic compressive strength ranged from 39.5 MPa (equivalent to F17 for sawn timber [89]) to 51.9 MPa (equivalent to F27 for sawn timber [89]). Characteristic bending MOE were not analysed but in view of the MOE distribution in McGavin, et al. [136], not segregating the veneers in the mill would result in an average MOE of the LVL equivalent to a F22 grade for sawn timber.

Gilbert, et al. [84] also performed a more recent and comprehensive study on the potential to manufacture LVL from 15-year-old and 19-year-old fibre-managed plantation *E. globulus* from Victoria. The overall analysed *E. globulus* resource (see Fig. 7) offered enough high MOE veneers to mainly manufacture high performance LVL (characteristic MOE of 18000 MPa - LVL18), by using 80% of the peeled veneers, and meet the market demand presented in Section 3. Additionally, to manufacture higher grade LVL, 42% of the peeled veneers could be used to manufacture LVL21 (characteristic MOE of 21,000 MPa) while the remaining veneers would produce a LVL12 (commodity LVL with a characteristic MOE of 12,000). LVL products were also manufactured and tested. At similar characteristic MOE, the tested LVL had similar or higher characteristic strength values than commercially available LVL, and F27 and F34 grades sawn timber. High stiffness (with a characteristic MOE greater than 20,000 MPa) and high strength (with a characteristic edge bending strength greater than 120 MPa) LVL were successfully manufactured. This comparison is presented in Table 2.

Farrell, et al. [140] manufactured plywood out of 16- to 26-year-old *E. nitens* and 33-year-old *E. globulus* fibre-managed logs. The plywood panels were fabricated with different strategies, including optimising the MOE of the final products by positioning the stiffer veneers as faces. The strength and stiffness of the plywood panels typically increased with the age of the trees. Overall F7 to F8 grades in AS 1720.1 [89] were encountered, with the shear strength being the limiting factor for higher grade classification. The 33-year-old *E. globulus*, 26-year-old *E. nitens* and 16-year-old *E. nitens* plywood reached a grade of F34, F27 and F11 [89], respectively, relative to their parallel to face bending characteristic values.

Regarding studies on other similar eucalyptus species, McGavin, et al. [123] found that F17 to F22 plywood sheets [89] were able to be produced from red mahogany (*Eucalyptus pellita*) thinnings. Plywood boards (5-ply) and LVL beams (13-ply) were further investigated by McGavin, et al. [131] using plantation eucalyptus thinnings of different species. Different construction strategies consisting of segregating the veneers based on their MOE values were investigated. In terms of stiffness and strength, the plywood panels typically resulted in high structural grades (F14 to F22 in AS 1720.1 [89]), irrespective of the construction strategies. Regarding the LVL beams, average edge bending MOE and MOR greater than 12,500 MPa and 70 MPa, respectively, were found. This corresponds to a characteristic MOE value of a F14 equivalent sawn timber grade [89]. The lowest average compressive and shear strengths, out of the four studied resources, were greater than 55 MPa and 30 MPa, respectively.

Additionally, in a literature review on the utilisation of plantation eucalypts in EWPs, Hague [40] found that LVL manufactured from unpruned 15-year-old New-Zealand *E. nitens* "had strength and stiffness properties which were higher than those of LVL made from New Zealand-grown radiata pine veneer". Freischmidt, et al. [41] referred to a 1996 CSIRO study which manufactured LVL out of various Eucalyptus species. The products showed overall excellent mechanical properties but with a shear strength lower than softwood LVL.

Table 2
Comparison of the predicted characteristic properties of E. globulus LVL manufactured and tested in Gilbert, et al. [84] against the characteristic properties of commercially available LVL internationally.

	MOE (MPa)	Strength (MPa)				
LVL product	Edge bending	Edge bending	Flat bending	Compression	Edge shear	Flat shear
E. globulus LVL12[a] [84]	14,652	97.1	115.2	64.0	7.8	6.1
E. globulus LVL21[a] [84]	20,802	121.4	135.1	78.6	8.4	5.1
e-beam [158]	13,200	50.0	–	47.0	5.0	–
e-beam + [159]	14,000	62.0	–	47.0	5.3	–
HySPAN [160,161]	13,200	50.0	42.0	42.0	4.6	3.5
hySPAN + [160,161]	14,000	52.0	–	48.0	4.6	–
hyONE [160,161]	16,000	65.0	52.0	48.0	4.6	3.2
LVL13 [162]	13,200	48.0	–	38.0	5.3	–
LVL-S [163]	11,600	44.0	50.0	35.0	4.2	2.3

[a] corresponds to a manufacturing scenario using 58% and 42% of all peeled veneers to manufacture LVL12 and LVL21, respectively. LVL12 represents a commodity product, competing directly with commercially available LVL (last seven rows), while LVL21 represents a high stiffness/strength product.

5.2.2. Gluing

The use of tannin–phenol–formaldehyde [164–166] or lignin–phenol–formaldehyde [167] adhesives were proposed to glue *E. globulus* veneers with the aim of reducing formaldehyde emission, improving spreading, allowing higher moisture content of veneers at the time of gluing and decreasing adhesive consumption. Substituting the phenol by tannin or lignin seemed to decrease the adhesion, measured in terms of wood failure percentage [165,167]. When tested for bond quality according to EN 314.1 [168] and EN 314.2 [169] by Vázquez, et al. [164], tannin–phenol–formaldehyde passed the requirements for exterior conditions.

Farrell, et al. [140] used PF to manufacture plywood out of 33-year--old *E. globulus*. When tested in accordance with former AS/NZS 2098.2 [170], samples passed the criteria for a A-bond quality.

In the study by Gilbert, et al. [84] mentioned above, using phenol-formaldehyde type resin (CASCOPHEN P6638) and a spread rate of 180–200 gsm, Type A bonds were achieved for LVL manufactured from 15-year-old and 19-year-old fibre-managed plantation *E. globulus* from Victoria.

Iwakiri, et al. [171] looked at the possibility of manufacturing plywood from nine eucalyptus species, including 18–19-year-old *E. globulus*. Veneers were glued with PF resin with a solid content of 49%, a pH of 11.5 and a Brookfield viscosity of 420 cP. The *E. globulus* samples passed the bond quality tests for exterior applications in EN 314.1 [168] and EN 314.2 [169].

Spanish company Garnica manufactures poplar and *E. globulus* plywood [172] using a formaldehyde-based adhesive and achieved a Class 3 bond durability, i.e., for external applications, following EN 636:2012 + A1 [173].

5.3. Synthesis

The literature showed that high grade structural GLT and LVL, meeting the market demand outlined in Section 3, can be manufactured from fibre-managed *E. globulus*. However, gluing high density boards (greater 800–850 kg/m^3) was proven challenging. Better results were obtained with RF adhesive. Planing and sanding the boards before gluing also showed promising results for these boards. Finger jointing boards, especially the high density ones, was also found difficult, with the joints failing the bond durability requirements in international standards. However, and despite the joints not meeting the bond durability requirements, high bending strength of the finger jointed boards was achieved in the literature, still allowing high grade GLT beams to be manufactured.

Regarding LVL, no challenges were reported in the literature, with *E. globulus* plywood already commercialised in Europe. Enough high MOE veneers can be recovered with minimum production waste to confidently manufacture LVL with mechanical properties superior to existing commercialised softwood LVL. Durable bonds between *E. globulus* veneers, especially with PF adhesive, were consistently reported in the literature.

6. Recommendations for future research to increase investment in EWPs manufacturing from *E. globulus*

This paper has demonstrated that GLT and LVL can be successfully manufactured from fibre-managed *E. globulus* plantations. However, further work is required before substantial investment in EWP manufacturing from this resource can be realised. Future research priorities can be grouped into two broad domains: 1) technical and 2) business environment.

6.1. Technical Factors

6.1.1. GLT

For GLT production, and as summarised in Section 4.4, key technical research priorities include refining adhesive protocols for face-laminating higher-density *E. globulus* boards and advancing finger-jointing techniques. As noted earlier, *E. globulus* sawn timber with densities above 800–850 kg/m^3 poses significant challenges for structural GLT manufacture due to poor adhesive performance. These high density boards are required to achieve high grade GLT. Gilbert, et al. [84] reported promising results using a planing followed by sanding surface preparation protocol prior to gluing; however, this method requires further validation. Additional research should therefore examine alternative adhesives, primers, and surface modification treatments, both physical and chemical to enhance bonding performance in high-density *E. globulus* sawn timber.

Finger-jointing of high-density *E. globulus* also remains difficult. Research efforts should focus on developing improved jointing techniques, assessing adhesive compatibility, and evaluating the mechanical performance of joints under structural loading.

Future work should investigate strategies to improve drying, reduce geometric imperfections and increase recovery rates to produce boards suitable for automation and high-speed production of larger scale GLT plants. IndustryEdge [19] highlighted that Australian industry representatives acknowledged the longer-term viability of producing locally manufactured GL18 products from plantation grown *E. globulus* would require revised plantation management or silvicultural regimes, designed to deliver fibre in the required form -most critically as larger individual trees and logs. These may be achieved through research into practices that support the selection of trees better suited to structural sawn timber production. As discussed in this paper, *E. globulus* presents several processing challenges, including log splitting, board distortion, and drying defects such as collapse and internal checking. Research aimed at mitigating these issues through improved tree selection, log handling, sawing strategies, and drying systems would be highly beneficial.

Finally, collaboration with equipment suppliers is recommended to identify the most cost-effective technologies for GLT production, with particular attention to their suitability across both small- and large-scale manufacturing operations.

6.1.2. LVL

As summarised in Section 5.3 and in contrast to GLT, manufacturing LVL from fibre-managed *E. globulus* is considerably less problematic. Previous studies discussed above have demonstrated that high structural grade LVL can be successfully produced from this resource with relatively few technical challenges identified. Plywood manufactured from *E. globulus* is already commercialised in Europe. Spindleless lathe technology has proven to be efficient in processing the resource. Future research should principally focus on resource variation. Further studies are needed across a broader range of fibre-managed *E. globulus* plantations, encompassing variables such as different ages and geographic locations. This will provide a more comprehensive understanding of variability in raw material properties and ensure that LVL production processes are robust across different resource conditions.

6.1.3. Commercial trials

It is recommended that, where feasible, future research incorporate larger commercial-scale trials of LVL and GLT manufacturing using fibre-managed *E. globulus*. Such trials are essential for validating technical findings under real-world production conditions, assessing process reliability, and demonstrating product performance in market-relevant applications. Commercial-scale evaluations would also generate critical insights into operational constraints, cost structures, and scalability, thereby helping to bridge the gap between research outcomes and industry adoption. Notably, commercial trials of *E. globulus* GLT exceeding the scale reported by Gilbert, et al. [84] have already commenced in Australia, and at least one company appears to be progressing toward full commercialisation.

At present, the vast majority of *E. globulus* plantations worldwide has been established and managed primarily for pulp and paper production, with the genetic selection driven for pulp production (volume) rather than structural properties. Consequently, most research on wood quality and processing has been conducted on plantations managed for fibre production. In the longer-term, however, the adoption of alternative silvicultural regimes may yield improved outcomes for the manufacture of both GLT and LVL [19].

6.2. Business Environment Factors

Even if considerable technical viability has been demonstrated for the production of LVL and GLT from fibre-managed *E. globulus* plantations, substantial investment will not occur unless the broader business environment is also favourable. Future research should therefore undertake a comprehensive barriers-to-investment analysis examining the full range of factors that may influence decision-making regarding investment in EWP manufacturing. Such an analysis should encompass:

- Resource availability - assessing the consistency, quality, geographic distribution, age profiles and scale of plantation *E. globulus* supply.
- Equipment needs and costs - identifying appropriate processing, manufacturing and treatment technologies and their economic implications across different production scales.
- Capital investment requirements - determining financial thresholds and funding models necessary to establish viable operations.
- Integration feasibility - analysing the potential to incorporate LVL and GLT manufacturing from *E. globulus* into existing processing and manufacturing operations, thereby reducing capital intensity and leveraging established infrastructure.
- Market conditions - continually analysing demand trends, customer preferences and potential growth opportunities in domestic and international markets.
- Logistics - evaluating infrastructure, transport networks, and supply chain efficiency to ensure cost effective delivery.
- Policy and regulatory environment - reviewing government policies, incentives and compliance requirements that may facilitate or hinder investment.
- Economic viability and business modelling -developing robust financial models to provide confidence and transparency for potential investors.

By systematically addressing these factors, future research can provide a clearer understanding of the conditions under which large-scale investment in LVL and GLT manufacturing from fibre-managed *E. globulus* plantations may be realised. In parallel, investment opportunities should be actively promoted through the preparation of detailed business cases and targeted investment prospectuses, ensuring that both technical and commercial viability are aligned to support industry uptake.

7. Conclusions

This paper has examined the market context, technical challenges, best-practice approaches, and emerging opportunities associated with manufacturing LVL and GLT from fibre-managed *E. globulus*. The principal findings are summarised below.

Sawn boards (processing and properties):

- Back-sawing is generally recommended for logs < 40 cm in diameter, with symmetrical release of growth stresses advised.
- Logs with tension wood should be avoided, yet the literature does not provide a methodology to predict the level of tension wood present in a log.
- While *E. globulus* boards present high levels of geometric imperfections, they can be removed when planing the dried boards to their final cross-sectional dimensions. However, thicker green boards than those typically sawn for other hardwood species may need to be sawn to satisfactory remove these imperfections.
- Fibre-managed *E. globulus* can produce boards with high mechanical properties, both in terms of MOE and strength, with an average board MOE greater than 15,000 MPa commonly reported.
- Current Australian visual structural grading systems for hardwoods are poor predictors of mechanical performance in fibre-managed plantation logs and tend to significantly underestimate board properties. Their use is therefore not recommended.
- A visual grading system developed in Europe for fibre-managed *E. globulus* warrants verification for application in Australia and other regions.
- Appearance-grade structural products are generally not viable from fibre-managed plantations due to the high frequency of defects; "high-feature" boards typically dominate.

GLT products:

- GLT with properties equivalent to GL18, the highest grade in Australian standards, can be produced from fibre-managed *E. globulus*.
- Finger-jointing remains a major constraint, with joints failing to meet the bond-durability requirements of AS 5068 [149]. Further research is needed to develop reliable finger-jointing systems capable of meeting certification and market expectations.
- Gluing performance is variable: RF adhesives outperform PUR, and lower-density boards (< 800–850 kg/m^3) bond effectively, whereas higher-density boards continue to present challenges requiring optimisation.

Veneers (processing and properties):

- Spindleless lathe technology is effective for rotary peeling small-diameter *E. globulus* logs, achieving recoveries of ~60% of billet volume into saleable veneers. This recovery was found to be up to six times higher than what would be recovered from the same resource if it was converted into sawn boards. This makes LVL a significantly more efficient EWP than GLT in terms of log conversion into a final product.
- Peeling also recovers more of the high density/stiffness wood at the periphery of the logs than sawing.
- Rotary veneer processing largely overcomes the problematic drying problems that can exist with sawn timber processing.
- D-grade veneers dominate fibre-managed plantations, and appearance-grade veneer products are not viable unless supplemented with higher-quality face veneers from other resources. However, contrary to plywood, structural LVL do not typically require appearance-grade face veneers.
- Veneers from 15- and 19-year-old *E. globulus* plantations in Victoria achieved average MOE values of 15,690 MPa and 20,119 MPa respectively, supporting the manufacture of high-stiffness LVL.

LVL products:

- Resulting LVL products achieved characteristic MOE values up to 20,000 MPa and characteristic edge bending strengths up to 120 MPa.
- Enough high-MOE veneers can be recovered with minimal production waste to enable confident manufacture of LVL with mechanical properties exceeding those of existing commercial softwood LVL.
- Phenol-formaldehyde adhesives have demonstrated strong performance with *E. globulus* veneers, achieving Type A bonds suitable for external applications.
- No technical challenges were reported in the manufacturing of *E. globulus* LVL.

Commercial opportunities:

- Significant commercial potential exists to manufacture LVL and GLT from Australian fibre-managed *E. globulus* plantations, supporting rising domestic demand and reducing reliance on imported EWPs.
- Fibre-managed *E. globulus* plantations, both in Australia and internationally, represent a strategically important yet underutilised forest resource. With targeted technical research and supportive industry and policy settings, this resource has substantial potential to contribute meaningfully to the growing global demand for high-performance structural wood products.

CRediT authorship contribution statement

William Leggate: Writing – review & editing, Writing – original draft, Formal analysis. **Tim Woods:** Writing – review & editing, Investigation. **Robert L. McGavin:** Writing – review & editing. **Gilbert Benoit Pierre:** Writing – review & editing, Writing – original draft, Investigation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The processing and manufacturing sections (Sections 3 and 4), as well as parts of the market analysis section (Section 2), were prepared by the authors as part of the *Splinters to Structures* project, funded through *Forest and Wood Products Australia* under the *Agricultural Trade and Market Access Cooperation* (ATMAC) programme of the Australian Government, Department of Agriculture, Fisheries and Forestry. The support obtained by the Queensland Government, Department of Primary Industries, is also acknowledged.

Data availability

The data used in the paper are published data

References

[1] Dalberg, The growing role of forest products in climate change mitigation & the need for nationally determined forestry approaches to achieve net zero emissions, in, Dahlberg report. (Retrieved on 17/12/2025 at ⟨https://dalberg.com/wp-content/uploads/2022/11/Forest-products-and-climate-change.pdf⟩), 2022.
[2] Gresham House, Global timber outlook 2025, in, (Retrieved on 17/12/2025 at ⟨https://greshamhouse.com/news-media/global-timber-outlook-2025/⟩), 2025.
[3] Wood Central, Demand for timber to increase fourfold by 2050: Where is the Wood, in, (Retrieved on 1/10/205 at ⟨https://woodcentral.com.au/demand-for-timber-to-increase-fourfold-by-2050-where-is-the-wood⟩), 2023.
[4] L. Peng, T.D. Searchinger, J. Zionts, R. Waite, "The carbon costs of global wood harvests", Nature 620 (2023) 110–115.
[5] F. Suter, B. Steubing, S. Hellweg, "Life cycle impacts and benefits of wood along the value chain: The case of Switzerland", J. Ind. Ecol. 21 (4) (2017).
[6] M. Liu, "Life cycle assessment of wood as a sustainable material: Greenhouse gas emissions and life cycle costs", J. Archit. Res. Dev. 9 (3) (2025).
[7] A. Starzyk, N.D. Cortiços, C.C. Duarte, P. Łacek, "Timber architecture for sustainable futures: A critical review of design and research challenges in the era of environmental and social transition, Buildings 15 (15) (2025) 2774.
[8] C. Fürhapper, K. Dobianer, "Living conditions in timber houses: Emission trends and indoor air quality", Front. Built Environ. 5 (151) (2020).
[9] IndustryEdge Pty Ltd, Outlook for Australian forestry & timber products, in, (Retrieved on 30/06/2024 at ⟨https://industryedge.com.au/wp-content/uploads/freestuff/PRESN_Woodntyouliketoknow_20220825.pdf⟩), 2022.
[10] AFPA, National farm forestry strategy submission, Australian Forest Products Association, 2022.
[11] FWPA, Identifying, measuring and modelling critical elements required of plantation forestry to maintain a social licence for operations and expansion in Gippsland, Forest and Wood Products Australia, 2025.
[12] ABARES, Economic potential for new plantation establishment, Australian Bureau of Agricultural and Resource Economics and Sciences, 2023.
[13] BAE, The economic potential for plantation expansion in Australia, BAEconomics, 2016.
[14] FWPA, Plantations for Australia's timber supply: Position statement, Forest and Wood Products Australia, 2025.
[15] V. Toscano, "Currency Fluctuations and their Effects on Global Supply Chains", J. Glob. Econ. 12 (4) (2024).
[16] D. Rasshyvalov, Y. Portnoi, T. Sigaieva, O. Alboshchii, O. Rozumnyi, "Navigating geopolitical risks: Implications for global supply chain management", e2024spe017, Multidiscip. Rev. 7 (2024). e2024spe017.
[17] A. Lavopa, F. Riccio, The multiplier effect of industrial jobs, United Nations, Industrial Development Organization, 2025.
[18] E. Moretti, "Local multipliers", Am. Econ. Rev. Pap. & Proc. 100 (2010) 1–7.
[19] IndustryEdge Pty Ltd, Value adding to exported wood fibre. Analysis of end-use applications, market size, scope and specifications for the selected engineered wood products. Australia Limited, Forest & Wood Products, 2025.
[20] R.L. McGavin, W. Leggate, J. Dorries, Increasing the value of forest resources through the development of advanced engineered wood products in, Foresst and Wood Products Australia, Project Report. PNB407-1516, 2020.
[21] L. Muszynski, Eat the problem': A case for use of small-diameter logs in specialty mass-timber panels, Int. Mass. Timber Report. (2023).
[22] M. Pramreiter, J. Konnerth, P. Mayencourt, "Engineered wood products (EWP)—Resource efficiency and environmental performance", Sustain. Mater. Built Environ. 352 (2025) 391–432.
[23] C. Jin, S. Zhu, H. Feng, "Life cycle assessment of engineered wood products in the building sector: A review", Buildings 15 (22) (2025) 4193.
[24] M. Brooker, H. Ian, Eucalyptus globulus, Royal Botanic Gardens Victoria, 2019.
[25] FWPA, Tasmanian blue gum. Private forestry guidance materials. Information sheet, Forest and Wood Products Australia, 2026.
[26] ABARES, Australia's State of the Forests Report, Australian Bureau of Agricultural and Resource Economics and Sciences, 2024.
[27] B. Potts, R.E. Vaillancourt, G. Jordan, "Exploration of the Eucalyptus globulus gene pool", *Eucalypts in a changing world*, Proc. IUFRO Conf. Aveiro 11-15 (2004).
[28] M. Rejmánek, D. Richardson, Eucalypts". Encyclopedia of Biological Invasions; Simberloff, University of California Press, *Loss Angeles, CA, USA*, 2011, pp. 203–209.
[29] J.S. Silva, M. Nereu, S. Pinho, L. Queirós, C. Jesús, E. Deus, "Post-fire demography, growth and control of Eucalyptus globulus wildings", Forests 12 (2) (2021) 156.
[30] FWPA, Splinters to Structures: Identifying new domestic and export markets for lower quality logs, in, Forest and Wood Products Australia (Retrieved 06/02/2026 at ⟨https://fwpa.com.au/news/splinters-to-structures-identifying-new-domestic-and-export-markets-for-lower-quality-logs/⟩), 2024.
[31] CWC, Laminate veneer lumber, in, Canadian Wood Council (Retrieved on 09/02/2026 at ⟨https://cwc.ca/articles/laminate-veneer-lumber)⟩, 2022.
[32] Wood Solutions, Glulam, in, Forest and Wood Products Australia (Retrieved on 09/02/2026 at ⟨https://www.woodsolutions.com.au/wood-species/wood-products/glulam)⟩, 2025.
[33] A.P.A., Glulam, Versatile Engineered Wood Product Delivers Strength, Beauty, and Reliability, in, The Engineered Wood Association (Retrieved on 09/02/2026 at ⟨https://www.apawood.org/glulam)⟩, 2021.
[34] H. Quesada, S. Adhikari, R. Smith, Glue-laminated timber, in, Virginia Tech., Report CNRE-151NP (Retrieved on 09/02/2026 at ⟨https://www.pubs.ext.vt.edu/content/pubs_ext_vt_edu/en/CNRE/cnre-151/cnre-151.html⟩), 2020.
[35] H. Pangh, H.Z. Hosseinabadi, N. Kotlarewski, P. Moradpour, M. Lee, G. Nolan, "Flexural performance of cross-laminated timber constructed from fibre-managed plantation eucalyptus", Constr. Build. Mater. 208 (2019) 535–542.
[36] A. Ettelaei, A. Taoum, J. Shanks, M. lee, G. Nolan, "Evaluation of the bending properties of novel cross-laminated timber with different configurations made of Australian plantation Eucalyptus nitens using experimental and theoretical methods", Structures 42 (2022) 80–90.
[37] A. Ettelaei, A. Taoum, J. Shanks, G. Nolan, "Rolling Shear Properties of Cross-Laminated Timber Made from Australian Plantation Eucalyptus nitens under Planar Shear Test", Forests 13 (2022) 84.
[38] A. Ettelaei, A. Taoum, G. Nolan, "Rolling shear properties of cross-laminated timber made of fibre-managed plantation eucalyptus under short-span bending", Wood Mater. Sci. & Eng. 17 (2022) 744–751.
[39] CUSP, Products/Services, Retrieved on 22/12/2022 at ⟨https://cusp.com.au/products/⟩, 2022.
[40] J.R.B. Hague, Utilisation of plantation eucalypts in engineered wood products, PNB290-1112, Forest & Wood Products Australia Limited, 2013.
[41] G. Freischmidt, P. Blakemore, Potential applications of the native hardwood resource available to VicForests as wood composite products. CMSE(C)-2008-312, CSIRO, 2009.
[42] Z. Pan, Y. Zheng, R. Zhang, B.M. Jenkins, "Physical properties of thin particleboard made from saline eucalyptus", Ind. Crops Prod. 26 (2007) 185–194.
[43] J. Chen, H. Xiong, Z. Wang, L. Yang, "Mechanical properties of a eucalyptus-based oriented oblique strand lumber for structural applications", J. Renew. Mater. 7 (2019) 1147–1164.
[44] P. Burton, CLST Comparison of properties of laminae that compose mass panels, Retrieved on 08/12/2022 at ⟨https://lignor.com/wp-content/uploads/2021/03/LIGNOR-CLST%C2%AE-v2.2.pdf⟩, Lignor, 2021.
[45] J. Chen, H. Xiong, Z. Wang, L. Yang, "Experimental buckling performance of eucalyptus-based oriented oblique laminated strand lumber columns under centric and eccentric compression", Constr. Build. Mater. 262 (2020) 120072.
[46] A.M. Krzysik, J.H. Muehl, J.A. Youngquist, F.S. Franca, "Medium density fiberboard made from Eucalyptus saligna", For. Prod. J. 51 (2001) 47–50.

[47] A. Kargarfard, N. Amir, G. Fardad, "Investigation on physical and mechanical properties of medium density fiberboard produced from Eucalyptus camaldulensis fibers", Iran. J. Wood Pap. Sci. Res. 25 (2010) 1–10.
[48] A. Kargarfard, "Investigation on physical and mechanical properties of medium density fiberboard produced from Eucalyptus steriaticalyx fibers", Iran. J. Wood Pap. Sci. Res. 27 (2012) 89–99.
[49] U.L. Belini, F.M. Tomazello, J.L.P.C. Louzada, J.C. de Carvalho Rodrigues, J.R. S. Astolphi, "Pilot study for MDF manufacture from sugarcane bagasse and eucalyptus fibers", Eur. J. Wood Wood Prod. 70 (2012) 537–539.
[50] S. Gouveia, L.A. Otero, C. Fernández-Costas, D. Filgueira, Á. Sanromán, D. Moldes, "Green Binder Based on Enzymatically Polymerized Eucalypt Kraft Lignin for Fiberboard Manufacturing: A Preliminary Study", Polymers 10 (2018) 642.
[51] H.J. Blaß, M. Frese, Biegefestigkeit von Brettschichtholz-Hybridträgern mit Randlamellen aus Buchenholz und Kernlamellen aus Nadelholz, Unversitat, Karlsruhe, 2006.
[52] C. Martins, A.M.P.G. Dias, H. Cruz, "Blue gum: assessment of its potential for glued laminated timber beams", Eur. J. Wood Wood Prod. 78 (2020) 905–913.
[53] M. Sciomenta, L. Spera, A. Peditto, E. Ciuffetelli, F. Savini, C. Bedon, M. Romagnoli, M. Nocetti, M. Brunetti, M. Fragiacomo, "Mechanical characterization of homogeneous and hybrid beech-Corsican pine glue-laminated timber beams", Eng. Struct. 264 (2022) 114450.
[54] G. Dill-Langer, S. Aicher, High performance glulam beams made of beech LVL and solid wood lamellas: experiments and modelling", Proc. 2014 World Conf. Timber Eng. Electron. Proc. (2014).
[55] H. Keskin, "Technological properties of laminated wood materials made up with the combination of oak (Quercus petraea liebl.) wood and scots pine (Pinus sylvestris lipsky) wood and possibilities of using them", gazi Univ. J. Sci. 17 (2004) 121–131.
[56] E. Burdurlu, M. Kilic, A.C. Ilce, O. Uzunkavak, "The effects of ply organization and loading direction on bending strength and modulus of elasticity in laminated veneer lumber (LVL) obtained from beech (Fagus orientalis L.) and lombardy poplar (Populus nigra L.)", Constr. Build. Mater. 21 (2007) 1720–1725.
[57] B.Cihad Bal, "Some technological properties of laminated veneer lumber produced with fast-growing Poplar and Eucalyptus", Maderas Cienc. Y. Tecnol. ía 18 (2016) 413–424.
[58] H.H. Nguyen, B.P. Gilbert, R.L. McGavin, H. Bailleres, "Optimisation of cross-banded laminated veneer lumbers manufactured from blending hardwood and softwood veneers", Eur. J. Wood Wood Prod. 77 (2019) 783–797.
[59] H.H. Nguyen, B.P. Gilbert, R.L. McGavin, H. Bailleres, H. Karampour, "Embedment strength of mixed-species laminated veneer lumbers and cross-banded laminated veneer lumbers", Eur. J. Wood Wood Prod. 78 (2020) 365–386.
[60] R.L. McGavin, H.H. Nguyen, B.P. Gilbert, T. Dakin, A. Faircloth, "A comparative study on the mechanical properties of laminated veneer lumber (LVL) produced from blending various wood veneers", BioResources 14 (2019) 9064–9081.
[61] Expert Market Research, Laminated veneer lumber market size, share and growth (2026-2035), Expert Market Research, 2026.
[62] IMARC, Laminated veneer lumber market report: Residential and commercial applications, new constructions and replacement sectors, and regional analysis, IMARC Group, 2026, pp. 2025–2033.
[63] Business Research Insights, 2026.
[64] FAO, The state of the world's forests 2024 - Forest -sector innovations towards a more sustainable future, 2024, Food and Agricultural Organisation of the United Nations, 2024.
[65] GVR, Glue Laminated Timber Market Size, Share & Trends Analysis Report, 2024–2030, Grand View, Research, 2026.
[66] 3RT, *Growing trees in machine. In one day. Anywhere on earth.*, ⟨https://3rt.com.au/⟩, Accessed on 2026.
[67] Research and Markets, Glue Laminated Timber Market Report 2025, Research and Markets, 2025.
[68] IndustryEdge Pty Ltd, *Outlook for Australian forestry & timber products*, ⟨https://industryedge.com.au/wp-content/uploads/freestuff/PRESN_Woodntyouliketoknow_20220825.pdf⟩, Accessed on 2024.
[69] M. Hemmati, T. Messadi, H. Gu, J. Seddelmeyer, "Comparison of embodied carbon footprint of a mass timber building structure with a steel equivalent", Buildings 14 (5) (2024) 1276.
[70] J. Abed, S. Rayburg, J. Rodwell, M. Neave, "A review of the performance and benefits of mass timber as an alternative to concrete and steel for improving the sustainability of structures", Sustainability 14 (9) (2022) 5570.
[71] A. Romero, C. Odenbreit, "Experimental investigation on strength and stiffness properties of laminated veneer lumber (LVL)", Materials 16 (22) (2023) 7194.
[72] L.Forest Products, Wood handbook: Wood as an engineering material, in, U.S. Department of Agriculture, Forest Service, General Technical Report FPL-GTR-190, 2010.
[73] P. Nepal, J.P. Prestemon, I. Ganguly, V. Kumar, R.D. Bergman, N.C. Poudyal, "The potential use of mass timber in mid- to high-rise construction and the associated carbon benefits in the United States", PLOS ONE 19 (3) (2024) e0298379.
[74] Expert Market Research, Laminated veneer lumber market size, share and growth (2026-2035), in, Expert Market Research (Retrieved on 09/02/2026 at ⟨https://www.expertmarketresearch.com/reports/laminated-veneer-lumber-market⟩), 2024.
[75] IMARC, Laminated veneer lumber market report: Residential and commercial applications, new constructions and replacement sectors, and regional analysis, 2025–2033., in, IMARC Group, Report SR112026A795 2024.
[76] Business Research Insights, Laminated Veneer Lumber (LVL) Market Size, Share, Growth, and Industry Analysis, By Type (Structural Type and Non Structural Type), By Application (Buildings, Bridges, Transportation Industry, Furniture Industry), Regional Insights and Forecast From 2026 To 2035 in, Business Research Insights, Report BRI108826, 2025.
[77] Market Data Forecast, North America laminated veneer lumber (LVL) market report, 2024-2033, in, Market Data Forecast, (Retrieved on 09/02/2026 at ⟨https://www.marketdataforecast.com/market-reports/north-america-laminated-veneer-lumber-market⟩), 2025.
[78] FAO, The state of the world's forests 2024 - Forest -sector innovations towards a more sustainable future, Food Agric. Organ. U. Nations (2024).
[79] GVR, Glue Laminated Timber Market Size, Share & Trends Analysis Report, 2024–2030, in, Grand View, Research (Retrieved on 09/02/2026 at ⟨https://www.grandviewresearch.com/industry-analysis/glue-laminated-timber-market⟩), 2024.
[80] Research and Markets, Glue Laminated Timber Market Report 2025, in, Research and Markets (Retrieved on 02/11/2025 at ⟨https://www.researchandmarkets.com/reports/5954715/glue-laminated-timber-market-report⟩), 2025.
[81] GMI, Glulam Market Size, Share & Industry Trends Report, 2025–2034, in, Global Market Insights, Report GMI14477 (Retrieved on 09/02/2026 at ⟨https://www.gminsights.com/industry-analysis/glulam-market⟩), 2025.
[82] I.U. Khan, M. Subhani, K. Ghabraie, M. Ashraf, "Experimental evaluation and theoretical prediction of single hardwood dowel connections in softwood and hardwood", Eng. Struct. 353 (2026) 122251.
[83] K.R. Bootle. Wood in Australia. Types, properties and uses, 2 ed., McGraw Hill/Australia, Australia, 2010.
[84] B.P. Gilbert, A. Faircloth, T.E. Davies, R.L. McGavin, W. Leggate, ATMAC - Splinters to Structures - Resources characterisation, manufacturing and testing of LVL and GLT structural products out of lesser value Eucalyptus globulus and Pinus radiata logs, Forest and Wood Products Australia, 2026.
[85] A. Hoare, Tackling Illegal Logging Relat. Trade - What Progress. Where ? (2015).
[86] J. Raison, E.K.S. Nambiar, "A review of the impacts of sustainable harvesting, non-harvest management and wildfire on net carbon emissions from Australian native forests", Aust. For. 87 (4) (2024).
[87] Wood Central, Victoria's native forest ban is poor science, in, (Retrieved on 2/02/2026 at ⟨https://woodcentral.com.au/ex-csiro-top-scientist-victorias-native-forest-ban-is-poor-science⟩), 2024.
[88] W. Leggate, B.P. Gilbert, "Improving resource availability for residential timber manufacturing and construction: outcomes from interviews of Australian frame and truss manufacturers" *(in preparation)*, Aust. J. Struct. Eng. (2025) *(in preparation)*.
[89] AS 1720.1, Timber structures, Part 1: Design methods, Standards Australia, 2010.
[90] WoodSolutions, Wood species, Gum, Southern blue, Retrieved on 15/01/2024 at ⟨https://www.woodsolutions.com.au/wood-species/hardwood/gum-southern-blue⟩, 2023.
[91] WoodSolutions, Wood species, Pine radiata, Retrieved on 15/01/2024 at ⟨https://www.woodsolutions.com.au/wood-species/softwood/pine-radiata⟩, 2023.
[92] K.R. Bootle, Wood in Australia, Types, properties and uses - 2nd edition, (McGraw-Hill), North Ryde, Australia, 2010.
[93] Private Forests Tasmania, Eucalypt Plantations. Info Sheet No.1 - Overview, Private Forests Tasmania, Tasmania, Australia, 2025.
[94] 2017, AS/NZS 2878:Timber-Classif. into Strength. Groups2000.
[95] AS 1720.1, Timber structures, Part 1: Design methods, Standards Australia, Sydney, Australia, 2010.
[96] R. Washusen, Processing methods for production of solid wood products from plantation-grown Eucalyptus species of importance to Australia, Forest & Wood Products Australia Limited, 2013.
[97] R. de Fégely, Sawing Regrowth and Plantation Hardwoods with Particular Reference to Growth Stresses Part B Survey results, PN02.1308,, Forest & Wood Products Research & Development Corporation, 2004.
[98] R. de Fégely, Sawing Regrowth and Plantation Hardwoods with Particular Reference to Growth Stresses Part A Literature Review, PN02.1308,, Forest & Wood Products Research & Development Corporation, 2004.
[99] J.-L. Yang, D. Fife, G. Waugh, G. Downes, P. Blackwell, "The effect of growth strain and other defects on the sawn timber quality of 10-year-old Eucalyptus globulus Labill", Aust. For. 65 (2002) 31–37.
[100] C. Hansmann, R. Stingl, O.G. Prieto, C.B. Lopez, H. Resch, "High-Frequency Energy–Assisted Vacuum Drying of Fresh Eucalyptus globulus", Dry. Technol. 26 (2008) 611–616.
[101] R. Washusen, P. Blakemore, R. Northway, P. Vinden, G. Waugh, "Recovery of dried appearance grade timber from Eucalyptus globulus Labill, grown in plantations in medium rainfall areas of the southern Murray-Darling Basin", Aust. For. 63 (2000) 277–283.
[102] T. Biechele, L. Nutto, G. Becker, "Growth strain in Eucalyptus nitens at different stages of development", Silva Fenn. 43 (4) (2009) 669–679.
[103] T. Murphy, M. Henson, J.K. Vanclay, "Growth stress in Eucalyptus dunnii", Aust. For. 68 (2) (2005) 144–149.
[104] J.E. Nicholson, "A rapid method for estimating longitudinal growth stresses in logs", Wood Sci. Technol. 5 (1971) 40–48.
[105] T. Innes, B. Greaves, G. Nolan, R. Washusen, Determining the economics of processing plantation eucalyptus for solid timber products, PN04.3007, Forest and Wood Products Research and Development Corporation, 2008.
[106] R. Washusen, D. Menz, A. Morrow, K. Reeves, R. Hingston, S. Davis, Processing pruned and unpruned Eucalyptus globulus managed for sawlog production to produce high value products, PN03-1315, Forest and Wood Products Research and Development Corporation, 2004.
[107] R. Washusen, C. Harwood, A. Morrow, J.C. Valencia, P. Volker, M. Wood, T. Innes, D. Ngo, R. Northway, M. Bojadzic, Gould's Country Eucalyptus nitens

Thinning Trial: Solid Wood Quality and Processing Performance Using Conventional Processing Strategies, Technical Report 168, CRC for Forestry, 2007.

[108] R. Washusen, C. Harwood, A. Morrow, R. Northway, J.C. Valencia, P. Volker, M. Wood, R. Farrell, "Pruned Plantation-Grown Eucalyptus nitens: Effect of Thinning and Conventional Processing Practices on Sawn Board Quality and Recovery", N. Z. J. For. Sci. 39 (2009) 39–55.

[109] J.-L. Yang, D. Fife, "Identifying check-prone trees of Eucalyptus globulus Labill. using collapse and shrinkage measurements", Aust. For. 66 (2003) 90–92.

[110] G. Waugh, A. Rozsa, Sawn products from regrowth Eucalyptus regnans, The Young Eucalypt Report - some management options for Australia's regrowth forest, CSIRO Publications, 1991.

[111] G.K. Brennan, R.A. Hingston, R.W. Moore, "Processing 17-year-old Tasmanian blue gum sawlogs grown at wide spacing", Aust. For. 67 (2004) 240–246.

[112] GTFIH, Personal. Commun. Green. Triangle For. Ind. Hub. (2022).

[113] AS 2796.1, "Timber - Hardwood - Sawn and. milled products, Part 1: Product specification, Standards Australia, 1999.

[114] R. Reid, R. Washusen, "Sawn timber from 10-year-old pruned Eucalyptus nitens (Deane & Maiden) grown in an agricultural riparian buffer", *Proceedings of the Third Australian Stream Management Conference proceedings: the value of healthy streams. Cooperative Research Centre for Catchment Hydrology* (Eds.: I. Rutherford, F. Sheldon, G. Brierley, C. Kenyon), Brisbane, Australia, 545–550, 2001.

[115] M. Derikvand, N. Kotlarewski, M. Lee, H. Jiao, G. Nolan, "Flexural and visual characteristics of fibre-managed plantation Eucalyptus globulus timber", Wood Mater. Sci. & Eng. 15 (2020) 172–181.

[116] S. Franke, J. Marto, "Investigation of Eucalyptus globulus wood for the use as an engineered material", Proc. 2014 World Conf. Timber Eng. Electron. Proc. (2014).

[117] T. Larson, R.W. Erickson, H.D. Petersen, "Saw-dry-rip processing: Taking the crook out of the stud game", Proc. 26th Annu. Jt. Meet. Midwest. wood Seas. Assoc. Wis. -Mich. wood Seas. Assoc. (1983) 13–30.

[118] R.J. Neumann, A. Saavedra, "Check formation during the drying of Eucalyptus globulus", Holz als Roh- und Werkst. 50 (1992) 106–110.

[119] S.C. Chafe, R.A. Ananias, "Effect of presteaming on moisture loss and internal checking in high-temperature-dried boards of Eucalyptus globulus and Eucalyptus regnans", J. Inst. Wood Sci. 14 (1996) 72–77.

[120] T. Bekele, "Kiln drying of sawn boards of young Eucalyptus globulus Labill. and Eucalyptus camaldulensis Dehnh. grown on the Ethiopian Highlands", Holz als Roh- und Werkst. 52 (1994) 377–382.

[121] T. Bekele, "Degradation of boards of Eucalyptus globulus Labill. and Eucalyptus camaldulensis Dehnh. during air drying", Holz als Roh- und Werkst. 53 (1995) 407–412.

[122] AS 2796, Timber - Seasoned hardwood - Milled products, Standards Australia, 1985.

[123] R.L. McGavin, M.P. Davies, J. Macgregor-Skinner, H. Bailleres, M. Armstrong, W. J. Atyeo, J. Norton, Utilisation Potential and Market Opportunities for Plantation Hardwood Thinnings from Queensland and Northern New South Wales, PN05.2022, Queensland Government, 2006.

[124] J.L. Yang, G. Waugh, "Potential of plantation-grown eucalypts for structural sawn products. I. Eucalyptus globulus Labil, ssp. globulus", Aust. For. 59 (1996) 90–98.

[125] AS 2082, Visually stress-graded hardwood for structural purposes, Standards Australia, Sydney, Australia, 1979.

[126] AS 2082, *Timber - Hardwood - Visually stress-graded for structural purposes*, Standards Australia, Sydney, Australia, 2007.

[127] J.I. Fdez-Golfín, R. Díez, E. Hermoso, C. Baso, J.M. Casas, O. González, Caracterización de la madera de E. globulus para uso estructural (in Spanish)", BoletíN. Del. CIDEU 4 (2007) 91–100.

[128] R. Washusen, A. Morrow, D. Ngo, R. Northway, M. Bojadzic, C. Harwood, P. Volker, M. Wood, J.C. Valencia, T. Innes, Eucalyptus nitens thinning trial: solid wood quality and procesing performance using conventional processing strategies, PN07.3019,, Forest and Wood Products Research and Development Corporation, 2008.

[129] A.J. Lara-Bocanegra, A. Majano-Majano, F. Arriaga, M. Guaita, "Eucalyptus globulus finger jointed solid timber and glued laminated timber with superior mechanical properties: Characterisation and application in strained gridshells", Constr. Build. Mater. 265 (2020) 120355.

[130] UNE 56546, Visual grading for structural sawn timber. Hardwood timber, Asociacion Espanola de Normalizacion, 2013.

[131] R.L. McGavin, H. Bailleres, F. Lane, J. Fehrmann, High value timber composite panels from hardwood plantation thinnings, Department of Agriculture, Fisheries and Forestry, Brisbane, Australia, 2013.

[132] R.L. McGavin, H. Bailleres, F. Lane, D. Blackburn, M. Vega, B. Ozarska, "Veneer Recovery Analysis of Plantation Eucalypt Species Using Spindleless Lathe Technology", Bioresources 9 (2014) 613-627.

[133] T.J. Venn, R.L. McGavin, A. Ergashev, "Accommodating log dimensions and geometry in log procurement decisions for spindleless rotary veneer production", -22411, Bioresources 15 (2020) 23585. -22411.

[134] R.L. McGavin, H. Bailleres, F. Lane, J. Fehrmann, B. Ozarska, "Veneer grade analysis of early to mid-rotation plantation Eucalyptus species in Australia", Bioresources 9 (2014) 6562-6581.

[135] R.L. McGavin, H. Bailleres, M. Hamilton, D. Blackburn, M. Vega, B. Ozarska, "Variation in rotary veneer recovery from Australian plantation Eucalyptus globulus and Eucalyptus nitens", Bioresources 10 (2015) 313-329.

[136] R.L. McGavin, H. Bailleres, J. Fehrmann, B. Ozarska, "Stiffness and density analysis of rotary veneer recovered from six species of Australian plantation hardwoods", Bioresources 10 (2015) 6395-6416.

[137] R.L. McGavin, A guide to manufacturing rotary veneer and products from small logs - Chapter 6: Rotary peeling, Australian Centre for International Agricultural Research, 2017.

[138] R.L. McGavin, J. McGrath, C. Fitzgerald, C. Kumar, C. Oliver, A. Lindsay, "Sawn timber and rotary processing and grade recovery investigation of Nothern Australian plantation grown African mahogany", Bioresources 16 (2021) 1891–1913.

[139] R.L. McGavin, Analysis of small-log processing to achieve structural veneer", The University of Melbourne, 2016.

[140] R. Farrell, S. Blum, W. D, D. Blackburn, The potential to recover higher value veneer products from fibre managed plantation eucalypts and broaden market opprtunities for this resource: Part A, PNB139-0809, Forest and Wood Products Research and Development Corporation, 2011.

[141] Standards Australia, 2008.

[142] Standards Australia, 2012.

[143] PFT, Eucalypt Plantations, Info Sheet No. 3 – Management Regimes, in, Private Forests Tasmania (Retrieved on 09/02/2026 at ⟨https://pft.tas.gov.au/volumes/documents/Species-Guides/Eucalypt/FF-Information-Series-EUCALYPTS-No.-3-Management-Regimes-September-2025.pdf⟩), 2025.

[144] AS/NZS 4063.2, Characterization of structural timber, Part 2: Determination of characteristic values, Standards Australia, Sydney, Australia, 2010.

[145] EN 14358, *Timber structures - Calculation and verification of characteristic values*, The European Union Per Regulation, Brussel, Belgium, 2016.

[146] A.J. Lara-Bocanegra, A. Majano-Majano, J. Crespo, M. Guaita "Finger-jointed Eucalyptus globulus with 1C-PUR adhesive for high performance engineered laminated products", *Construction and Building Materials*, 135, 529-537, 2017.

[147] EN 14080 "Timber structures - Glued laminated timber and glued solid timber - Requirements", *European Committee for Standardization*, 2013.

[148] EN 15497 "Structural finger jointed solid timber - Performance requirements and minimum production requirements", *European Committee for Standardization*, 2014.

[149] AS 5068, "Timber - Finger joints in structural products - Production requierements, Standards Australia, 2006.

[150] O. González-Prieto, J.M. Casas Mirás, L.O. Torres, "Finger-jointing of green Eucalyptus globulus L. wood with one-component polyurethane adhesives", Eur. J. Wood Wood Prod. 80 (2022) 429–437.

[151] AS/NZS 1328.1, Glued laminated structural timber, Part 1: Performance requirements and minimum production requirements, Standards Australia, 1998.

[152] F. López-Suevos, K. Richter, "Hydroxymethylated Resorcinol (HMR) and Novolak-Based HMR (n-HMR) Primers to Enhance Bond Durability of Eucalyptus globulus Glulams", J. Adhes. Sci. Technol. 23 (2009) 1925–1937.

[153] A. Suleimana, C.S. Sena, J.M. Branco, A. Camões, "Ability to Glue Portuguese Eucalyptus Elements", Buildings 10 (2020) 133.

[154] B.P. Gilbert, H. Bailleres, H. Zhang, R.L. McGavin, "Strength modelling of Laminated Veneer Lumber (LVL) beams", Constr. Build. Mater. 149 (2017) 763–777.

[155] B.P. Gilbert, "Compressive Strength Prediction of Veneer-Based Structural Products", ASCE J. Mater. Civil. Eng. 30 (2018) 04018225.

[156] B.P. Gilbert, H. Bailleres, M.F. Fischer, H. Zhang, R.L. McGavin, "Mechanical Properties of Rotary Veneers Recovered from Early to Midrotation Subtropical-Hardwood Plantation Logs for Veneer-Based Composite Applications", ASCE J. Mater. Civil. Eng. 29 (2017) 04017194.

[157] B.P. Gilbert, J.M. Husson, H. Bailleres, R.L. McGavin, M.F. Fischer, "Perpendicular to grain and shear mechanical properties of veneer-based elements glued from single veneer sheets recovered from three species of juvenile subtropical hardwood plantation logs", Eur. J. Wood Wood Prod. 76 (2018) 1637–1652.

[158] Wesbeam, Wesbeam e-beam lvl, Characteristic values & design criteria, Western Australia, Australia, 2023.

[159] Wesbeam, e-Beam+ [F17], Wesbeam, Western Australia, Australia, 2014.

[160] Carter Holt Harvey, Futurebuild LVL, Specific design guide, Australian version, Auckland, New-Zealand, 2020.

[161] Carter Holt Harvey, Futurebuild LVL, specific engineering design guide, Auckland, New-Zealand, 2019.

[162] NelsonPine, Framing solutions, NelsonPine, Nelson, New Zealand, 2021.

[163] Stora Enzo, LVLby Stora Enso, Technical brochure, Stora Enzo, Helsinki, Finland, 2021.

[164] G. Vázquez, J. González-Álvarez, F. López-Suevos, G. Antorrena, "Effect of veneer side wettability on bonding quality of Eucalyptus globulus plywoods prepared using a tannin–phenol–formaldehyde adhesive", Bioresour. Technol. 87 (2003) 349–353.

[165] P.M. Stefani, C. Peña, R.A. Ruseckaite, J.C. Piter, I. Mondragon, "Processing conditions analysis of Eucalyptus globulus plywood bonded with resol-tannin adhesives", Bioresour. Technol. 99 (2008) 5977–5980.

[166] G. Vázquez, G. Antorrena, J. González, J.C. Alvarez, "Tannin-based adhesives for bonding high-moisture Eucalyptus veneers: Influence of tannin extraction and press conditions", Holz als Roh- und Werkst. 54 (1996) 93–97.

[167] G. Vázquez, G. Antorrena, J. González, J. Mayor, "Lignin-phenol-formaldehyde adhesives for exterior grade plywoods", Bioresour. Technol. 51 (1995) 187–192.

[168] EN 314.1, Plywood - Bonding quality - Part 1: Test methods, European Committee for Standardization, 1993.

[169] EN 314.2, Plywood - Bonding quality - Part 2: Requirements, European Committee for Standardization, 1993.

[170] AS/NZS 2098.2, Methods of test for veneer and plywood, Bond quality of plywood (chisel test, Standards Australia, 2006.

[171] S. Iwakiri, J.L.Monteiro de Matos, J.Guilherme Prata, R. Trianoski, L.Soares da Silva, "Evaluation of the use potential of nine species of genus Eucalyptus for

production of veneers and plywood panels", 264Cerne Lavras 19 (2) (2013) 263–269.
[172] B. Martínez, Declaration of Performance - Reinforced Globulus Maple LG, Reinforced Globulus Poplar LG (DOP.GAR.39.EN), in, Garnica (Retrieved on 20/12/2022 at ⟨https://www.garnica.one/uploads/140e05e2-c34b-4321-874f-f4a844ea8e7e/140e05e2-c34b-4321-874f-f4a844ea8e7e.pdf⟩), 2022.
[173] EN 636:2012+A1, Plywood - Specifications, European Committee for Standardization, Brussel, Belgium, 2015.