Exploring physical and mechanical properties of OSB and underutilized species to be used in the Glulam industry.

by

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April 27, 2021

Creating a Superior Glue Laminated Product by changing the Core Species using O.S.B., and Birch

by

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An Undergraduate Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Honours Bachelor of Science in Forestry

Faculty of Natural Resources Management

Lakehead University

April 27, 2021

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ABSTRACT

Glulam lumber is a great building alternative to steel for its strength, aesthetics, and ecofriendly nature. Most of the Glulam produced in North America is made from Spruce, Pine, or Fir (SPF) species due to their superior strength characteristics and availability. There is a largely untapped market for underutilized species to be used in Glulam construction and engineered products such as OSB. This thesis provides an overview of the species currently used in the Glulam industry worldwide, a breakdown of OSB, and underutilized species such as birch as a potential product to be used in Glulam production. The physical and mechanical properties of OSB and a wide variety of tree species are discussed to compare different strengths between each species/ product. This literature review found that birch has favourable strength characteristics and, in theory, would prove beneficial in a Glulam beam. Like birch, mixed hardwood OSB was found to have similar strength properties to white pine used as a Glulam species. Incorporating underutilized species into Glulam design is essential because it will diversify the Canadian lumber market, help create a more resilient market, and improve efficiency in the Glulam industry.

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ACKNOWLEDGEMENTS

I would like to thank Dr. Mathew Leitch for being my thesis advisor, Robert Glover for always assisting me whenever it was needed, and Rob Spring for being my second reader.

INTRODUCTION

Glue laminated Timber (Glulam) is a structural product that is used around the world. The laminating lengths of wood and end jointing give Glulam the advantage to span longer distances than a typical tree length. Glulam is a greener alternative to steel "I" beams and, in some cases, is stronger under stress. Glulam is currently used in single-story portal-frame buildings worldwide and even in commercial buildings eight-plus stories high (Buchanan 1993). Canada's current forest products consist of solid wood products, wood pulp, paper products, and bioproducts, with the primary species used being Spruce (*Picea)*, Pine (*Pinus),* and fir (*Abies)* (Government of Canada 2020a). Canada is home to various species other than spruce, pine, and fir, capable of becoming the next species utilized in Glulam. It is crucial to explore underutilized wood species as options for Glulam as Canada has the resources available. If more of our species can create value-added products, we will be more efficient, therefore creating more capital. Canada is a global leader in the wood products market, and if such a title is to be held, exploring new options is inevitable. If underutilized species are used in the creation of Glulam, it would diversify the Canadian lumber industry and help create a more resilient industry. In addition to underutilized species, engineered wood products such as OSB could be incorporated into glulam structures as a filler material. This report will provide the reader with a good understanding of the history of Glulam, the common species used, and the species/products being suggested for use. Manufacturing processes of both Glulam and OSB will be covered in depth along with each tree species silvics, habitat, and utilization.

1.1 Objective

The purpose of this thesis is to explore the literature on OSB, white birch, and Glulam. Describing each species/product will provide the reader with a great understanding of alternatives that can be used in the Glulam industry other than the typical SPF combinations.

LITERATURE REVIEW

2.1 Species Description (Silvics, Utilization, Habitat)

2.1.1 White Spruce (*Picea glauca)*

2.1.1.1 Habitat

White spruce is a medium to tall tree with an excurrent form and a cone-shaped crown Figure 1(Barnes 2004, Abrahamson 2015).

Figure 1. White Spruce in Alaska. Photo courtesy of L.B. Burbaker.

The native range of this tree stretches from Newfoundland and Labrador to the far west coast of British Columbia (Nienstaedt 1990). This species is found as far north as latitude 69 degrees and as far south as Montana (Figure 2) (Nienstaedt 1990; Abrahamson 2015).

Figure 2. White spruce distribution map in North America (Abrahamson 2015).

White spruce is native to the Boreal forest and is found in bogs, stream borders, hardwood conifer swamps, and upland sites (Barnes 2004). White spruce is also found growing with yellow birch (*Betula alleghaniensis*), white birch (*Betula papyrifera*), red maple (*Acer rubrum*), black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), and even eastern white pine (*Pinus strobus*) (Barnes 2004). White spruce can grow in a wide variety of soils, including soils of low acidity to high (4.7pH to 7 pH) and even on alkaline soils in the prairies (Nienstaedt 1990). This species can germinate and grow in shaded areas under other tree species in wet sites (Barnes 2004).

2.1.1.2 Silvics

Many silvicultural systems are used to manage white spruce, including clearcutting with site prep, clearcutting without site prep, clearcutting with retained seed trees, and the shelterwood system (Navratil 1996). Naturally, this species has adapted to forest fires and will grow well when a silvicultural system that emulates natural disturbances is used (Navratil 1996).

2.1.1.3 Utilization

White spruce is widely used in Canada and is found in pulp, lumber, furniture, musical instruments, trim, and canoe paddles, for example. The indigenous peoples historically used the roots for lacing birch bark canoes (Barnes 2004).

In the pulp industry, white spruce is considered a high-value tree and black spruce (*Picea mariana*) is used as a baseline to compare all other species against (Wellwood 1960). The appeal of white spruce in the pulping industry comes from this species light colour of wood, low resin content, lightweight, favourable fibre length-diameter ratio, and the minor changes in springwood to latewood (Wellwood 1960). The pulp produced from white spruce is used to make tissue paper, newsprint, books, bond, specialty papers, rayon and is even incorporated into other pulping mixtures to add strength (Wellwood 1960).

In the lumber industry, white spruce is widely used to create dimensional lumber such as 2x4s, sheathing, subflooring, joists, rafters, trusses, etc. (Wellwood 1960). White spruce has also been used in aircraft construction (Wellwood 1960). The use of white spruce is so widely used due to its excellent strength-to-weight ratio (Wellwood 1960). White spruce is common in engineered wood products such as engineered wood flooring, Glulam, Laminated Veneer Lumber (LVL), Cross-Laminated Timber (CLT), and wooden I-beams (Government of Canada 2021; Blanchet et al. 2002).

2.1.2 White Birch

2.1.2.1 Habitat

White birch is a medium-sized tree that grows to 40-70 feet high and 30-60 cm in diameter (Barnes 2004). The bark on this tree is arguably the most distinguishing feature of a mature white birch. The bark of a mature white birch is bright white and tends to peel like strips of paper (Figure 3).

Figure 3 The bark of a mature white birch (Tree Time Services Inc).

White birch is North America's most widely dispersed Birch species and can be found as far south as Tennessee and as far north as the Yukon and Alaska (Figure 4) (Barnes 2004; Government of Canada 2020b).

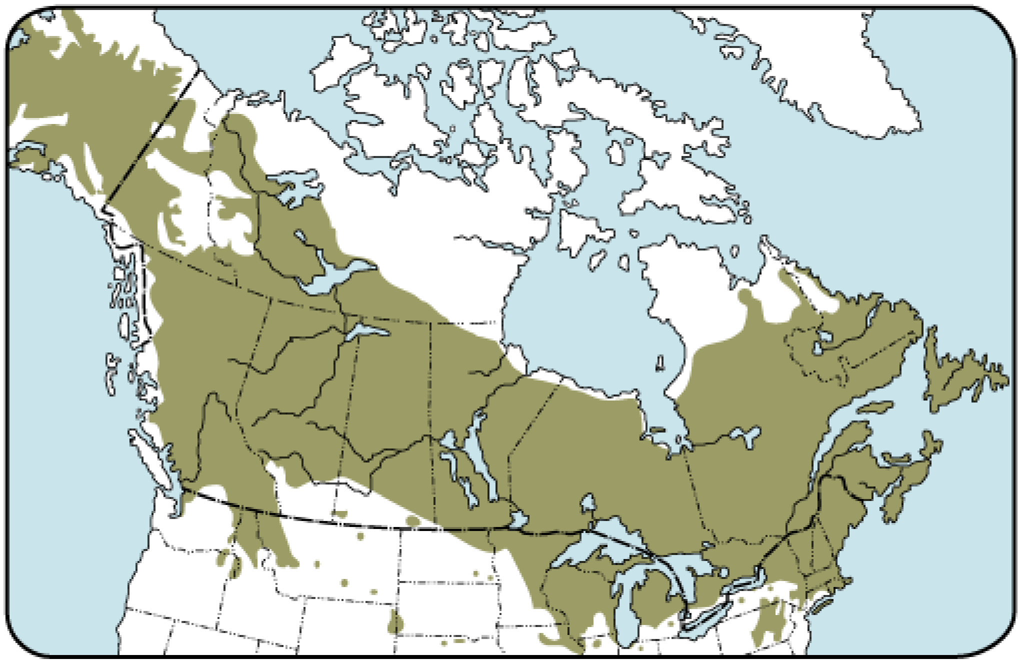

Figure 4. White birch distribution in Canada (Government of Canada 2020b).

This tree can easily be found in areas that have recently been burnt or clear-cut (Barnes 2004). Because of the wide distribution, white birch can grow on a wide variety of soils from very acidic to poorly drained (Safford et al. 1990). Given the abundance of white birch seen in figure 4, it should be noted that if this species could be incorporated into the Glulam industry, it would be readily accessible and available in large quantities in any province or territory. If white birch could be used with white spruce to create Glulam beams, each province and territory would be able to source the lumber locally; therefore, less fuel would be burnt in transportation, and a species that is already in high abundance could be utilized.

2.1.2.2 Silvics

White birch is best managed under an even-aged silvicultural system such as an even-aged shelterwood system, clear-cut system, and modified clear-cut systems (Burnes 1983). This species can be found on roadsides because it prefers disturbed sites with exposed mineral soil. White birch is one of the first species found on a site after a forest fire, which puts it into a pioneer species category. White birch is successful at growing on almost any soil type but prefers deep, well-drained soils with lots of nutrients (Burns 1983). White birch is a shade-intolerant species that will not grow well under canopy cover (Burns 1983).

In Scandinavia, birch is managed in plantations to produce high-quality timber (Cameron 1996). The silvicultural system preferred by Scandinavian foresters is the shelterwood system with seed tree retention (Cameron 1996). This system provides the stand with seed trees to help regenerate the next stand, which is vital given that birch has a relatively low seed dispersal range (Cameron 1996). It was shown that under sufficient light (about 43% full light), birch seeds do not require stratification; however, if seeds are presoaked, evidence supports that germination will be more successful (Cameron 1996). It is stressed that in addition to the proper quantity of light, birch seedlings should be free from competition, frost, and summer drought to obtain desired stocking quantities (Cameron 1996).

Once the birch stand is established and the desired stocking is obtained (2-meter spacing), stand tending can begin. Stand tending birch stands includes weed removal, thinning, and protection (Cameron 1996). Weed removal in the early summer ensures minimal competition for birch seedlings and provides good light sources (Cameron 1996). The first thinning is conducted when the stand reaches 12-14 meters in height

(Cameron 1996). At this stage, the stocking of the stand is brought down from 3000-2000 stems/ hectare to anywhere around 700-900 stems/hectare (Cameron 1996). Cameron (1996) explains that after the first thinning, it is essential to maintain a crown length of no less than 40-50% and eliminate the neighbouring tree's crown's from overlapping (Cameron 1996). Following this silvicultural system, Scandinavia has produced high-quality birch in 40-year rotations, around 40 years quicker than white spruce in Canada (Cameron 1996, Luo 2021).

2.1.2.3 Utilization

Historically, the indigenous population used the bark of white birch to build canoes. Currently, white birch is used for a wide variety of applications. White birch is commonly used to make popsicle sticks, toothpicks, spoons, and tongue depressors (Forest Products Laboratory 2010). In the medical field, white birch has been used to treat blood diseases and dysentery, induce sweating, and help nursing mothers maintain a constant milk supply (USDA 2006b).

In the commercial industry, white birch is used in plywood, high-quality veneer, woodturning, biofuel and in some cases, the chips are used for paper production (USDA 2006b). White birch is commonly seen as a decorative tree due to its white bark and nice appearance: however, in the wild, it is commonly browsed by many animals, including moose, deer, and rabbit (USDA 2006b).

White birch has also been used in restoration projects to reduce erosion in riparian buffers (USDA 2006b). As a result, biodiversity is increased, and aquatic environments are protected from silt and other harmful erosion side effects (USDA 2006b).

2.1.3 <u>Poplar (Trembling Aspen)</u>

2.1.3.1 Habitat

Poplar is the most common and widely distributed native species of trees in North America and is found as far south as Mexico on the west coast of the U.S. up to British Columbia and as far East as Canada's East coast (Figure 5) (Barnes 2004).

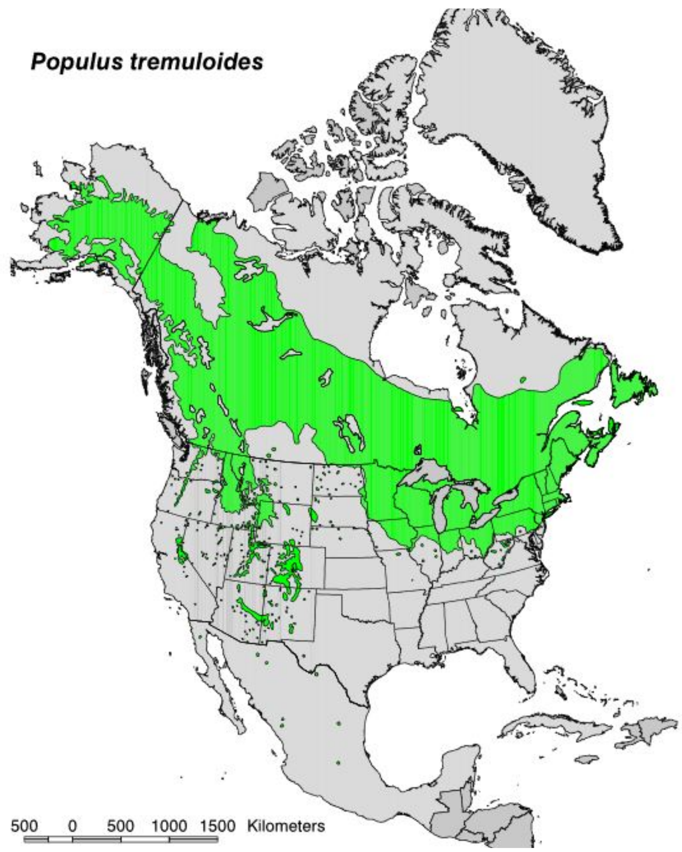

Figure 5. The natural range of Poplar in North America (Howard. J. L. 1996)

Northern ranges of poplar can reach Northern Alaska and south to southern Michigan (Barnes 2004). Ontario is home to three native species of poplar, trembling aspen (*Populus tremuloides*), large-toothed aspen (*Populus grandidentata*), and balsam poplar (*Populus balsamifera*) (Government of Ontario 2019b). Trembling aspen can be described as a medium to a large-sized tree that will grow anywhere from 50-110 feet tall and 30-60 cm in diameter (Barnes 2004). This tree's trunk has a slight taper and possesses a creamy-white-coloured bark (Figure 6) (Barnes 2004).

Figure 6. Trembling aspen bark (lamtree.com).

2.1.3.2 Silvics

Trembling aspen is a suckering tree species and greatly benefits from silvicultural systems such as clearcutting, uniform shelterwood, group selection, and single-tree selection (Perala 1972). Logging methods for trembling aspen include full-tree and tree-length (OMNR 1998). If residual trees are left, but most are cut, then suckering will occur, and if there is low competition, then trembling aspen will provide 100% stocking in the stand. Some of the clones produced from suckering poplar are as big as 40 hectares in the Rocky Mountains (Kemperman 1976).

In Northern Europe, poplar is being managed in plantations under short rotations known as short rotation forestry (SRF) (Tullus et al. 2012). SRF works by using fast-growing species such as poplar and harvesting them at around 30-year rotations or when the mean annual increment (MAI) is highest (Tullus et al. 2012). Once the plantations are planted, intensive silvicultural practices are applied until harvest (Dickmann 2006). Some examples include fertilization, irrigation, and competition control such as thinning and weed management (Dickmann 2006). Many EU countries use hybrid poplars that produce fast-growing trees to help shorten rotation periods (Dickmann 2006).

2.1.3.3 Utilization

Poplar is primarily used for pulp, paper, and composite board products such as OSB in Ontario (Government of Ontario 2019b; Barnes 2004). Poplar accounts for 18 % of Ontario's annual harvest and 22% of Ontario's growing stock volume (Government of Ontario 2019b). Poplar was considered a weed species, but in the mid-seventies, the Ontario Ministry of Natural Resources and Domtar Inc. started research into hybrid poplar stands that soon became globally recognized but unfortunately came to a halt when the Domtar mill in Cornwall shut down in 2005 (Richardson 2007).

The hybrid poplar stands in Northern Europe could be used as an excellent example for Canadian poplar plantations. Tullus et al. (2012) provides three reasons as to why the SRF poplar plantations are beneficial. The three examples are as follows; firstly, there has been an increase in pulp and fibre demand worldwide, and SRF can help reduce pressure on natural forests for this demand (Tullus et al. 2012). Secondly, farmland is becoming abandoned due to political, social, and economic changes, creating favorable spaces for poplar plantations (Tullus et al. 2012). Lastly, in the EU there has been a push for green energy use, and policies were put in place to increase renewable green energy usage to 20% by 2020 (Tullus et al. 2012).

2.1.4 Jack Pine

2.1.4.1 Habitat

Jack pine is a predominant Boreal tree species and is found as far south as Lake Michigan shoreline near Berrien Co (Barnes 2004). Jack pine extends Northwest to the Southern parts of the Yukon and Northwest Territories (Figure 7) (Barnes 2004).

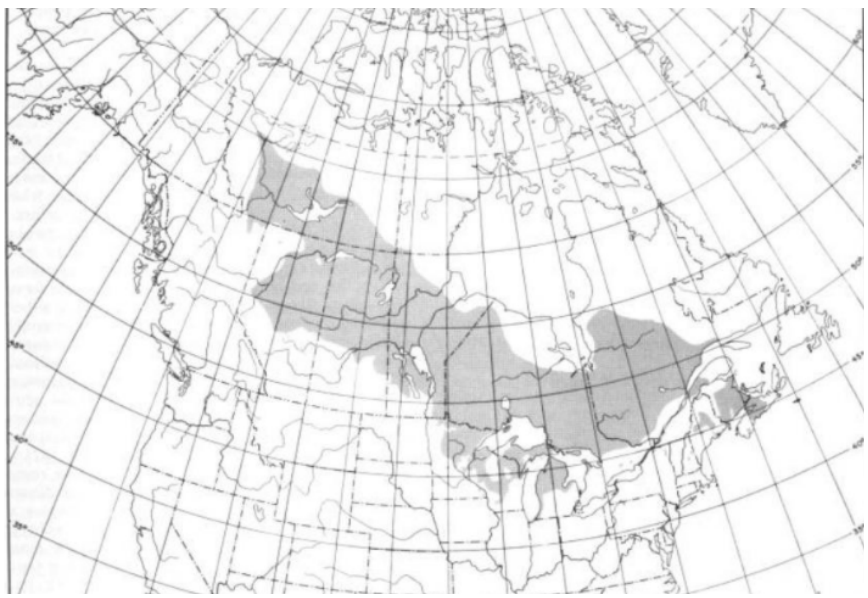

Figure 7. The natural range of Jack pine in Canada (Rudolph 1990).

This species grows on very sandy soils that are well-drained, very low in nutrients, and highly acidic (Barnes 2004, USDA 2006). Shallow soils over bedrock are also inhabited by Jack pine (USDA 2006). Jack pine can be described as a straggly tree when open-grown; however, it can grow well on good sites with a tall, straight trunk with slight taper (Barnes 2004). Jack pine trees can reach 50-88 feet tall with diameters of 40-60 cm (Figure 8) (Barnes 2004).

Figure 8. A Jack pine tree found in the Boundary Waters of Minnesota. (American Forests).

2.1.4.2 Silvics

Jack pine silvicultural systems include clearcutting, both conventional and single seed-tree (OMNR 1997). Jack pines have a particular type of cone called a serotinous cone that can only open under high heat. Serotinous cones are an evolutionary adaptation to forest fires (OMNR 1997). Like the yellow birch, jack pine prefers exposed mineral soil, so site prep is encouraged to emulate a wildfire and provide a suitable seed site (Barnes 2004). Some jack pine trees have a genetic trait that allows them to open their cones without heat; however, this trait is associated with low tree quality characteristics (OMNR 1997).

2.1.4.3 Utilization

In Ontario, dimensional lumber is the primary utilization for Jack pine; however, it is also used in OSB and pulp and paper (Government of Ontario 2019a). Posts, boxes, and firewood are occasionally made from jack pine though very little compared to the commercial industry's use (Barnes 2004).

2.2 Physical and Mechanical Properties of Wood

To understand the strength of wood, physical and mechanical properties need to be understood. The physical properties of wood can be described as the quantitative characteristics and how wood reacts to outside influences (Winandy 1994). Mechanical properties can be described as the response characteristics of a piece of wood when external forces are applied (Winandy 1994). Physical and mechanical wood properties are all tested using clear and straight grained wood to avoid defects that could skew results (Forest Products Laboratory 2010). The orthotropic nature of wood mixed with the unpredictable growing conditions can cause the same species of wood to have different testing results depending on where the sample was sourced from (Forest Products Laboratory 2010). For example, if a white birch sample were taken from Thunder Bay, Ontario, Canada it would show different physical and mechanical properties from a white birch taken from Toronto, Ontario, Canada. This also applies when two trees are taken from geographically close locations but had different growing conditions, i.e., wet, or dry soil.

2.2.1 Physical Properties

Physical properties of wood include directional properties, moisture content, dimensional stability, thermal expansion, pyrolytic properties, density and specific gravity, electrical resistance, decay resistance, and chemical resistance (Winandy 1994). Physical properties of wood are a significant factor affecting the wood's strength properties used in structural applications (Winandy 1994).

2.2.1.1 Directional properties

Directional properties of wood are essential because, unlike other structural materials like metal, wood is orthotropic and anisotropic (Winandy 1994). This means that the physical properties will be different when tested along three axes (Forest Products Laboratory 2010). Figure 9 shows the three different axes found in wood.

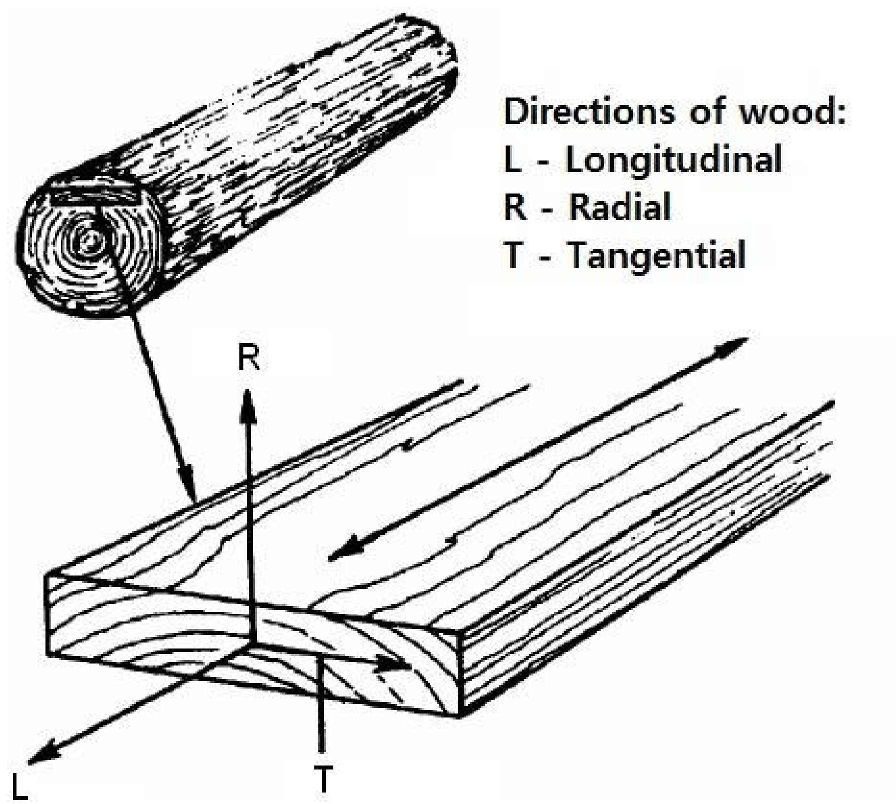

Figure 9. The three axes in wood with respect to grain direction (Winandy 1994).

It is important to note that the wood properties will differ between each axis; however, the most extreme difference will be seen between the tangential and radial axes (Winandy 1994). This change in dimensional strength characteristics is a direct result of how the cells in the wood are arranged (Forest Products Laboratory 2010). Cells in wood are arranged in such a way that the long axis of the cell is oriented parallel to the grain (Forest Products Laboratory 2010). With this orientation there is little change with fluctuating moisture content in the longitudinal axis but a large change in the lateral axis (Forest Products Laboratory 2010).

2.2.1.2 Moisture Content

When wood is to be used in structural applications, the moisture content is a beneficial source of information as it has direct effects on the mechanical properties of the wood (Winandy 1994). Moisture content is defined as the weight of water in a piece of wood and is represented as a percentage (Winandy 1994). The formula used to find the moisture content in wood is as follows; MC= $\frac{\text{moist weight}-\text{dry weight}}{\text{dry weight}} \times 100\%$ (Winandy 1994). Inside a tree, the sapwood has a relatively higher moisture content than heartwood (Winandy 1994). Depending on the species of tree, the green wood moisture content can vary from 30% to 200% (Forest Products Laboratory 2010). Water is held inside the cell cavity (free water) or the cell wall (bound water). When all the free water is extracted, and just the cell walls hold a minimal amount of water, the term fibre saturation point is used (Forest Products Laboratory 2010). All wood is considered hygroscopic, which means moisture is absorbed and exuded depending on the surrounding environment's humidity (Forest Products Laboratory 2010). Water can be absorbed by wood in three different ways, either through the cell lumens as a fluid, as a vapour also through the lumens, and through the cell walls by means of diffusion (WoodProductsfi. 2021). Since the moisture content can increase and decrease wood's strength properties, it is essential to make sure that structural lumber does not fluctuate too much and loose strength. Sealants and other products have been produced to minimize moisture absorption and create a more reliable and weather-resistant piece of lumber (Winandy 1994).

2.2.2 Mechanical Properties

Results from testing the mechanical properties of wood are presented in stress and strain values such as force per unit area (Winandy 1994). When testing mechanical properties, the samples must be clear from any defects and straight-grained to create a global standard for testing and comparing results (Winandy 1994). Such wood samples will also represent each species' actual properties without the negative influence of any deformities.

Strength properties are tested to find the maximum load or maximum capacity that a sample of wood can withstand (Winandy 1994). Different wood properties are described below and include compression parallel to the grain, shear modulus, modulus of rupture, modulus of elasticity, hardness, and density.

Glulam and OSB have their own unique testing procedures. Two common testing procedures involve a three-point and four-point system. The three-point system can be seen below in figure 10 and is commonly used for homogenous materials such as solid wood or Glulam (Test Resources 2014). The four-point test is best used on materials that are not homogenous such as OSB and can spread the load out along the test sample (Test Resources 2014). Test Resources (2014) explains that the four-point system can help prevent a premature failure on a sample that is being tested. The Flexural properties standard that must be followed for Glulam in Ontario is ASTM D7341 which outlines all tests and applicable machines that can be used. OSB structural panels must follow ASTM D7033 to generate the design capacities which outlines code recognition and the capacity per unit dimension.

2.2.2.1 Modulus of Elasticity (MOE)

MOE is described as how far a wood sample can bend under low stress and return to its original form (Forest Products Laboratory 2010). This test can be seen in figure 10.

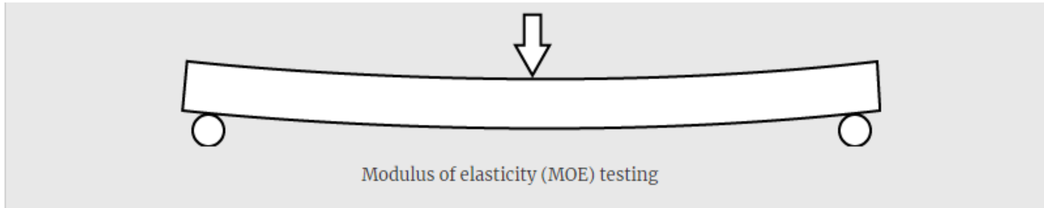

Figure 10. A visual representation of MOE testing perpendicular to the grain (Meier 2008).

The MOE of wood can be measured in all three axes; however, it is most commonly measured perpendicular to the grain (Winandy 1994). MOE measurements are essential in products such as floor joists that need to flex under stress and return to their original position without creating any defects (Shmulsky 2019).

2.2.2.2 Compression parallel to the grain

Figure 11 shows a visual of what compression parallel to the grain looks like with the possible deformations that can occur.

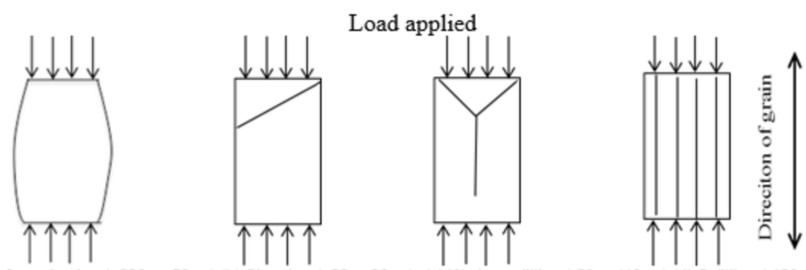

Figure 11. Compression parallel to the grain with common deformities (Jiang 2014)

The Forest Products Laboratory (2010) defines compression parallel to the grain as “The maximum stress sustained by a compression parallel-to-grain specimen having a ratio of length to least dimension of less than 11”. Structural lumber that is put under such stresses includes studs, posts, columns, and struts (Woodworks 2021).

2.2.2.3 Shear modulus

The shear modulus is described as the resistance to deformation when shear stresses are applied (Winandy 1994). If a load is applied to a piece of wood in the longitudinal axis, it can cause the cells inside the wood to “slip,” causing deformation (Winandy 1994). The second picture in figure 11 provides an excellent visual of slip. This property can be tested in three moduli; G_{LR}, G_{LT}, and G_{RT} where G_{LR} is the shear modulus of shear strain in the LR plane and shear stresses in the LT and RT planes (Forest Products Laboratory 2010).

2.2.2.4 Modulus of Rupture (MOR)

MOR is described as the maximum load that a sample of wood can hold before it breaks (Winandy 1994). This measurement is tested in the same manner as MOE and is a direct strength characteristic (Winandy 1994). The Forest Products Laboratory (2010) states that this is not defined as a true stress because of the formula that is used to define the MOR. Meier (2008) explains that the value from testing MOR alone is not that useful; however, when multiple species are tested it provides an easy comparison. When multiple species are compared, MOR testing becomes useful especially to structural engineers when looking for the proper wood species to use in a building project (Meier 2008).

2.2.2.5 Hardness

The hardness of wood is defined as the woods resistance to denting (Winandy 1994). This will become useful when choosing the proper species for flooring or even for the construction of bowling alley lanes (Shmulsky 2019). This test (Janka Ball or Brinell Hardness) is measured by finding the amount of force that is required to embed a metal ball with a 11.28 mm diameter to one half of its diameter (Forest Products Laboratory 2010).

2.2.2.6 Density

Density is arguably one of the most influential characteristics of wood strength (Saranpää 2003). The density of wood directly influences the strength properties, stiffness, and even wood market value (Saranpää 2003). Wood density is defined as the mass of wood divided by its volume at a specific moisture content and it usually expressed as kg/m^3 (previously pounds per cubic foot) (Forest Products Laboratory 2010). The density of wood can be found by first measuring the weight of a wood sample at 12% moisture as per ASTM standards. Once the weight is confirmed, the volume is found by submerging the sample in a cup of water on a scale (water displacement method). The equation D=M/V, where D represents density, M represents mass, and V represents volume, is used to find the density of the sample. Density can be measured at oven dry, 12%, FSP, and green. When wood is oven dried the cell wall material is about 1.5 grams per cubic centimeter (solid material, no voids) and has little fluctuation between different species (Panshin 1970). Once moisture is introduced the density changes for each species because the cell wall micro-cavities fill with water (Panshin 1970). As the moisture content increases the strength properties change. The fiber saturation point (FSP) is different for every species but hangs around 25-30% moisture content (Panshin 1970). As more moisture is absorbed by wood the MOE, MOR, and Compression parallel to the grain decrease therefore showing that measuring these values is essential when using wood as a building material (Panshin 1970).

Table 1 shows the strength properties and Janka hardness values for the species described in this thesis.

Table 1. Strength properties of jack pine, poplar, white birch, and white spruce (Meier 2008).

Species	Janka Hardness (Kg/m)	MOR (MPa)	MOE (MPa)	Compression Parallel to the Grain (MPa)	Density (Kg/m^3)
Jack Pine	848	68.3	9310	39	N/A
Poplar	803	69.7	10900	38.2	419
White birch	1354	84.8	10970	39.2	509--770
White spruce	714	59.6	9070	32.6	450

Table 2. strength properties found among common North American commercial species (Hiziroglu 2016).

Species common name	MOR (MPa)	MOE (MPa)	Compression Parallel to the Grain (MPa)	shear Parallel to the Grain (MPa)	Specific Gravity
Douglas fir	85	13000	26	6	0.48
Sitka spruce	70	10000	38	7	0.40
White pine	59	8000	33	6	0.35
Eastern red cedar	60	6000	24	6	0.47
Red pine	75	11000	41	8	0.46
Cottonwood	46	7000	27	5	0.34
Red oak	92	15000	45	12	0.54
Red maple	92	15000	45	12	0.54
White oak	71	7000	41	12	0.64
Black walnut	100	11000	6	9	0.55

2.3 <u>Oriented Strand Board (OSB)</u>

O.S.B. is one of the most modern forms of a composite wood panel. Composite wood panels have a history that goes back to the 1920s (Zerbe 2015). Ever since logging and forestry became commercialized, there has been a drive to increase productivity and efficiency. In the early 1900s, before composite products were around, it was recognized that there was a large amount of residual waste being burnt and not utilized; up to 60%

of log volumes delivered to the mill could be classified as residual (Zerbe 2015). With this much leftover or wasted wood, it needed to be used or built into a profitable product, and thus the creation of composite boards arose in the 1920s with "hardboards" (Zerbe 2015). The utilization of residual wood to create composite boards increased dramatically in the U.S. in the 1940s, and with this came more research into the product. The names associated with composite boards over the years are as follows; particle board (1941 Germany), NOVOPLY (1946 Switzerland), waferboard (1949 developed in a lab in Idaho), PLYSTRAN (late 1960s Idaho), flakeboard (1978 Kansas), O.S.B. (became popular in the U.S. commercially in the early 1980s) (Zerbe 2015). OSB has not been able to show impressive fire resistance like that of Glulam. Incorporating OSB into glulam has the potential to put the beam at higher risk of fire damage; however, studies are being done on how to create a more fire retardant OSB sheet using boron and Phosphorus compounds (Ayrilmis 2020).

2.3.1 Common Species

OSB samples provided by Norbord are comprised of aspen and pine strands 1-2 inches in width and 6-9 inches in length. In the US, four Southern Yellow Pine (SYP) species are used to create OSB (CWC 2021). Other species that can be used as a filler material to make up for a low supply of the SYP species include Birch, Maple, and Sweetgum (*Liquidambar styraciflua)* (CWC 2021). Every step of the manufacturing process can affect the OSB panel's quality, especially the species mix (CWC 2021). Each species has its fibre characteristics; therefore, different species mixtures will affect the final product's strength properties (CWC 2021). Other popular species used in OSB include less valuable faster-growing species such as poplar (CWC 2021).

2.3.2 Manufacturing Process

Manufacturing OSB starts with logs being brought to a manufacturing site or mill. The logs get placed into a hot water bath to soak, making the log more tender to reduce the amount of effort it takes to de-bark and chip the log (CWC 2019a). After the bath, the logs are then de-barked and processed into strands (CWC 2019a). The strands are screened to remove any small particles and then dried to 3-7 percent moisture content in large rotating cylinders (CWC 2019a). Once dry, the strands are mixed in a vat with resin and wax (CWC 2019a). The wax is there to ensure that the resin can evenly coat every strand and not pool in areas or miss others (CWC 2019a). Once coated, the strands are arranged into a mat several layers thick by a machine (CWC 2019a). The strand's orientation is essential, and for OSB, the faces are oriented in the long direction with the grain running the length of the mat (CWC 2019a). The middle layers of OSB can come in two configurations, either random orientation or oriented perpendicular to the mats faces to increase stiffness values (CWC 2019a). The mats of the resin coated strands are then transferred to a large press where the mats get pressed in between two hot plates at high pressure (CWC 2019a). The common temperatures and pressure used are over 400 degrees Fahrenheit and up to 600 psi; however, the duration varies on the thickness (Weyerhaeuser 2021). Different press cycles (press pressure and duration) are used for different end product thicknesses (CWC 2019a). The press's heat and pressure cause the strands, resin, and wax to polymerize to form the strong bond and strength of OSB sheets (CWC 2019a). Sheets are then passed through a trimming saw to be cut to their final dimensions (CWC 2019a). Lastly, the sheets are placed in heated storage, and this is where the resin undergoes its final curing process before being placed on the market (CWC 2019a). CWC (2019a) explains that some custom processes may be done at this point, such as the addition of tongue and groove edges or chemical treatment to accommodate final uses.

2.3.3 Size Configurations of OSB

OSB can be manufactured into many sizes, both metric and imperial. The most popular size of OSB is 1220 x 2440 (4x8 ft) (CWC 2019a). Imperial sizes of 4 x 9 ft and 4 x 10 ft are also available from most manufacturers (CWC 2019a). In particular circumstances, panels with dimensions up to 8 x 24 ft can be ordered (CWC 2019a). Panels of this size are commonly used in the construction of wooden I joists as it prevents the need to web splice the wooden I-joists (CWC 2019a). Panels smaller than 4 x 8 ft may also be specially ordered (CWC 2019a). Every panel is available in 1/4-inch (6 mm) to 1-1/8-inch (28.5 mm) thickness (Table 3) (CWC 2019a).

Table 3. Thickness and weights available for OSB panels (CWC 2019a).

OSB (CSA 0325)			
Thickness		1220 x 2440 mm (4 x 8 ft) Panel Weight	
mm.	in.	kg	lb
9.5	3/8	18	40
11	7/16	21	46
12	15/32	23	50
15	19/32	29	63
18	23/32	34	76
22	7/8	42	92
28.5	1-1/8	54	120

Notes: Weight calculated on the basis of 640 kg/m^3 (40 lbs/cu.ft.) density and nominal thickness.

2.3.4 Physical and Mechanical Properties

Although not as strong as plywood, OSB has favorable strength properties and is being utilized for more applications every year. Table 4 provides a quick guide to some MOE and MOR strength properties of OSB.

Table 4. MOE and MOR values for OSB samples 23/32 thick produced from pine, aspen, and hardwood (Wang et al. 2004).

OSB Sample (23/32)	MOE (MPa)		MOR (MPa)	
	Perpendicular	Parallel	Perpendicular	Parallel
Pine Group Average	2417	5816	17.6	31.8
Aspen Group Average	2600	7067	15.8	35.2
Hardwood Group Average	1935	5123	40.6	113
CSA 0437 Standard	1500	5500	12.1	29

Another report by Beck et al. (2010) compared the strength properties of OSB made from birch with OSB made from trembling aspen. The results showed that both OSB products met standards and would prove to compete with current commercial OSB panels (Beck et al. 2010). Table 5 provides the MOE and MOR properties of the OSB panels that Beck et al. (2010) created.

A study conducted by Lunguleasa et al. (2020) studied the MOE and MOR of OSB made from mixed softwood and mixed hardwood. The species used to create the mixed softwood OSB were spruce, pine and fir and the mixed hardwood OSB was made from poplar, willow, and birch (Lunguleasa et al. 2020). The results from this study showed that the mixed hardwood OSB had a MOE value of 7110 MPa and a MOR value of over 40 MPa (Lunguleasa et al. 2020). When these values are compared to the average MOE and MOR values of white pine (8000 MPa and 59 MPa) used in Glulam OSB has the strength properties available for Glulam production.

Table 5. MOE and MOR properties of OSB made from trembling aspen and paper birch (Beck et al. 2010).

Species	Perpendicular to the Grain		Parallel to the Grain	
	MOR (MPa)	MOE (MPa)	MOR (MPa)	MOE (MPa)
Trembling aspen	72.2	11754	43.4	10567
Paper birch	64.4	10601	43	10340

These values show that OSB produced from fast growing species such as trembling aspen and birch can produce OSB panels that would meet today's standards. Beck et al. (2010) compared these values to that of TimberStrand, a laminated strand lumber (LSL) product that is produced by Weyerhaeuser and found that the values of the LSL were in the range of 9000-10700 MPa for MOE edgewise bending. The comparison was also made to SPF dimensional lumber values that showed an MOE value of 8500 MPa (Beck et al. 2010).

A study from Japan showed the strength properties of OSB made from sugi (*Cryptomeria japonica*) and Japanese cedar. In this study Suzuki (2000) found that the OSB samples they produced could show MOE values of up to 10,600 MPa Parallel to the orientation and MOR values of 69.7 MPa parallel to the orientation. These values are consistent with other published literature as seen in table 5.

2.3.5 <u>Utilization/Uses</u>

OSB has many different uses including, subfloors, underlayment, furniture, roofs, and even wall sheathing (CWC 2021). OSB is also used as a connecting material (the web) in wooden I-joists (CWC 2021). Seeing that OSB has already been incorporated into other engineered wood products, it would be beneficial to experiment with OSB as filler materials (for example in the neutral axis layer) in Glulam products. Using OSB as a filler layer in the layup stage could help reduce SPF species' use, given that OSB can be produced from faster and underutilized species such as poplar. It is important to note that OSB has been competing with plywood and is now recognized by the U.S and Canada to be used for the same applications as on a thickness-by-thickness basis (Ayrilmis 2007). Another opportunity may be in the engineered floor joists where some issues are occurring during fires where the OSB web is burning quickly causing failures in the flooring system. An alternate to this may be a larger joist web with a web made with multiple layers of OSB or with a layer of solid wood on the outside or inside of a panel. This could present an opportunity to fix a problem and expand the use of OSB in an engineered product. The two major downsides to OSB, when compared to plywood, is that it swells when introduced to moisture and has lower strength properties (CWC 2021).

2.4 Glulam

Glulam is a structural product produced from laminating prepared pieces of wood into structural members, posts and beams (AWC 2018). In Glulam members, the grain of each piece of wood runs parallel to the longitudinal axis of the member (AWC 2018). The lumber that is laminated into Glulam is generally one or two inches thick (AWC 2018).

Different Glulam styles are available and include members made of different grades of lumber or even different species depending on the final use of the product (AWC 2018). When different grades of lumber are utilized to create a member, two common combinations can be used, as seen in figure 12. Equal sized pieces of lumber in the glulam product such as 2” x 6” lumber is more common.

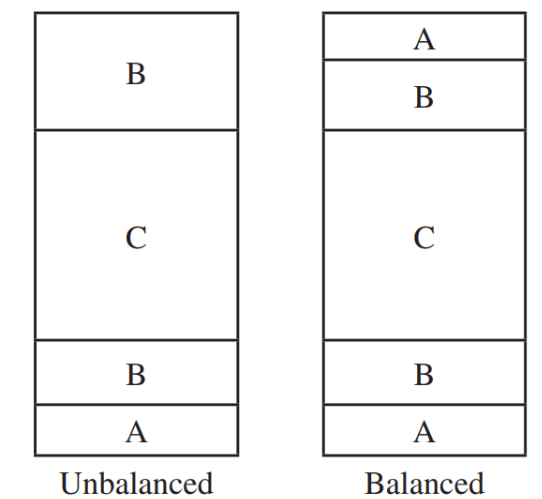

Figure 12. Balanced and Unbalanced combinations in a Glulam member (AWC 2018).

2.4.1 Common Species

Glulam in Canada is primarily constructed from either Douglas fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), all spruce except coast Sitka (*Picea sitchensis*), jack pine, and lodgepole pine (*Pinus contorta*) (CWC 2020). Globally, Glulam is made from geographically available species. In Germany, a building is built with Glulam beams made of beech (*Fagus*) (Milner 2014). Central Europe is looking at using Ash (*Fraxinus*) and Maple (*Acer*) in the creation of Glulam because of the increasing availability of hardwoods in Europe (Schlotzhauer et al. 2019). Other species that are being utilized worldwide for Glulam production include poplar and blue gum (*Eucalyptus globulus*) (MOE 10,600 MPa) in Portugal, and studies are being conducted on the use of blackwood in Europe (MOE of 13,864 MPa) due to it being an invasive species (Martins et al. 2020).

2.4.2 Manufacturing Process

The Glulam manufacturing process involves many steps and can be seen in figure 13. It should be noted that this is a generic figure and that the manufacturing process varies from company to company depending on the Glulam members application.

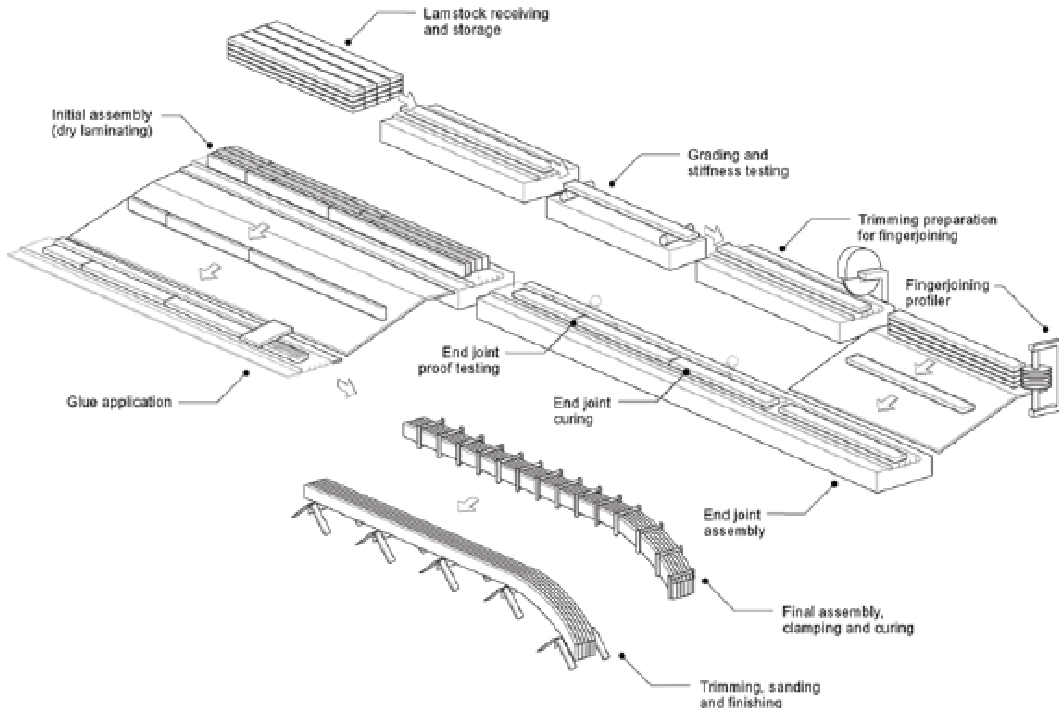

Figure 13. The manufacturing process of Glulam beams (CWC 2020a)

Creating Glulam is extensive and starts with selecting a specialized category of dimensional lumber called lamstock (CWC 2020a). Each piece is purchased directly from the mill and then dried to a moisture content of 7-15% (CWC 2020a). If the dried lamstock needs to wait before being constructed into Glulam, it will be housed in a controlled environment to maintain its dried moisture content (CWC 2020a). Before the dimensional lumber is end jointed and laminated, it must be planed to create a more even and precise gluing surface (CWC 2020a). To reach the desired length of Glulam, each piece of dimensional lumber is end jointed (CWC 2020a). Before the lamstock is laminated, it must be sorted into different categories that group together similar strength and stiffness qualities (CWC 2020a). Lamstock that exhibits higher strength properties is placed in a beam or column where the most significant stress is produced (CWC 2020a). The stronger pieces are usually placed near the top and bottom of a beam (compression and tension layers, respectively), with the weaker pieces near the middle (neutral axis layer) (Issa 2004). This technique is called grade combination (CWC 2020a). To create Glulam's beneficial strength qualities, these strips of end jointed lumber are then laminated using a waterproof adhesive (CWC 2020a). When required, a slight camber can be built into a glulam beam to reduce the amount a beam will bend past a flat orientation when it is under a heavy load (CWC 2020a). Glulam beams need to use unique joinery to span the enormous distances that they do. The most common joint used to end joint Glulam beams is called the finger joint and is used for its many benefits. Finger joints have many advantages that include high strength, reduced warping, twisting, and reduced waste by utilizing wood sections that would be otherwise thrown out due to defects (BFP 2021). Finger jointing also provides a cleaner-looking surface than other joinery methods and produces very strong sections due to the high surface area utilized in the gluing process (BFP 2021). Figure 14 displays a common finger joint.

Figure 14. A common finger joint before it is glued and pressed together. Note the significant amount of surface area for gluing (Government of Canada 2020c).

2.4.3 Size Configurations of Glulam

Glulam is available in all the commonly used dimensions for residential and commercial buildings (APA 2021). Some widths produced by APA (2021) include 3-1/8, 3-1/2, 5-1/8, 5-1/2, and 6-3/4 inches. CWC (2019c) provided standard glulam dimensions in table 6.

Table 6. common Glulam widths in Canada (CWC 2019c).

Initial Width of Glulam Stock		Finished Width of Glulam Stock	
mm.	in.	mm.	in.
89	3-1/2	80	3
140	5-1/2	130	5
184	7-1/4	175	6-7/8
235 (or 89 + 140)	9-1/4 (or 3-1/2 + 5-1/2)	225 (or 215)	8-7/8 (of 8-1/2)
286 (or 89 + 184)	11-1/4 (or 3-1/2 + 7-1/4)	275 (or 265)	10-7/8 (or 10-1/4)
140 + 184	5-1/2 + 7-1/4	315	12-1/4
140 + 235	5-1/2 + 9-1/4	365	14-1/4

Glulam members are also available in almost any custom size for commercial uses in dome structures, bridges, and mass timber buildings (APA 2021).

2.4.4 Utilization/ Uses

Glulam has become a popular material in the commercial and residential building industry due to various benefits. Glulam is pound for pound stronger than steel, and a green alternative to steel due to its carbon storage characteristics. It provides greater stiffness ratings than the exact size of dimensional lumber (APA 2021). Glulam is seen in many architectural designs due to the appealing look of wood and the fact that it can be made into almost any arch or configuration and still hold strong (APA 2021). Vaulted ceilings are an excellent example of an architectural utilization for Glulam as is shown in figure 15.

Figure 15. Vaulted ceilings created from Glulam beams and rafters (APA 2021).

An additional appeal towards Glulam over products such as solid lumber is Glulam's ability to span longer distances (APA 2021). Glulam can span up to 500 feet in some dome structures and 100 feet in other custom applications (APA 2021).

Some examples of where Glulam timber was used include the Mistissini Bridge in Quebec, the Reveley Nursery Facility at the University of Idaho, Pharmacy Brunet in Wakefield QC, and the Brock Commons residence mass timber building at the University of British Columbia (APA 2021, Element5 2021, UBC 2015).

The Mistissini Bridge spans 160 m and is divided into four sections of straight beams that are supported by Glulam arches (Nordic Structures 2021). This bridge uses 24 m long beams that attach to 15 m long arches that are then attached to concrete pillars (Nordic Structures 2021). Due to the amazing design of the bridge, it has received four awards including the Engineering a Better Canada Award and the Award of Excellence from ACEC (Nordic Structures 2021).

Glulam can be used in the residential world for garage door headers, columns, I-joists, ridge beams, and open space designs (APA 2021). It is common to find high ceilings in today's houses, and Glulam provides a very strong yet highly appealing look when used as a ridge beam, as seen in figure 16.

Figure 16. A Glulam beam utilized as a Ridge beam to create a high ceiling and raise the aesthetics of a room (APA 2021).

The main advantages of using Glulam in a residential application are as follows. Glulam is very dimensionally stable; thus, cupping and swelling are minimal. Glulam can span a considerable distance, and the cost is very reasonable compared to other engineered wood products, and it is available in standard framing sizes (APA 2021).

Additional benefits such as fire resistance are highly beneficial when using Glulam. Unlike metal, wood can hold its strength for longer periods of time during a fire (AITC 2003). According to AITC (2003) and NIST (2018), fires inside buildings can reach temperatures of up to 1800 °F. Unfortunately metal I beams are known to only have 10% of their original strength at 1380 °F causing buckling and failure (AITC 2003). Glulam beams burn very slow at about 1/40th of an inch per minute and this is regulated and tested under ASTM E-119 (AITC 2003). With this information, a 30 min fire would only burn a Glulam beam about ¾ of an inch (AITC 2003). Additionally, when wood is burnt a charcoal layer is formed which slows the burning process even more and protects the fresh unburnt wood underneath (AITC 2003). International

Building Code (IBC) 602 has five different codes for buildings using Glulam pertaining to fire resistance (WPC 2019). Type 3 or ICB 602.3 states that timber can be used in floors, roofs, and interior walls; however, this timber must be able to withstand fire for up to 2 hours (WPC 2019). Figure 17 provides a comparison between wood and streel strength during a fire.

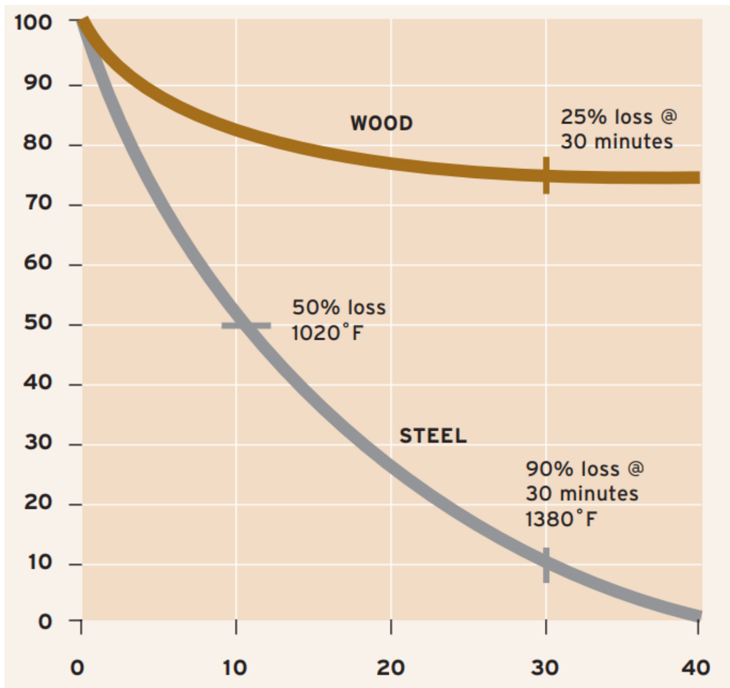

Figure 17 Wood vs steel strength characteristics during exposure to fire (AITC 2003).

2.4.5 Physical and Mechanical properties

Glulam beams are heavily regulated for strength and visual quality and are broken up into different stress grades in Canada as seen in table 7.

Table 7. represents the different strength grades produced for Glulam in Canada (CWC 2019b).

Stress Grade		Species	Description
Bending Grades	20f-E 20f-EX	D.Fir-L or Spruce Pine	Used for members stressed principally in bending (beams) or in combined bending and axial load.
	24f-E 24f-EX	D.Fir-L or Hem-Fir	Specify EX when members are subject to positive and negative moments or when members are subject to combined bending and axial load such as arches and truss top chords.
Compression Grades	16c-E 12c-E	D.Fir-L or Spruce Pine	Used members stressed principally in axial compression, such as columns.
Tension Grades	18t-E 14t-E	D.Fir-L or Spruce Pine	Used for members stressed principally in axial tension, such as bottom chords of trusses.

The grades of 20f-E, 20f-EX, 24f-E, and 24f-EX represent 2000 or 2400 pounds per square inch (PSI) of bending stress (CWC 2019b). The "f" represents the product's use as flexural bending members (CWC 2019b). The compression grades of 16c-E and 12c-E and tension grades of 18t-E and 14t-E are broken down similarly to the bending grades (CWC 2019b). The first letter, either "c" or "t," represents the member to be used in either a compression or tension application (CWC 2019b). The "E" at the end of the grades indicated that these Glulam members are tested using a machine (CWC 2019b).

The grades that include "EX" are intended for uses in which the member will undergo stress reversals, and these members have an identical tension and compression side of the member (CWC 2019b). the addition of OSB into Glulam beams could potentially hinder the aesthetic look. With OSB as a layer the beam would look less homogeneous and have a line of OSB running the entire length.

2.5 Markets and Market Demand

2.5.1 Softwood Lumber

The global wood market has a wide variety of wood, from softwood lumber to veneer logs. New technologies are expanding this market with new wood-based technologies such as biofuels and chemicals produced from wood (Skjerstad et al. 2021). Although new materials and products are flooding into the market, softwood lumber still accounts for the most significant global wood market volume (Skjerstad et al. 2021). Statistics gathered from FAO (2020) state that in 2018 softwood lumber accounted for 72% of the global sawn wood, which had a production volume of 354 million m^3. The top producing and exporting countries in the softwood lumber market are the USA, China, Canada, Russia, and Germany. The USA is the largest producer and importer, and Russia and Canada are the most prominent exporters, shown in table 8 (Skjerstad et al. 2021).

Table 8. The top countries involved in the softwood lumber trade with respects to production, imports, exports, and consumption. all values are in Million m^3 (Skjerstad et al. 2021).

Country	Production	Import Quantity	Export Quantity	Consumption
United States of America	57.6	26.7	2.9	81.4
China	38.4	26.1	0.1	64.4
Germany	22.1	4.7	7.5	19.3
Canada	48.2	0.7	31.1	17.8
Japan	8.6	6.1	N/A	14.7
United Kingdom	3.7	7.1	0.2	10.6
Russia Federation	37.8	0	28	9.9
Sweden	18.3	0.5	13.1	5.7
Finland	11.7	0.5	9.4	2.9
World Total Volume	345	122	126	341

As seen in table 8, Russia and Canada are the two largest exporters of softwood lumber. This could be a direct result of softwood availability as Russia and Canada cover most of the globe's Boreal forest.

Skjerstad et al. (2021) used the most current statistics from FAO and SSP models to predict the increase in demand for softwood lumber from now until 2030. The study found that the demand for softwood lumber on a global scale would increase significantly just with the knowledge of the global economic growth in the next decade (Skjerstad et al. 2021). On average, Skjerstad et al. (2021) estimated that from the five scenarios ran that the demand for softwood lumber should increase by 2-3% in 2025 and 2030. It should be noted that this study did not account for policies that affect the use of sawn timber (Skjerstad et al. 2021).

2.5.2 Engineered Wood Products market

The global Glulam market has been more and more successful as the years pass due to the various new applications being found for the engineered wood product (Albee 2019). The mass timber movement is another factor affecting engineered wood product's success (Albee 2019). The appeal for mass timber construction, which includes Glulam, Cross Laminated Timber (CLT), and Laminated Veneer Lumber (LVL), for example, stems from finding alternatives to concrete and steel environmentally (Albee 2019). Changes in the International Building Codes (IBC) have significantly increased the utilization for Glulam (MTCC 2021). In 2018 14 code-change proposals were submitted to the International Code Council (ICC), and all of them were either approved or approved with modifications (MTCC 2021). Some of the proposals include changes in the type of construction and fire safety during construction (MTCC 2021).

In Europe, Austria is the largest producer of Glulam, and in 2015 the country produced around 1.5 million m^3 (UNEC 2017). Japan imported almost 800,000m^3 of Glulam and CLT in 2016, with most of it coming from Europe (UNEC 2017). In North America, Glulam production steadily increased from 2009-2017, as shown in Figure 18.

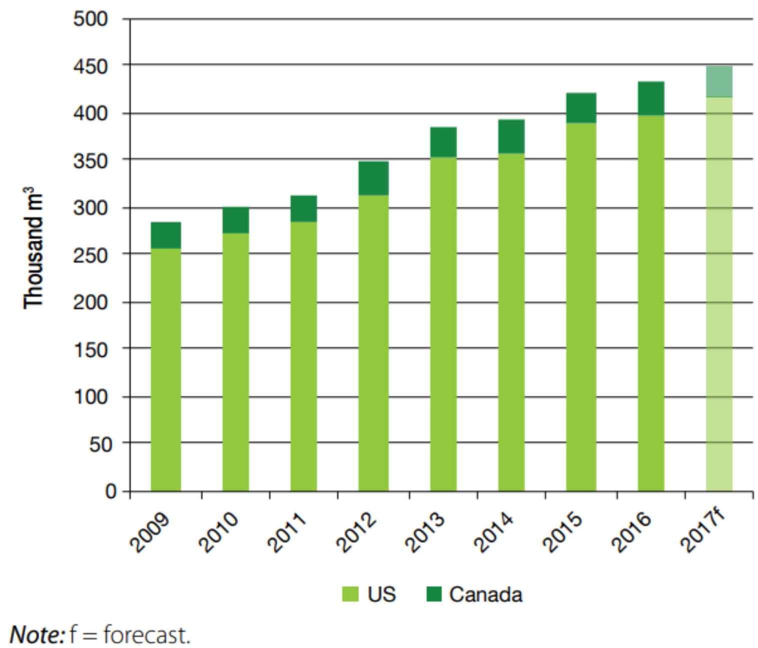

Figure 18. North America's Glulam Production from 2009-2017 in thousand m^3 (UNEC 2017).

Like most wood products, OSB production took a hard fall in 2008 but has been on the rise ever since (Omar 2020). OSB has continuously competed with plywood in the residential and industrial sectors; however, OSB now accounts for more volume than plywood in the residential sector (Omar 2020). Figure 19 demonstrates the market trends in the USA from 1980 to 2016 (Omar 2020).

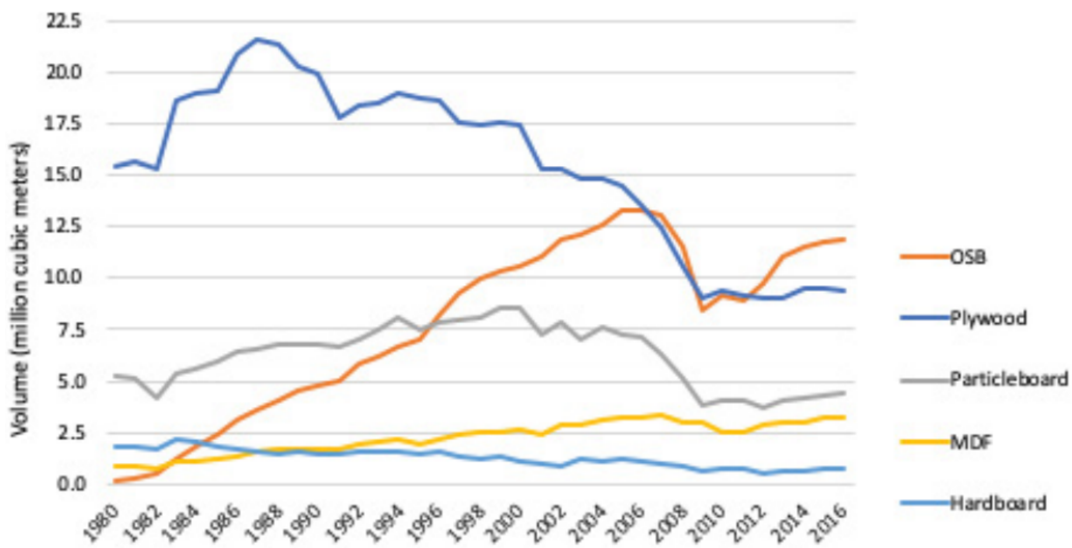

Figure 19. United States market trends of various wood-based panel products (Omar 2020).

Figure 19 shows that OSB accounts for the highest production volume out of all the wood-based panel products in the U.S. (Omar 2020). This rising trend in the production of OSB is also seen in Europe. Since 2008, OSB panel's volume has increased from just above 4 million m^3 to almost 7 million m^3 in 2018, as shown in figure 20 (EPF 2018).

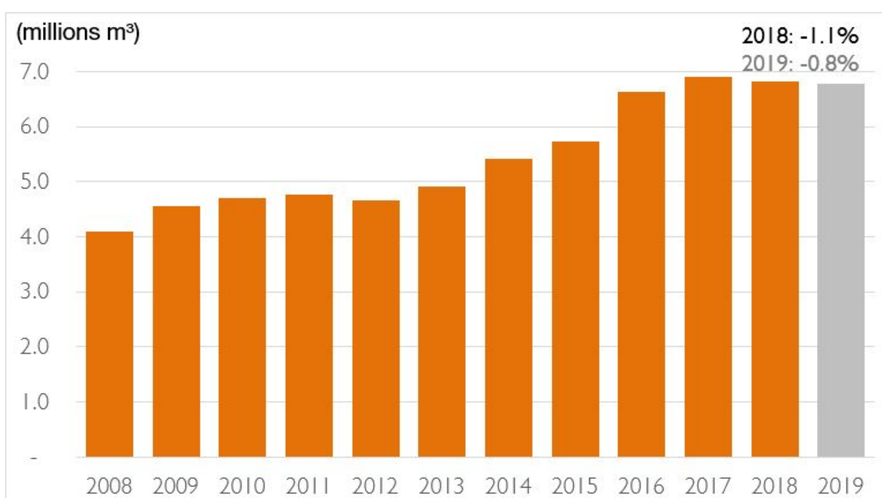

Figure 20. OSB Production in EU-28 Plus EFTA (EPF 2018).

CONCLUSION

The Glulam market and the wood-based panel markets are continuing to rise worldwide. This expansion is providing the materials necessary for new research and finding new ways to utilizes these products. Canada has a surplus of underutilized species that could significantly reduce the pressure currently put on the natural forest's SPF species. Specific management systems like those used in the Scandinavian countries for fast-growing species could prove very effective for Canada's white birch. If these systems were adopted, Canada could use white birch as an alternative to SPF species in Glulam production in a sustainable manner.

New applications for engineered wood panels such as OSB are being found every year. OSB manufacturing techniques have greatly improved the physical and mechanical properties of the panel since its debut. These attributes combined with the benefits explored in white birch could work in unison in Glulam production.

The forestry industry is no stranger to natural disasters such as forest fires, disease, and insect infestations, all of which can decimate entire forest stands and tree species. The heavy reliance on SPF species could leave the Glulam industry at risk of such disasters that would significantly impact the Glulam industry, residential, and industrial building markets. If alternative species and OSB could be utilized to produce Glulam, it would increase the resilience of the Glulam industry against the risks of natural disasters. Increasing the resilience of the Glulam market is vital to the future of the environmentally sustainable building movement.

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