Veneer Mechanical Grading Based on Online Local Wood Fiber Orientation Measurements to Model and Manufacture Stiffness Optimized Structural Beams

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ABSTRACT

Grading veneer for plywood manufacturing is often performed on line using visual criteria issued from EN 635-3 standard. For mechanical applications, the only visual criteria can be not sharp enough to accurately grade veneers as it was noted in the literature for sawmill industry. For logs with a high variability and heterogeneity, the transformation in LVL (laminated veneer lumber) product can be a good valorisation if the veneer grading is efficient. This article presents a new methodology to measure in process the local fiber orientation of a peeled veneer using tracheid effect on a specific apparatus. This device called LOOBAR for Local Online Orientation fiBer AnalyseR, is composed of 4 cameras and a beam supporting 50 red-dot lasers disposed above the peeling lath conveyers allowing for grain angle surface scanning on the ribbon or each veneer if located after the clipper. This field data, put together with the veneer global density, allow for modeling accurately the local elastic properties of each veneer produced to sort them and latter on, to optimize the mechanical properties of a composed engineering wood product such as LVL by adapting the local beam stiffness to the desired purpose.

This article presents the results of LVL beams manufacturing and characterization using computed local stiffness to sort veneers. Veneer grading using ther local longitudinal modulus of elasticity and EN635-3 method are compared. The pertinence of the local fiber orientation usage to estimate mechanical veneer properties appears clearly. This approach opens important perspectives using local density and grain angle to sort heterogeneous veneers.

Keywords: Veneer Grading, Local fiber orientation, peeling, Laminated Veneer Lumber, Douglas fir.

INTRODUCTION

Laminated Veneer Lumber (LVL) is a type of composite material composed of veneers obtained through the rotary-peeling process. This material offers several advantages. Firstly, unlike sawn timber, it enables a distribution of defects within the material, preventing the accumulation of defects and resulting in a more uniform product. Secondly, it allows for the strategic placement of veneers based on their quality, thereby optimizing the performance characteristics of the final product. This advantage is particularly significant when dealing with highly diverse wood species in terms of density, as well as the quantity and size of defects, such as large Douglas-fir woods. Moreover, unlike sawing that loss a non negligible amount of wood into dust due, veneer production creates a very low amount of waste; being favorable to improve the global yield of the second transformation.

Within the peeling industry, veneers are typically sorted based on appearance criteria such as knot size, slots, resin pockets, and other relevant factors. This sorting process follows the guidelines outlined in the EN 635-3 standard (1). The classification of veneers based on appearance criteria is commonly done using cameras integrated into the panel-making line. However, the visual characteristics of the veneers may not necessarily reflect their strength or performance capabilities. LVL industries also grad veneers using global properties obtained mainly from ultrasonic measuring systems (2).

In the sawmilling industry, mechanical property assessment of timber using grading machines (stress grading, vibrational tests) based on physical measurements has been developed. In recent scientific advances, two main technologies are used for better timber quality assessment: X-ray scanning, which provides local density through board thickness, and laser-dot scanning, which provides the local fiber orientation on board surfaces. With wood being a highly anisotropic material, the strength and stiffness properties are far better in the longitudinal fiber direction than in perpendicular. It appears that models based on local properties and especially local fiber orientation measurement could provide greater improvements in bending strength prediction (3).

Laser-dot scanning, also referred to as fiber-orientation scanning, relies on the principle of light scattering from a laser dot projected onto the surface of wood. This phenomenon is known as the "tracheid effect" (4,5). Indeed, when laser dots are projected onto the wood surface, they scatter and form quasi-elliptical light spots, which major-axis corresponds to the fiber orientation of the wood under the spot. These elliptical patterns can be captured using standard cameras, and the resulting images can be analyzed. Much research using this technology has been performed recently. Viguier et al (6) successfully implemented a modeling method based on fiber orientation scanning using a laser-dot scanner, which is typically used for sawn timber, to assess small-sized veneers. The authors demonstrated that it was feasible to model the flatwise bending stiffness of Laminated Veneer Lumber (LVL-P) by employing laser-dot scanning on the individual veneers that make up the composite material. Although, this approach was performed using a timber grading type device and the width of veneers in use was consequently limited (less than 200 mm). To full-size scan veneers, the LaBoMaP develop a new apparatus called LOOBAR for: Local Online Orientation fiBer AnalyseR (7). This article will first describe the LOOBAR characteristics and usage principle on variable local French resource: large Douglas Fir. Then, a method will be proposed that allows classes to be developed using physical parameters, combining the local fiber orientation and the average density.

MATERIALS AND METHODS

Wood material and veneer peeling

Three different samples compose the Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco) resource used for the experimental peeling/scanning (Table 1). Different stands were selected by different partners from sylvicultural sector according to their representativeness of French Douglas fir resource.

The peeling operation was carried out using the LaBoMaP rotary peeling machine located in Cluny, France. Prior to peeling, all logs underwent a soaking process in water at a temperature of 50 °C for a minimum duration of 36 hours. This soaking process was employed to enhance the deformability of the material, thereby facilitating the rotary peeling process. The linear cutting speed was automatically controlled by the machine at 1.5 $m.s^{-1}$ (8). The rotary peeling operation was carried out without the use of a pressure bar. This choice was made to avoid any problems coming from the Horner effect (9). The peeling thickness was set to obtain dried veneers with a thickness of 3 mm. Spur knifes were set up, allowing the incision of the log on the surface prior to the cutting of the knife with a length between 700 and 750 mm. Two chosen veneer widths were 850mm and 1,000mm. In total, the data coming from 286 veneers were treated in the following studies, coming from the peeling and online scanning of 12 Douglas-fir logs (see Table 1).

	Forest Stand 1	Forest Stand 2	Forest Stand 3
Locality	Sémelay (Nièvre, France)	Anost (Saône-et-Loire, France)	Cluny (Saône-et-Loire, France)
Average altitude	300–400 m	300–400 m	300–400 m
Cutting age	50–60 yo	50–60 yo	50–60 yo
Silviculture	Fourth thinned-out plot, non pruned wood	Clearcut, dynamic sylviculture, pruned wood	Classic (high forest)
Number of logs	4	4	7
Number of veneers	Sapwood: 68 Heartwood: 57	Sapwood: 8 Heartwood: 24	Sapwood: 47 Heartwood: 82
Average under bark trunk diameter	Min: 425 mm Max: 470 mm	Min: 410 mm Max: 445 mm	Min: 420 mm Max: 455 mm
Veneer average density	527 $kg{\cdot}m^{-3}$	508 $kg{\cdot}m^{-3}$	544 $kg{\cdot}m^{-3}$

Table 1. Logs characteristics

Veneer scanning

An innovative device was involved to measure the local fiber orientation of each veneer: the LOOBAR. It was developed within the LaBoMaP Wood Material and Machining (WMM) team and was integrated directly on their instrumented industrial peeling line. The LOOBAR hardware, shown in Figure 1, is localized after the clipper of the peeling line, and thus it scans already clipped veneers (Figure 1a).

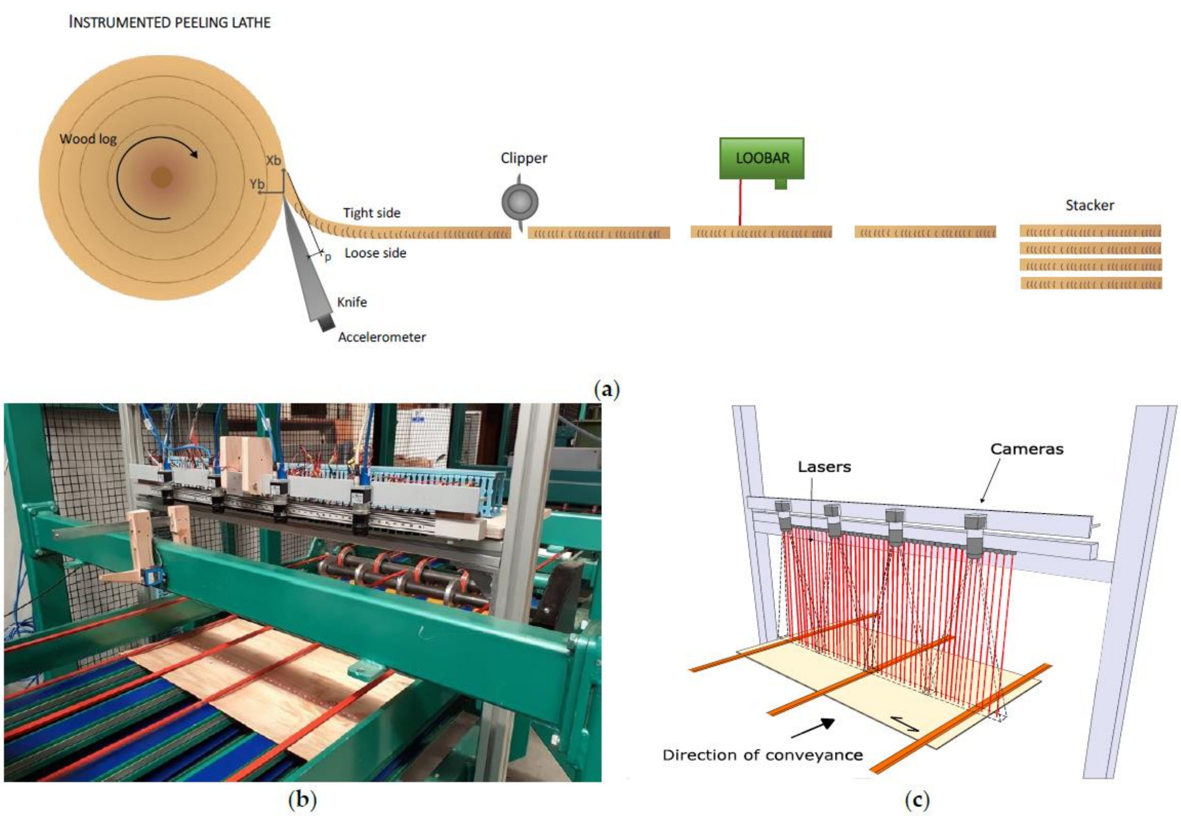


Figure 1: The LOOBAR, a veneer fiber orientation-measurement: (a) schematic representation of LaBoMaP's instrumented rotary peeling line, (b) picture, and (c) scheme of the LOOBAR.

Usually in a sawmill, industrial scanners use 4 rows of laser dots to scan simultaneously the four sides of a timber board conveyed longitudinally. Here, due to the low thickness of the veneers, the fiber orientation was considered to be the same across its thickness, justifying the measurement on only a single face. As shown in Figure 1b,c, the LOOBAR is composed of:

- Fifty laser-dot modules with an output power of 5 mW each which project circular beams onto the veneers superior surface. They are positioned in line at a distance in the full 800mm width of the peeling line, fixed on a support above it, and are thus perpendicular to the direction of the ribbon and parallel to the main direction of the grain.

- Four cameras (Basler acA2440-75 µm), performing video acquisition of the reflected ellipses on the veneer surface. Their resolution is of 2048 pixels in the width of the line (or the main direction of the grain) and 120 pixels in the scrolling direction of the band (perpendicular to the main direction of the grain). The maximal acquisition rate is 1000 frames/s. The measurement resolution in the main direction of the fibers (perpendicular to the conveyor) was about 16mm, corresponding to the mean distance between each laser-dot module. The measurement resolution across the main fiber direction depends on the acquisition speed of the cameras and on peeling line veneer conveyor speed. For the linear cutting speed of $1.5 m.s^{-1}$ applied here to Douglas-fir veneer peeling, it was close to 3.5mm. In the main fiber direction, it was necessary to use a distance of 16 mm between the lasers so that the centers of the ellipses were not too close to avoid superimposing parts of ellipses.

After being cut by the clipper, veneers have the potential to undergo slight rotation during conveyance. To address this, a second processing step was implemented to correct the information obtained from the cameras. This involved transforming the coordinate system from the LOOBAR to the local coordinate system of the veneer. In this step, the cut edges of the veneer were detected, and a conversion from pixels (px) to millimetres (mm) was performed. This allowed for an angular correction of the fiber orientation values and a rotation of the grayscale image. As a result, the veneer could be visualized in its own local coordinate system (Figure 2a), where x_{green} represented the position of a pixel in the longitudinal main direction of the veneer, and y_{green} represented the position of a pixel in the tangential main direction of the veneer. This correction step enabled the utilization of the information obtained, even if the veneer's coordinate system was not aligned with the coordinate system of the measurement apparatus.

Finally, the outputs of the LOOBAR scanning after these processing steps were as follow: x_{green}, the position of ellipses center along the fiber orientation in the veneer coordinate system (mm); y_{green}, the position of ellipse center along the perpendicular axis to the fiber orientation in the veneer coordinate system (mm); Θ, the angle (°); major and minor axis (mm) that enable ratio calculation (dimensionless quantity); and the ellipse area (mm2). All those parameters, arising from an example of a scanned veneer, are plotted in Figure 2b.

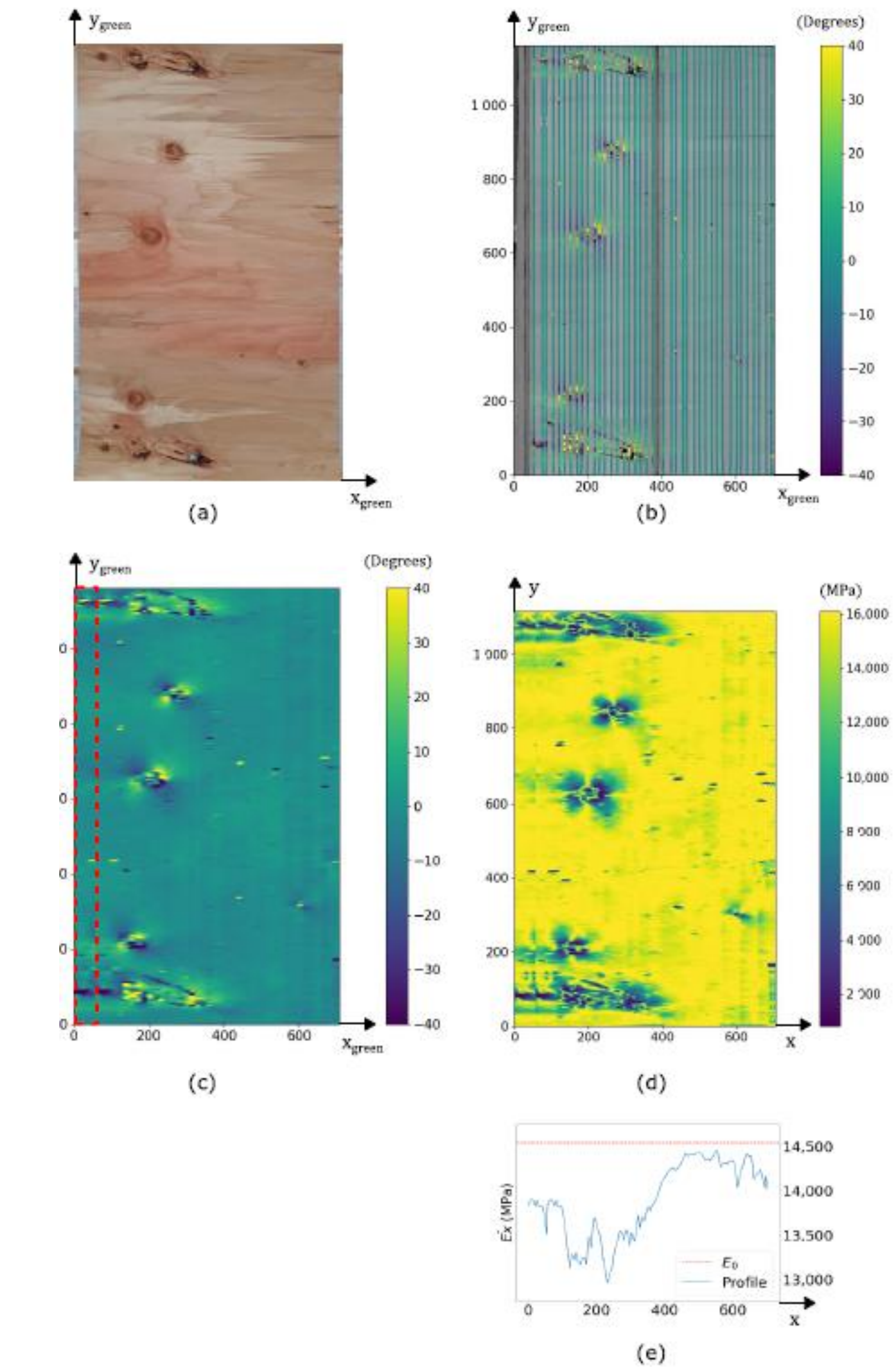


Figure 2: The veneer to fiber orientation grid: (a) veneer picture using a camera, (b) grayscale image and fiber orientation laser points, (c) interpolated local fiber orientation grid, (d) local elastic modulus grid, (e) stiffness profile.

Equivalent Longitudinal Stiffness Profile model

From LOOBAR outputs it was possible to obtain a standard-property grid at 12% moisture content to conform to structural standard. A local fiber orientation regular grid was extracted for each veneer, and then a linear interpolation of the measured raw data points corresponding to the centers of the ellipses over their entire surface (Figure 2c) was undertaken to obtain a regular grid with an X by Y resolution, as in (10). The fiber deviation area was clearly visible in the vicinity of knots, with a positive or negative deviation that was almost symmetrical around them, as widely described in (10).

Using the regular grid of fiber orientation measurement of each veneer, the calculation of a local elastic modulus was performed in two steps following the method developed in Viguier's study (6). First, the average density of the veneer was calculated. The mass of each veneer was weighed after drying at 9% of MC with an accuracy of 0.1 g. The influence of density on E_0, the theoretical elastic of modulus in the fiber orientation, was computed according to Pollet (11) who studied clear Douglas-fir wood specimens by differentiating between juvenile and mature wood). Only the mature wood equation from Pollet was used in this study because: sapwood does not contain juvenile wood, and moreover, the peeling operation leaves a core of wood at the pith with a diameter of 70mm, which certainly contains almost exclusively juvenile wood concerning heartwood (more details are available in 11).

The effect of the local fiber orientation, noted as $q(x, y)$, on the local modulus of elasticity in the longitudinal main direction of the veneer, denominated as$E_x(x, y)$, was taken into account using Hankinson's formula (Equation (1)) (13), with parameters according to Wood Hand Book data (14):

$$E_x(x, y) = E_0 \frac{k}{\sin^n(\theta(x,y)) + k \times cos^n(\theta(x,y))} \qquad \text{Equation (1)}$$

From $E_x(x, y)$, the averaged local modulus of elasticity on all veneer surface was calculated to give a criterion to estimate the global quality of the veneer, accordingly the Equation (2) has been built-up.

$$\overline{E_{veneer}} = \frac{\sum_{x=1}^{n_x} \sum_{y=1}^{n_y} E_x(x,y)}{n_x n_y} \qquad \text{Equation (2)}$$

The stiffness profile of each veneer, visible in Figure 2e, was obtained by averaging the modulus of elasticity values along the $\vec{y}$ direction, as calculated in Equation (3) where n_y is the number of pixels in $\vec{y}$ direction.

$$\overline{E_x}(x) = \frac{\sum_{y=1}^{n_y} E_x(x,y)}{n_y} \qquad \text{Equation (3)}$$

Coarsely, the general elevation of the profile is given by the density, which affects the E_0 value (red dashed line in Figure 2 (e)), and downward peaks are symptomatic of the presence of knots. These peaks are all the more important because knots are mostly aligned along the same *x* coordinate according to the fact that, in Douglas-fir, they come from the same crown branch, as shown by blue curve in the example of Figure 2 (e).

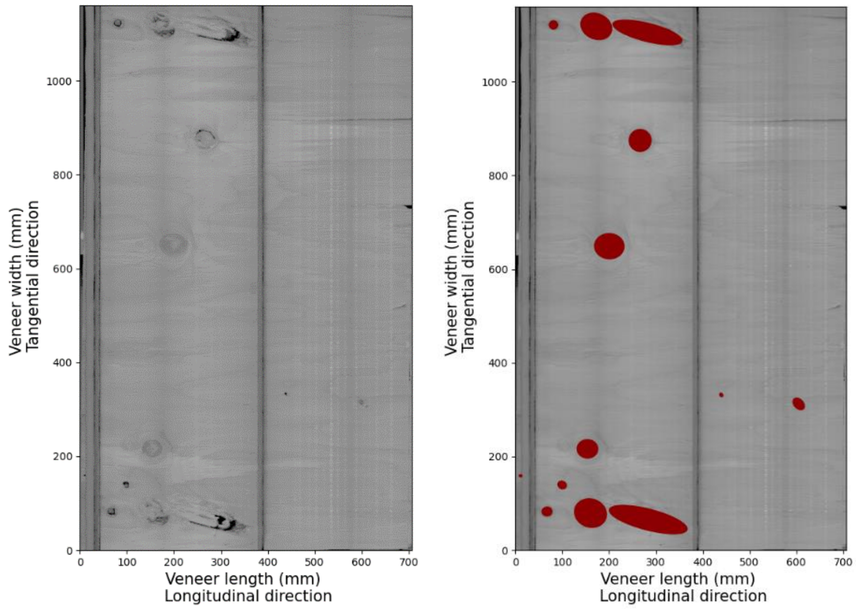
EXPERIMENTS

Veneer sorting and grading

Two distinct methods for grading veneers are compared in this section. The first method involves grading based on appearance criteria, while the second method utilizes average density and local fiber orientation for grading. The following provides a description of each sorting and grading process:

Grading based on appearance criteria: In this method, veneers are sorted and graded based on visual appearance criteria. These criteria typically include factors such as knot size, slots, resin pockets, and other visible defects. This approach relies on human judgment or automated systems, such as cameras, to detect and categorize the visible characteristics of the veneers. The grading is performed according to established industry standards, such as the EN 635-3 standard (1).

Cropped grayscale images (Figure 3 (a)) from the Loobar LOOBAR cameras were used to detect the knots of the 286 veneers. Each veneer was processed manually using ImageJ image processing and analysis software. Knots were identified by the grayscale nuance difference with clear wood and then approximated by ellipses (Figure 3 (b)).



(a) (b)

Figure 3. Veneer: (a) grayscale image from LOOBAR device, (b) manual knot detection on the same image using ImageJ software

Grading Based on Average Density and Local Fiber Orientation: In this method, veneers are graded based on average density and local fiber orientation measurements. The stiffness profile obtained from Equation (2) is used for sorting. In this study, a method is proposed, using the minimum stiffness profile value of each veneer as the sorting criterion. Veneer classes were thus established. Two classes were envisaged for: high-quality class A, and low-quality class B. Class A qualifies veneers whose elastic modulus profile minimum was superior to a given threshold over its entire length. Class B qualifies veneers which elastic modulus profile minimum was lower than the threshold.

RESULTS AND DISCUSSIONS

150 random panels from each class were modelled, in which 5 beams were digitally cut. Figure 4 shows example of Sapwood Class A beam.

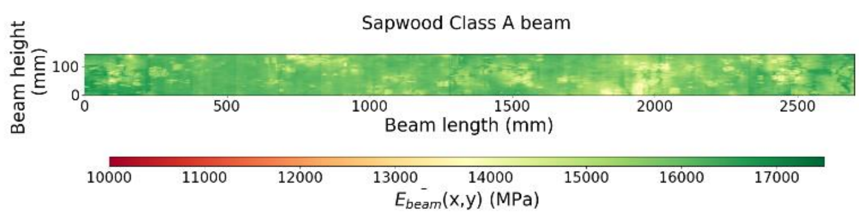
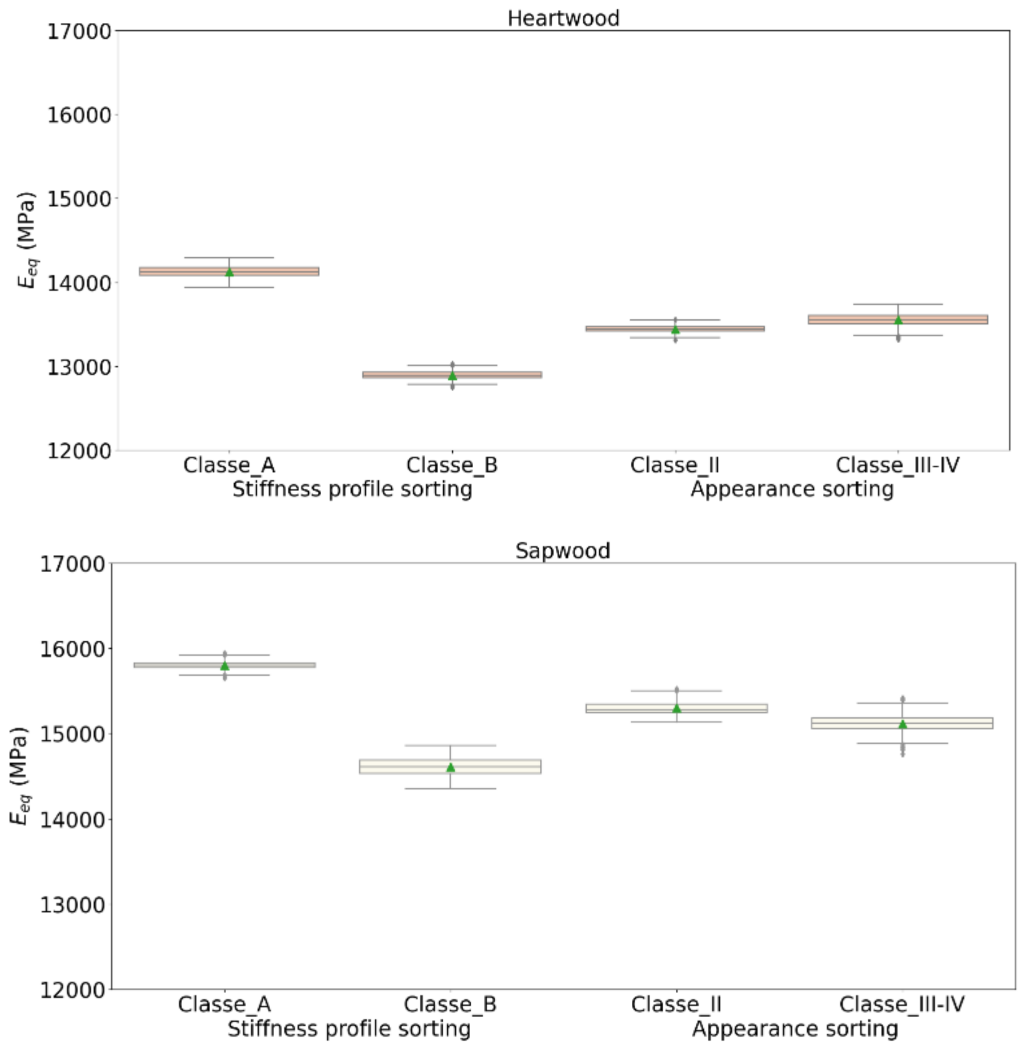


Figure 4. Example of Sapwood Class A beam

In the case if a class had fewer than 60 veneers, some were doubled, representatively of forest plots and logs which compose the batches. These beams were then tested by the analytical calculation model. The aim is therefore to be able to compare the performance of beams composed of veneers from classes. (E_{eq}) was calculated for each class. Figure 5 shows results for each class.



(a)

(b)

Figure 5. Sorting Method comparison on E_{eq} criteria (a) heartwood, (b) softwood**.**

In the context of profile sorting, it was observed that panel beams composed of Class A veneers exhibited higher E_{eq} results compared to Class B beams. This suggests that incorporating fiber orientation and density in the grading methodology proves to be more effective in discriminating between different quality levels than the conventional appearance-based sorting standards.

To ensure the reliability of the E_{eq} results, 150 control randoms panels were generated for each class. It appears that on the results presented, the maximum relative difference between samples presented and control samples (E_{eq}) has always been less than 0.2%.

For sapwood, it is noted that the beams from the Class A random panels, which is the top-graded class, have an (E_{eq}) that is 8.2% higher than the Class B random beams (15,805 MPa vs 14,610 MPa). The difference between appearance sorting Classes II and III-IV averages 1.2% (15,301 MPa vs 15,119 MPa). For heartwood, there is a 9.6% difference (14,126 MPa vs 12,894 MPa) between Class A and Class B beams. By comparison, the difference between appearance sorting classes II and III-IV is on average equivalent (13,442 MPa vs 13,555 MPa). It can therefore be concluded that sorting by stiffness profile is much more selective and dissociates nicely the product qualities from the local modulus.

By considering factors such as fiber orientation and density, the grading methodology provides a more comprehensive understanding of the structural qualities of the veneers. This allows for a more accurate assessment of the veneers' potential performance and behavior when incorporated into panel beams.

CONCLUSIONS

This research work introduces a novel apparatus called LOOBAR (Local Online Orientation Fiber AnalyzeR), designed in LaBoMaP (Arts et Métiers) to measure the local grain angle of veneers. The aim is to improve the accuracy of sorting veneers based on their mechanical properties. The study involved analyzing 286 veneers from French Douglas Fir, from which 150 virtual panels were created. Two different methods were employed for grading the veneers: visual grading using EN 635-3 criteria, and a method based on local grain angle and average density. The results clearly indicate that the latter method, which incorporates local fiber orientation and average density, is more effective in distinguishing veneers based on their presumed mechanical characteristics. This approach represents a significant advancement in veneer grading by providing an objective measurement of local properties, opening up a new field of research in this area.

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