WCTE 2018
2018 World Conference on Timber Engineering
August 20 - 23, 2018 | Seoul, Republic of Korea

TECHNICAL SOLUTIONS TO INCREASE COMPETITIVENESS OF CROSS-LAMINATED TIMBER FROM THE NORDIC COUNTRIES – AN OVERVIEW

Magnus Fredriksson[1], Mattias Brännström[2,3]

ABSTRACT: In order to increase the competitiveness of cross-laminated timber (CLT) produced in northern Europe, several methods are presented in this paper. One deals with increasing the strength and stiffness properties of CLT panels, something that has a potential to decrease material use. This is achieved by changing the alteration angle of transverse CLT panel layers to 45° instead of 90°. Two other methods focus on increasing the volume yield of CLT panel production, utilizing the natural taper of the log when edging flitches. One is a *trapeze edging* method, following the taper closely, while the other is a more conventional crosscutting and straight edging method. Both are based on live sawing of small diameter logs. The result is a yield increase of 10-17 percentage points, compared to more conventional cant sawing.

KEYWORDS: Cross-laminated timber, Efficiency, Production, Small diameter logs, Yield

1 INTRODUCTION

The forestry industry in northern Europe is characterized by slow growth forest and a high cost of labour. This means that to stay competitive, it is important to utilize the material in an efficient way, while keeping production volumes as high as possible and increasing value adding operations. Especially material efficiency is important since the raw material cost stands for a large part of the costs in a forestry value chain [1]. In addition, substantial efforts have already been made to reduce the labour-related costs per produced unit. In other words, increasing productivity [2, 3].

This paper gives an overview of alternative methods for producing cross-laminated timber (CLT) more efficiently in terms of material use, and discusses their possible impact on competitiveness of production in the countries of northern Europe.

CLT is an engineered wood product mainly used for construction purposes. In general, it consists of layers of sawn timber boards that are bonded together using glue or similar adhesives, and the layers are stacked, each consecutive layer being orthogonal to the previous. This increases both dimensional stability and load-bearing capacity compared to for instance timber frames, mainly since the effect of the orthotropicity of wood is reduced when the direction is alternated. The use of CLT has been heavily increased in many countries in the past decades [4]. However, its production requires a rather large amount of raw material. This means that to increase the competitiveness of CLT, especially in countries with long rotation cycles, it is important to use the raw material as efficiently as possible. In this case, small diameter logs are extra interesting since they are often underutilized, and are cheaper to procure than larger logs.

2 NOVEL PRODUCTION METHODS

A short overview of the investigated methods is given, including methods from the literature as well as methods still under development.

2.1 CONFIGURATION OF LAYERS

In Buck et al. [5] and Buck [6], an investigation was made where Norway spruce (*Picea abies* (L.) H. Karst.) boards where used to produce two types of CLT panels: one with the conventional configuration where alternating layers were rotated 90° to each other, and one where the transverse layers were rotated ±45° instead of 90°. In this way, the mechanical stresses were distributed in a direction that was closer to the fibre orientation for the transverse layers. The panels were tested for strength and stiffness using a four point bending test. The results showed an improvement in all tested properties, when comparing the ±45° solution to the 90° solution. Furthermore, the variation of properties was smaller, meaning a more predictable performance. A proposal for a possible industrial production process has also been made, aiming at a resource usage that is the same as for the 90° solution [7].

1 Magnus Fredriksson, Luleå University of Technology, 93187 Skellefteå, Sweden, magnus.1.fredriksson@ltu.se
2 Mattias Brännström, Renewinn AB, Bengtsgårdsvägen 32, 790 22 Sågmyra, Sweden, mattias@renewinn.eu
3 Setra Group AB, Gårdsvägen 18, 169 70 Solna, Sweden

2.2 TRAPEZE EDGING FOR INCREASED YIELD

In Fredriksson et al. [8], a method for producing CLT panels from small diameter logs is presented, where a larger volume yield is retained compared to more conventional production methods. The difference lies mainly in the sawing and edging of boards for the panels, where logs are live-sawn (through-and-through) and the resulting flitches are edged in a way that follows the natural taper of the log, Figure 1. This edging method is referred to as *trapeze edging*, and it was described by Grönlund [9] in 1987, albeit not aiming specifically at CLT.

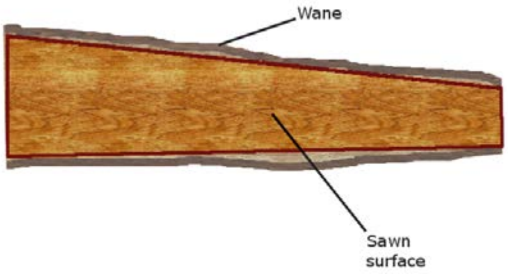

Figure 1: *Trapeze edging method for producing components for CLT panels out of sawn flitches. The thick red line indicates the shape of the sawn and edged component. Proportions have been exaggerated to illustrate the principle.*

Trapeze edging was found to increase material volume yield from small logs, compared to cant sawing and straight edging, by 17 percentage points (pp). However, the trapezoid components need to be handled in production and stacked in a way that takes care of the shape.

2.3 CROSSCUTTING AND STRAIGHT EDGING

Another possible method that is similar to the trapeze edging method is to crosscut live sawn flitches into pieces of certain lengths, and thereafter edge the resulting smaller flitches, Figure 2. In this way, the taper of the log is followed somewhat, with the added advantage that components are rectangular. A modular width system could also ensure that the variation of component dimensions is reduced compared to the trapeze edging case. This method is investigated in more detail in this paper.

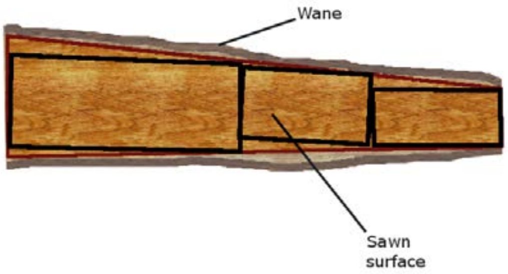

Figure 2: *Edging method with crosscutting and subsequent straight edging. The thick black line indicates the shape of the sawn and edged component. Proportions have been exaggerated to illustrate the principle.*

3 MATERIALS AND METHODS - CROSSCUTTING AND STRAIGHT EDGING

For studying the crosscutting and straight edging method, Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) logs from the Swedish Pine Stem Bank [10] as well as the European Spruce Stem Bank [11] were used. The stem bank trees, from well-documented sites at different locations in Europe, have been documented thoroughly regarding both tree properties and silvicultural treatments. They were bucked into logs that were scanned with a medical CT scanner (Siemens SOMATOM AR.T) to record internal properties such as knots. Knots in the stem banks are described by a parameterized model, which takes into account curvature of the knot and diameter in two log directions, tangential and longitudinal. Each knot is divided into a green part and a dead part. Details on the log and knot models are given by Grönlund et al. [10] and Nordmark [12]. This, together with outer shape data that can be easily obtained from CT images since the density difference between wood and air is substantial, results in realistic log models [12].

Logs with a top diameter of less than 140 mm were used for this study. The reason for this focus on small diameter logs was that logs below this cut-off are usually underutilized in sawmills. 281 logs fell within this diameter interval.

The logs were processed by means of computer simulations that were based on the log models of the stem banks. An overview of the process is presented in Figure 3, with its operations and material, both incoming, outgoing and intermediate products. The outgoing product is components that can be used for CLT production or other construction applications. More details on the production operations are given in subsequent paragraphs.

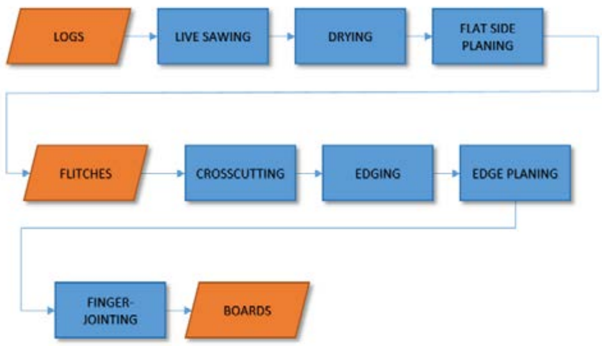

Figure 3: *Flow chart describing the studied process.*

The log models obtained from the stem banks were used for sawing simulation using the simulation software Saw2003, developed by Nordmark [12]. The input was log models from the stem banks. An example of a log model used in Saw2003 is shown in Figure 4, with outer shape and knots. Saw2003 has been used extensively in earlier research [12-16].

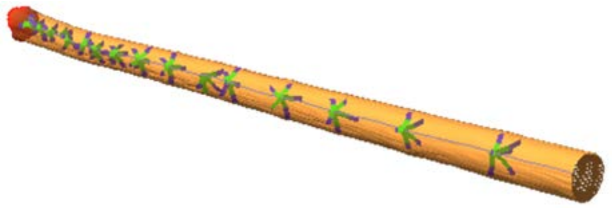

Figure 4: *Example of log model used in this study. The green colour corresponds to the green knot part, while the blue coloured tips of the knots correspond to the dead knot part.*

Saw2003 models a sawmill, that in this case employed live sawing with two different sawing patterns depending on the top diameter of each log, Table 1. The measurements in the table correspond to sawn, dried and planed dimensions. To account for drying and planing, the green target sizes were set to 25.2, 36.0 and 46.6 mm for the three respective nominal thicknesses of 20, 30 and 40 mm. This corresponds to a green dimension that is 6% larger than the dry dimension, and a planing depth of 4 mm.
The sawing simulation resulted in sawn flitches.

Table 1: *Sawing patterns used. Top diameters were rounded to the nearest millimetre, and the log was sawn in the corresponding sawing pattern. The numbers in the second column refer to the nominal thicknesses of the sawn flitches, from left to right. The centre flitch was sawn thicker than the other flitches.*

Top diameter interval (mm)	Sawing pattern (mm)
0-101	20-20-30-20-20
102-140	20-20-40-20-20

A profile description of the sawn flitches was exported in a format that describes the sawn outer surface at every 10 mm lengthwise. It was assumed that it would be possible to edge and trim boards based on the outer sawn surface alone, since it is usually smaller than the inner surface. Furthermore, knots on the sawn flitches were stored, recording knot position, size and shape.
The exported flitch data was then used to calculate crosscutting and edging into rectangular timber. Each virtual flitch was crosscut in the following way:

1) Using the knot data, zones where crosscuts were not allowed were determined. These zones were set to three times the lengthwise knot size, but knots under 6 mm were not considered. This was done to avoid knots near the finger-joints. Figure 5 shows the results of the zone allocation.
2) A lengthwise search of the flitch was made, setting the starting position at the butt (widest) end.
3) The maximum possible board width for a portion of the flitch corresponding to the minimum allowed board length (500 mm or 1.5 times the width, whichever was largest) from the starting position was calculated. For this a list of modular widths were used, the same list as in the subsequent edging.
4) The lengthwise search was continued to see how long this width could be maintained until the sawn surface was too narrow to accommodate the width.
5) If this position was in a zone where crosscuts were not allowed, a backwards search was made until a crosscut was allowed. This was set as the final position.
6) If the distance between the starting position of the search and the final position was larger than the minimum allowed length, a crosscut was made. If not, the width was reduced by one width module and the search was restarted at step 4 until a sufficiently long distance was found.
7) The starting position was updated to the final position of the current search.
8) Steps 3-7 was repeated until the full length of the flitch had been covered.

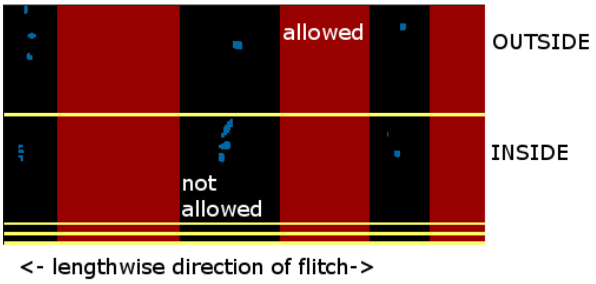

Figure 5: *Example of zones where crosscuts were allowed (darker red) or not allowed (black). Blue irregular shapes show the knots on each flitch side, the sides are delimited by the yellow horizontal lines that do not show the actual sawn profile, just delimiting the four sides. The two smaller sides are the left and right edges of the flitch. The uppermost large side is the outside, and the lowermost large side, second from the top overall, is the inside. The image has been cropped and it shows only a portion of a flitch to ease interpretation.*

Edging was done by using the crosscut flitch profiles, and adapting the angle of the board to a least square regression line of the lines describing the edges of the sawn surface. Then, a rectangle was centred on the regression line, and maximized in terms of surface area while keeping its borders within the sawn surface and increasing the width modularly. Three module widths were tested: 10, 15 and 20 mm. The reason for using width modules is usually to limit the number of widths in storage and production, and for this reason, a modular width system was chosen here as well. The minimum width was set to 1.5 times the flitch thickness, i.e. at 30, 45 or 60 mm depending on the thickness. So for instance for a 20 mm thick flitch and a 10 mm module width, the width modules were 30, 40, 50,… mm. Figure 6 shows an example result of edging.

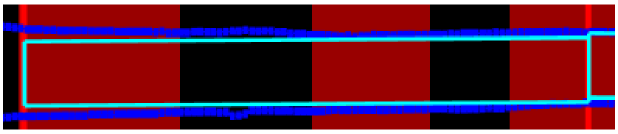

Figure 6: *Example of edging result. The bright red vertical lines correspond to crosscut decisions, the blue line represents the sawn outer surface seen from the outside of the flitch, and the cyan rectangle is the edged and trimmed product, i.e. a board. The darker red areas mean that crosscuts were allowed and the black areas that crosscuts were not allowed, in the same way as in Figure 5 and because of point number 1 in the algorithm. The image has been cropped and it shows only a portion of a flitch to ease interpretation.*

The crosscutting and edging algorithm resulted in a within-flitch variation of board width with the taper of the log. For a heavily tapered log, the sawn surface usually tapers off as well, towards the top end of the log. For flitches cut from this type of logs, board width was larger at the butt end of the flitch than at the top end, the principle being shown in Figure 2. For logs with a small taper, the difference to regular edging was small (only one board was produced, that was the same length as the log and flitch).

The total volume of sawn, dried, planed, crosscut, edged and finger-jointed pieces was calculated. To this end, the width was reduced by a factor of 1.06 and 4 mm to account for drying and planing, in the same way as the thickness had before. In the lengthwise direction, reductions were made at each crosscut to account for the kerf width of the crosscutting saw and the depth of the finger-joint. In this case, a 4 mm kerf width and a 15 mm deep finger-joint was used. The yield of the process was calculated as the total volume of sawn, dried, planed, crosscut, edged and finger-jointed pieces, divided by the total volume of green logs as measured by the log outer shape obtained from CT scanning.

Besides the three different module widths tested, one case where crosscuts inside knots were allowed was also tested. This was done to be able to make a fair comparison to a regular cant-sawing scenario, where full-length boards are produced with no crosscutting, i.e. no regard to knots. For this comparison, a 10 mm module width was used.

Two reference scenarios were used for comparison, using the same simulation tools and material as the studied cases. Reference scenario *cant sawing* (CS) was executed using two cant-sawing patterns for different log diameters. These produced two centre boards of dimensions 38×75 mm for logs with top diameter less than 130 mm, and 38×100 mm for all others, and sideboards with 19 mm thickness. These were sawn with the same shrinkage allowance and planed 4 mm as in the studied cases. Edging and trimming was done in a value-optimized way, favouring higher qualities over lower ones and using full-length straight edging.

Reference scenario *full length edging* (FLE) was based on live sawing in the same way as the studied cases. Edging was done using straight edging in 10 mm width modules and maximizing the volume of the edged and trimmed board.

4 RESULTS – CROSSCUTTING AND STRAIGHT EDGING

The process yield for the four scenarios (three different module widths and one with knots allowed) together with the two reference scenarios is presented in Table 2.

Table 2: *Volume yield for the tested scenarios. CS = cant sawing, FLE = full length edging of live sawn flitches. The volume yield was calculated as the total volume of sawn, dried, planed, crosscut, edged and finger-jointed pieces, divided by the total volume of green logs. “knots allowed” mean that crosscutting was made with no regard for knots, only the shape of the flitch.*

Scenario	10 mm	15 mm	20 mm	10 mm, knots allowed	CS (ref)	FLE (ref)
Yield (%)	36.2	35.7	34.4	40.7	31.2	31.3

In Figure 7, the yield has been calculated for the different module width scenarios together with the FLE reference scenario, for different top diameter intervals.

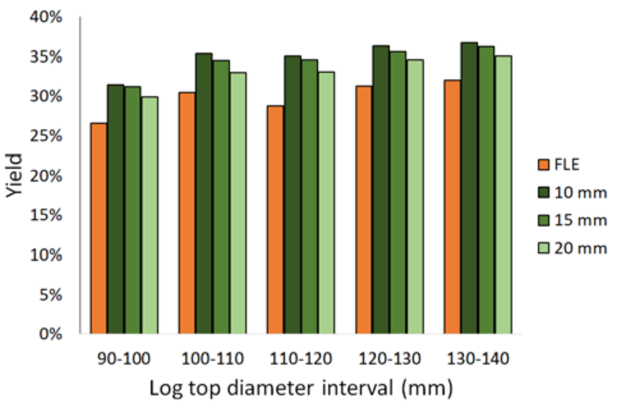

Figure 7: *Volume yield for different log top diameter intervals and production scenarios. FLE = full length edging of live sawn flitches. ‘10 mm’, ‘15 mm’ and ‘20 mm’ all refer to the crosscutting/straight edging method with different module widths.*

5 OUTLOOK AND DISCUSSION

The methods show potential for reducing raw material use and therefore costs. However, other factors need to be considered as well, such as ease of production, material handling, machinability etc.

The advantage of crosscutting and straight edging boards compared to trapeze edging is that rectangular pieces are produced, which can be finger-jointed into boards that are easier to handle in production than trapezoid pieces.

5.1 CONFIGURATION OF LAYERS

This method is promising in terms of increasing performance of Norway spruce CLT panels. With increased strength and stiffness for a ±45 panel using the same amount of material as a 90° panel, it is possible to change the panel dimensions so less material can be used for the same performance. This means reduced raw material usage and -costs. The strength-to-weight ratio is increased, meaning that material handling, installation

etc. can be simplified. It has also been shown that the method can be implemented in an industrial process.
One other potential advantage is that freedom in layer design is increased, with perhaps other angles being possible, to customize the product for various applications.

5.2 TRAPEZE EDGING FOR INCREASED YIELD

While using small diameter logs with a retained yield is attractive from a raw material cost point of view, especially in countries with slow growth, there are issues with using this type of logs. Juvenile wood creates trouble since it tends to be detrimental for important material characteristics [17–21]. In addition, an automated production system has to be able to handle components that are trapeze shaped, in varying angles. This requires scanning systems that can acquire the component shape, and control stacking to produce regularly shaped panels. It is possible in theory but impractical.

5.3 CROSSCUTTING AND STRAIGHT EDGING

Another option would be to crosscut the live sawn flitches and thereafter edge the crosscut pieces individually, something which creates rectangular components but still results in a relatively high yield since the natural taper of the log is followed to a certain degree. Components are also better defined in terms of width, especially with modular widths. This means easier handling in production regarding transportation, storage and the gluing and pressing process. The module width affects the yield since a smaller module width means more width modules, and therefore more options when optimizing edging. It appears as though the difference between 10 mm and 15 mm module width is around 0.5 pp, while the difference between 15 mm and 20 mm is around one pp, Table 2. The drawback with using smaller module widths is that the number of different component widths in production will increase, thus making material handling and logistics more complex. The trade-off between volume yield and material handling costs has not been addressed in this paper.
When allowing knots, the potential yield increase compared to the reference cases was about 10 pp. The effect of log top diameter on the yield difference between methods was quite small, probably since all logs were rather thin with the maximum top diameter at 140 mm. In general, the yield increased with the top diameter. The reason for this is that for thinner logs, it is more difficult to fit rectangular sawing patterns within the log circumference, even if live sawing is used. The absolute difference in yield between the different methods was almost the same regardless of the top diameter, so this means that the relative difference is larger for smaller top diameters, i.e. thinner logs.
The reason for applying the method to production of components for CLT is that this product is less sensitive for various widths than sawn commodity products. In addition, the value adding increases in comparison to planed boards. It is quite difficult to motivate a more complex edging method for a commodity product such as sawn and planed timber. Producing a rather refined product such as CLT from a raw material stock that is not very high in demand means that the value yield can be kept high, especially with methods that increase the volume yield. This has the potential to increase competitiveness of wood industries where rotation cycles are long and material costs therefore might be higher.
The study of this method was only aimed at improving yield, and has so far not considered implications on strength or other mechanical properties of the product. The use of thinner logs can potentially be detrimental to these properties, since thinner logs might contain a larger share of juvenile wood. Kliger et al. [19] reported decreased mechanical properties for boards sawn closer to the centre of the log than closer to the bark. This could be due to a higher amount of juvenile wood in the centre of the log. Similar results have been reported by Pearson et al. [20] and Ivković et al. [21]. This was another reason to study CLT, since CLT is not as sensitive as regular sawn timber to wood anisotropy and lower strength of individual pieces. Focusing on volume yield makes sense from a cost reduction perspective, since material costs represent a large majority of costs in the wood industry. For future work, it is of interest to follow up with mechanical testing of the final products.
As with most computer simulation, any predictions regarding the actual outcome of a certain scenario are difficult to make. In this study, different cases are compared, and it can be concluded that the crosscutting and straight edging method is better than the references in terms of overall yield. No predictions regarding the actual yield are made, merely that it can be improved by several percentage points.

6 CONCLUSIONS

It can be concluded that there are several interesting avenues open for new ways of producing cross-laminated timber. Among the more promising are novel production techniques where the volume yield and therefore profitability can be increased. Edging methods that adapt to the natural shape of the tree can increase yield for small diameter logs with 10-17 pp. If rules for knots near finger-joints are also added, the potential yield increase drops somewhat. There is however, a large potential yield increase associated with an edging method that takes the natural taper of the log into consideration. Furthermore, alternative layer configurations has proven to be a possible way of increasing mechanical properties of CLT with the same material use, or conversely reduce the material use and achieve the same properties.

ACKNOWLEDGEMENT

The work was financed by the European Commission through the Horizon 2020 programme, more specifically through the BERTIM (Building Energy Renovation through Timber prefabricated Modules) project (www.bertim.eu).

REFERENCES

[1] O. Broman, and M. Fredriksson. Wood material features and technical defects that affect yield in a finger joint production process. *Wood Mat. Sci. Eng.* 7:167-175, 2012.

[2] A. Falk. Cross-laminated timber: Driving forces and innovation. *Structures and Architecture: Concepts, Applications and Challenges* 511-518. CRC Press, 2013.

[3] A. Roos, M. Flinkman, A. Jäppinen, G. Lönner, and M. Warensjö. Production strategies in the Swedish softwood sawmilling industry. *Forest Policy Econ.* 3:189-197, 2001.

[4] M.F.L. Mallo, and O. Espinoza. Awareness, perceptions and willingness to adopt cross-laminated timber by the architecture community in the United States. *J. Clean. Prod.* 94:198-210, 2015.

[5] D. Buck, X. Wang, O. Hagman, and A. Gustafsson. Bending Properties of Cross Laminated Timber (CLT) with a 45° Alternating Layer Configuration. *Bioresources*., 11:4633-4644, 2016.

[6] D. Buck. Mechanical Performance of Cross-Laminated Timber Panels. Master's thesis, Luleå University of Technology, Sweden, 2016.

[7] D. Buck, and O. Hagman. Production and In-Plane Compression Mechanics of Alternatively Angled Layered Cross-Laminated Timber. *Bioresources.*, 13:4029-4045, 2018.

[8] M. Fredriksson, P. Bomark, O. Broman, and A. Grönlund. Using Small Diameter Logs for Cross Laminated Timber Production. *Bioresources*., 10:1477-1486, 2015.

[9] A. Grönlund. Utbyte och produktionsteknik vid trapetssågning jämfört med olika andra sågmetoder (Yield and production technology of trapeze sawing compared to various other sawing methods). Dissertation, Kungliga Tekniska Högskolan (Royal Institute of Technology), Stockholm, Sweden, 1987. In Swedish.

[10] A. Grönlund, L. Björklund, S. Grundberg and G. Berggren. Manual för furustambank (in Swedish). English title: Manual for pine stem bank. Technical Report 1995:19 Luleå University of Technology, Luleå, Sweden, 1995.

[11] G. Berggren, S. Grundberg, A. Grönlund and J. Oja. Improved spruce timber utilization (STUD). European shared cost research project within FAIR (DGXII/E2), contract no. FAIR-CT96-1915. Final report sub-task A 1.2, database and non-destructive "glass-log" measurements. Technical Report, AB Trätek and Luleå University of Technology, 2000.

[12] U. Nordmark. Value recovery and production control in the forestry wood chain using simulation technique. Dissertation, Luleå University of Technology, Sweden, 2005.

[13] C.G. Lundahl and A. Grönlund. Increased yield in sawmills by applying alternate rotation and lateral positioning. *Forest Prod. J*. 60:331-338, 2010.

[14] A. Berglund, O. Broman, A. Grönlund and M. Fredriksson. Improved log rotation using information from a computed tomography scanner. *Comput. Electron. Agr*. 90:152-158, 2013.

[15] M. Fredriksson. Optimizing sawing of boards for furniture production using CT scanning technique. *J. Wood Sci*. 61:474-480, 2015.

[16] S. Chiorescu and A. Grönlund. Validation of a CT-based simulator against a sawmill yield. *Forest Prod. J*. 50:69-76, 2000.

[17] P.R. Larson, D.E. Kretschmann, A. Clark III, and J.G. Isebrands. Formation and Properties of Juvenile Wood in Southern Pines. Forest Products Laboratory General Technical Report FPL-GTR-129. Madison, Wisconsin.

[18] F.C. Bao, Z.H. Jiang, X.M. Jiang, X.X. Lu, X.Q. Luo, and S.Y. Zhang. Differences in wood properties between juvenile wood and mature wood in 10 species grown in China. *Wood Sci. Tech.* 35:363-375, 2001.

[19] I.R. Kliger, M. Perstorper, and G. Johansson. Bending properties of Norway spruce timber. Comparison between fast-and slow-grown stands and influence of radial position of sawn timber. *Ann. For. Sci.* 55:349-358, 1998.

[20] R.G. Pearson, and R.C. Gilmore. Characterization of the strength of juvenile wood of loblolly pine (Pinus taeda L.). *Forest Prod. J.* 1:23-31, 1971.

[21] M. Ivković, W.J. Gapare, A. Abarquez, J. Ilic, M.B. Powell, and H.X. Wu. Prediction of wood stiffness, strength, and shrinkage in juvenile wood of radiata pine. *Wood Sci. Tech.* 43:237-257, 2009.