Using Small Diameter Logs for Cross-Laminated Timber Production

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Sawing small diameter logs results in lower yield compared to sawing large diameter logs. This is due to geometry; fitting rectangular blocks inside an approximately cylindrical shape is more difficult for small than for large diameters. If small diameter logs were sawn in a way that follows the outer shape, yield would increase. The present study considers whether this can be done by sawing flitches into trapeze shapes. These can be glued together into rectangular products. Cross laminated timber (CLT) products are suitable for this. The study was based on 4,860 softwood logs that where scanned, and the scanning data was used for sawing simulation. The log top diameters ranged from 92 to 434 mm. The volume yield of CLT production using trapeze edging was compared to cant sawing of boards. The trapeze edging and CLT production process improved yield compared to cant sawing by 17.4 percent units, for logs of a top diameter smaller than 185 mm. For all logs, the yield decreased using the trapeze edging method. To conclude, a trapeze edging method shows promise in terms of increasing volume yield for small diameter logs, if boards can be properly taken care of in a CLT production process.

Keywords: *Cross-laminated timber; Edging; Norway spruce; Sawing simulation; Sawmill; Scots pine; Yield*

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INTRODUCTION

Cross-laminated timber (CLT) is becoming increasingly common in wooden structures being used as pre-fabricated wall and floor elements. CLT products are normally made of several wooden layers, stacked on top of each other, glued together and arranged so that the wood fibres of each layer are perpendicular to those of the neighbouring layers. The layers themselves consist of boards that are edge-glued together. Usually, an odd number of layers are used. This results in a product with high dimensional stability and load bearing capabilities in more directions than regular sawn timber or glulam (Gagnon and Pirvu 2011).

In most cases, sawing small diameter logs results in lower volume yield than sawing large diameter logs (Pinto *et al.* 2005; Knapic *et al.* 2011). This is due to the geometry of logs; fitting rectangular blocks inside an approximately cylindrical shape, *i.e.* boards into logs is more difficult for small diameters of the cylinders than for large diameters. If logs could be sawn in a way that follows the outer shape of the log to a larger degree, yield could be increased, especially for small diameter logs. In this work small diameter logs are defined as logs with a top diameter of less than 185 mm. When processing logs of this size, the volume yield is often below 45% (Lowell and Green 2000; Lundahl 2009). All other logs were considered as “large” within this context.

The hypothesis of this study was that following the shape of the log when sawing can be done in the edging operations of a sawmill, where boards are sawn into trapeze shapes instead of rectangular blocks. These trapeze shapes can then be glued together to form a rectangular end product, in order to take care of the trapeze-shaped pieces in a proper way. In this case, a CLT product is suitable since it is normally made out of several edge glued wood pieces.

The objective of this study was to investigate how much yield can be improved by using an edging method called trapeze edging, which follows the natural taper of boards, compared to a normal straight edging method, for production of boards for CLT panels. This was tested both for logs of varying size, as well as for small diameter logs, through sawing simulation.

EXPERIMENTAL

Materials

The study was based on 4,860 logs: 1465 computed tomography (CT) scanned logs from the Swedish Stem Bank (SSB) (Grönlund *et al.* 1995; Berggren *et al.* 2000), and 3,395 logs that were scanned at a Swedish sawmill using a RemaLog optical 3D scanner (RemaSawco 2014). The wood species distribution was 48.3% Norway spruce (*Picea abies* (L.) H. Karst) and 51.7% Scots pine (*Pinus sylvestris* L.). The length, top diameter, and taper distributions of the logs are shown in Fig. 1.

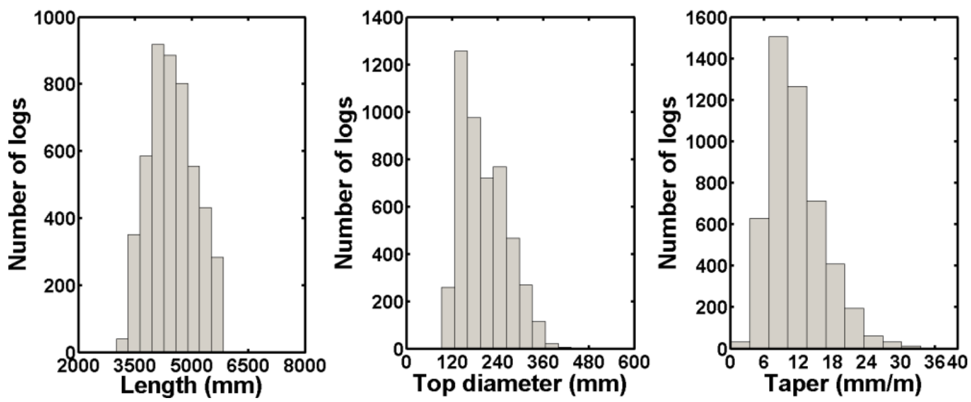

Fig. 1. Distributions of length, top diameter and taper for all logs used in this study, presented as histograms. Numbers on the horizontal axis correspond to the upper limit of intervals.

In general, sawn timber from spruce has a modulus of elasticity of around 8 to 15 GPa, a dry density of roughly 300 to 500 kg/m^3, and a bending strength of around 30 to 60 MPa (Kliger *et al.* 1998; Johansson and Kliger 2002; Hanhijärvi and Ranta-Maunus 2008; Raftery and Harte 2013). For pine, the material properties are rather similar, with a modulus of elasticity of around 8 to 12 GPa, a dry density of about 300 to 500 kg/m^3, and a bending strength of 30 to 45 MPa (Hanhijärvi and Ranta-Maunus 2008). These properties vary between specimens and depend on other factors than the wood species alone. For individual boards, the properties can be far smaller or greater than the intervals stated.

The outer shape of the SSB logs was obtained from CT scanning data. It was described at 10 mm-intervals in the lengthwise direction of the log, as a radius at each degree for all 360 degrees of the log cross section, measured from the pith to the log surface. For the logs scanned at the sawmill, the outer shape was described at 100 mm-intervals, and a cross section radius at every tenth degree. These outer shape descriptions were the basis for sawing simulations, and were also used to calculate the volume of each log.

Methods

Sawing simulation

Scanned logs, such as those of the Swedish Stem Bank, can be used for sawing simulation through the simulation software Saw2003, developed by Nordmark (2005). The input is log models, based on scanning of logs, either by a 3D optical scanner or a CT scanner. Saw2003 models a sawmill that employs cant sawing with two sawing machines, with curve sawing in the second saw. Saw2003 and its predecessors has been used extensively in earlier research (Chiorescu and Grönlund 1999; Nordmark 2005; Moberg and Nordmark 2006; Lundahl and Grönlund 2010). An example of a log model used in Saw2003 is shown in Fig. 2. When edging and trimming is performed in Saw2003, the results are virtual boards with information about dimensions, value, quality, and so on. If edging and trimming is not performed, then the results are shape profiles of un-edged board flitches.

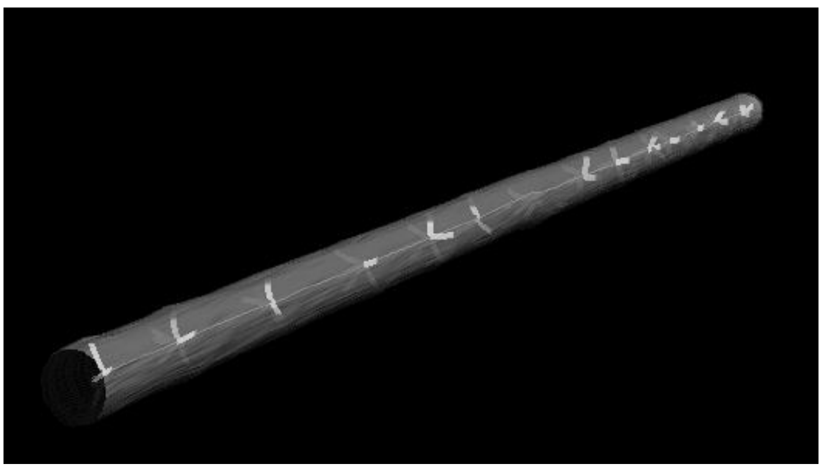

Fig. 2. Example of log model used in Saw2010. The outer shape, pith and knots of the log are visible.

Overview of the study

This study was made using four scenarios, which are described in Table 1.

Table 1. Overview of the Four Scenarios Investigated

		Logs	
		All	Top diameter <185 mm
Process	Cant sawing	Reference scenario 1	Reference scenario 2
	CLT	Scenario A	Scenario B

Two reference scenarios are based on cant sawing of logs, a common procedure in many sawmills. The two CLT product scenarios are based on trapeze edging and production of CLT panel layers. One reference and one CLT scenario had all logs as input data, while the two others had only logs with a top diameter of less than 185 mm as input data. This limit was set to separate between small diameter and large diameter logs, and correspond to the separation of the fourth and fifth sawing pattern presented in Table 2.

Reference scenarios

Two reference scenarios, 1 and 2, were tested. In reference scenario 1 all logs were used, and in reference scenario 2 logs of a top diameter of less than 185 mm were used. The number of logs in the latter group was 2,214. In these scenarios, all logs were sawn in Saw2003 using a cant sawing pattern, that was decided for each log depending on top diameter, as presented in Table 2. This represents the regular production procedure of many sawmills. Sideboards were edged, and all boards were trimmed to the Nordic Timber Grading Rules (Swedish Sawmill Managers Association 1997) grade B. Only wane was considered since internal defects of the logs were not used. After edging and trimming the dried and planed dimensions of all boards were calculated. This was used to calculate the yield of the two scenarios, as total produced dried and planed board volume divided by total log volume.

Table 2. Sawing Patterns Used for the Reference Scenarios

Lower limit (mm)	Upper limit (mm)	No. of centerboards	Width (mm)	Thickness (mm)
0	129	2	75	38
130	149	2	100	38
150	169	2	100	50
170	184	2	125	50
185	194	2	125	63
195	209	2	150	50
210	219	2	150	63
220	229	2	175	50
230	249	2	175	63
250	264	2	200	63
265	284	2	200	75
285	304	2	225	75
305	324	4	200	50
325	344	4	225	50
345	384	4	200	63
385	-	4	200	75

Lower limit = smallest top diameter allowed for logs within this sawing pattern. Upper limit = largest top diameter allowed for sawing pattern. Width = width of centerboards. Thickness = thickness of centerboards. Sideboards were edged to various sizes depending on value.

Alternative scenarios

In two alternative scenarios, called A and B, sawn timber resulting from sawing simulation was further processed into a CLT product. The product used as target in this study was a wall element used for pre-fabrication of houses. It was made from three timber layers, 16000 × 2450 mm, with a thickness of 20, 30, or 40 mm, stacked on each other and glued together. No wane was allowed in the pieces used for CLT production. Two types of layers were used in the CLT products, L-layers and C-layers. The L-layers had lengthwise oriented boards, *i.e*. 16 m long finger-jointed boards glued together to 2.45 m width, while the C-layers had crosswise oriented boards, *i.e*. 2.45 m long boards glued together to 16 m width. The largest difference between the reference scenarios and the alternative scenarios was that a trapeze edging method was employed rather than a straight edging method for board flitches.

Trapeze edging was done by following the natural taper of the sawn surface of a flitch, which is exemplified in Fig. 3. The direction of the two edges was decided in three steps for each side, left and right. First, a linear regression line was fitted to the edge of the sawn surface. Secondly, the regression line was moved vertically until it tangented a single point of the wane. Thirdly, the line was tilted counterclockwise or clockwise, until it encompassed another point of the wane. The tilting direction resulting in the largest total volume of the edged board was chosen. Consequently, the shape of the trapeze edged piece depends on the shape of the sawn flitch. The details of the method are described in Grönlund (1987).

The shape profile description of each sideboard flitch resulting from sawing simulation was exported to a data file, and further processing of these flitches was modelled in a program specifically written for this purpose. The following operations were done on the profile data: Each sideboard flitch was crosscut at a position 250 cm from the butt end. This corresponded to the CLT panel width plus a 5 cm margin for crosscutting errors, end cracks and so on. The result of this was a butt end flitch and a top end flitch. The 250 cm long butt end flitch was edged using trapeze edging, while the top end flitch was straight edged, maximizing the volume of the obtained board. The straight edging was done in 10 mm modules, starting at 30 mm. A minimum allowed length was set at 1.5 times the board width, or 200 mm, whichever was smallest. Apart from this the length was set to the one giving the highest possible yield.

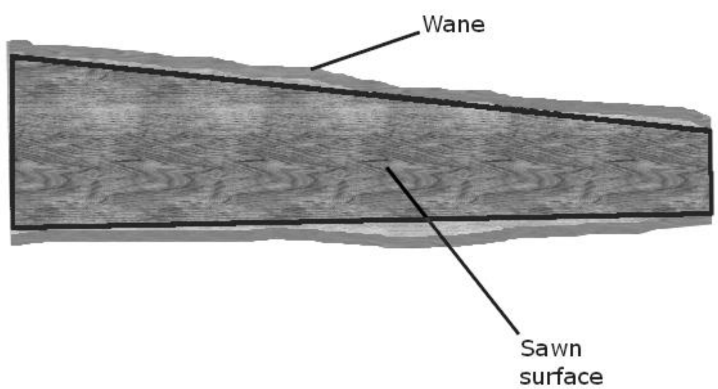

Fig. 3. Principal illustration of trapezoid edging of a flitch. Note that the proportions are exaggerated to illustrate the principle. The dark line shows the trapezoid board, and the faded areas that include the wane are removed during edging.

The trapeze edged pieces were used for C-layers, while the straight edged pieces were finger-jointed, crosscut at 16 m length, and stacked to be used as L-layers. To form C-layers, trapeze edged boards was stacked together edge to edge until the target length of 16 m was acquired.

Stacking the trapezoidal pieces

In order to make layers of the trapeze edged pieces without the sheet wheeling out of control, stacking was done using a method where each trapeze edged piece could be placed in either direction (Fig. 4). The direction chosen was the one resulting in the smallest angle of the upper edge of the CLT layer, *i.e*. keeping the sheet as straight as possible at all times by alternating how the next piece is placed. All pieces were pushed as far as possible to one side to avoid aggregating errors. The edge unevenness was less than 2 mm when using this strategy.

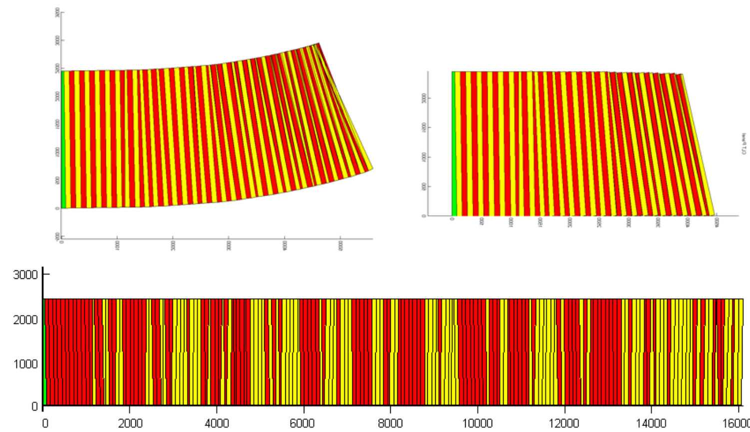

Fig. 4. Illustration showing layup of the trapeze edged pieces into a CLT layer. Red pieces have been flipped on their long axis. The top two graphs show failed layups where every other piece was flipped, the left one shows the layup without pushing every piece towards the bottom edge. The bottom graph shows a successful layup where the pieces were placed as to minimize the resulting angle of the rightmost edge.

CLT scenario A

This CLT scenario, Fig. 5, was based on the same sawing patterns as in the reference scenarios, *i.e.* cant sawing patterns. In this scenario all 4,860 logs were used. The center boards resulting from sawing simulation were trimmed and planed to be used as regular sawn timber. The side boards were sawn at 24 mm green thickness which corresponded to a nominal, planed, thickness of 20 mm. These were then trapeze edged to be used in CLT panels. Only 20 mm thick panel layers were considered in this scenario.

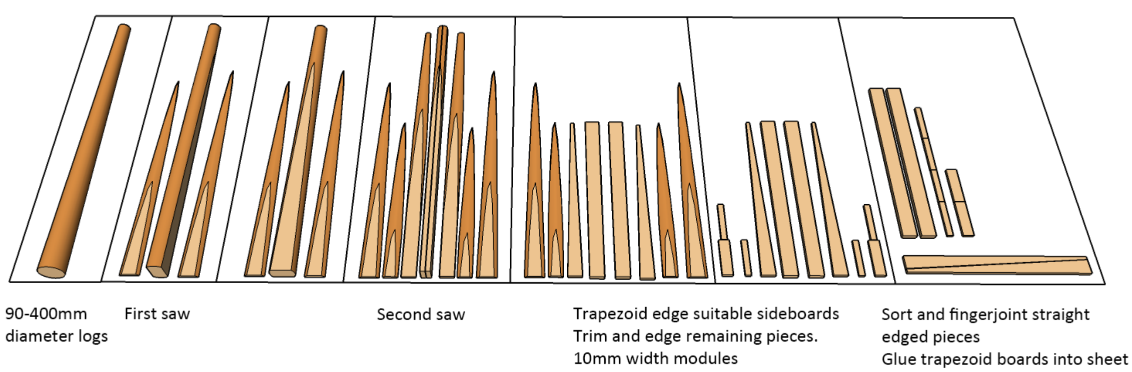

Fig. 5. Illustration showing CLT scenario A.

CLT scenario B

In this scenario, described in Fig. 6, all 2,214 logs with a top diameter of less than 185 mm were live sawn, using four different sawing patterns defined in Table 3. The boards were sawn at 24, 35, or 46.5 mm green thickness, which corresponded to a nominal, planed, thickness of 20, 30, and 40 mm, respectively. All produced flitches were used for CLT production, and the panel thicknesses were 20, 30, and 40 mm.

Table 3. Sawing Patterns Used for the CLT Scenarios

Sawing pattern	1	2	3	4
Nominal, planed board thicknesses (mm)	20 20 30 20 20	20 20 40 20 20	20 30 30 30 20	20 40 40 40 20
Log top diameter interval (mm)	90-100	101-143	144-159	160-185

For both CLT scenario A and B, the yield was calculated as the total volume of CLT panel layers divided by the total volume of the logs. The sources of material losses incurred from log to CLT panel layer were: Sawing, drying, planing, edging, crosscutting, and finger-jointing.

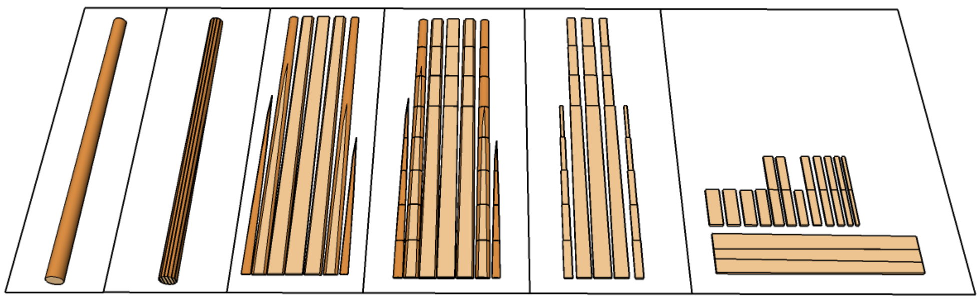

Fig. 6. Illustration showing CLT scenario B.

RESULTS AND DISCUSSION

The yields corresponding to the different scenarios are presented in Table 4. As can be seen, in Scenario A the yield is decreased by 0.9 percent units compared to the reference scenario. For scenario B, there is an increase of 17.4 percent units compared to the reference.

Table 4. Yield of Investigated Scenarios

Log top diameter (mm)	Scenario	Yield calculated from	Yield (%)
90-400	Reference 1	Planed boards to log volume	43.7
	CLT A	CLT panels to log volume	42.8
90-185	Reference 2	Planed boards to log volume	35.8
	CLT B	CLT panels to log volume	53.2

The results presented in this paper show that compared to cant sawing and straight edging, live sawing combined with trapeze edging can increase the yield for logs with a top diameter of less than 185 mm. When using logs with a top diameter of up to 400 mm, and using the sideboards in a cant sawing pattern for trapeze edging and CLT production, the yield is decreased compared to cant sawing and straight edging of regular sawn timber. The reason for this is probably that larger logs mean higher yield using cant sawing patterns and straight edging compared to small diameter logs, so the positive effects of the edging method are mitigated by the CLT production operations that decrease yield, compared to just sawing, drying, and planing regular boards.

It can also be speculated that a trapeze edging method would result in lower usage of glue than using straight, fingerjointed boards, both due to the absence of fingerjoints and due to the larger average width of the trapeze edged pieces compared to straight edged pieces. This would result in both lower material costs in production as well as a more environmentally friendly product.

This study was made on a rather specific production scenario, and the results should be interpreted in the light of this fact. However, the large amount of logs used and the large volume yield increase for small diameter logs suggest that there is a positive potential in using a method such as this, to process small diameter logs in a more material efficient way.

To realize a trapeze edging method in practice would require separate handling of small diameter logs in a sawmill, or a sawmill specialized in sawing small diameter logs. Edging machinery would need to be adapted to facilitate trapeze edging. Also needed is a specialized production line for making CLT out of trapeze edged pieces, with equipment for scanning and turning the pieces in the correct way to keep layers as straight as possible. Otherwise, since CLT layers for wall panels usually are rather long, there is a risk of curved panels. This study did not take into account that different amounts of panels or different panel thicknesses will be needed in a real production process, which will affect the yield and choice of sawing patterns etc. The edging algorithm is possible to implement using a numerically controlled edging machine, since the mathematical and programmatic methods used are rather straightforward. The method would depend on purpose built hardware in terms of sawing machines though. There will be increased handling and surveillance operations associated with the proposed method compared to traditional CLT production, which affect profitability. This was not accounted for in this study. Also, an increased volume yield would mean less material such as sawdust and wood chips available for energy or pulp production. Even though this is outside the scope of this article, it is probably more profitable to use the wood material for a relatively high valued CLT product than for a relatively low valued product such as sawdust. It is necessary to take this into account when assessing the profitability of the method however. Overall, the results are an indication that the potential for a trapeze edging method is very high when it comes to utilizing small diameter logs in a material efficient way.

CONCLUSIONS

1. A live sawing and trapeze edging method for CLT panel production from small diameter logs increases yield compared to cant sawing and straight edging of regular sawn timber, from 35.8 % to 53.2 %.

2. Using a similar method on large diameter logs, but using the sideboards of a cant sawing pattern instead, the yield is decreased from 43.7% to 42.8% compared to production of regular sawn timber.

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