EXTERNAL LOG SCANNING FOR OPTIMIZING PRIMARY BREAKDOWN OF TROPICAL HARDWOOD SPECIES

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ABSTRACT

The sawing of tropical hardwood species is a big challenge for sawmills in developing countries. In order to investigate sawing strategies and volume recovery of tropical hardwood species, a log shape database was created using a portable 3D laser scanner. The data were collected in Mozambique, where twelve Jambirre (*Millettia stuhlmannii* Taub.) and five Umbila (*Pterocarpus angolensis* DC) logs were scanned. The logs were selected among the most commercialized species and the crook was the main selection parameter. In addition, straight logs were incorporated as reference. A saw simulation Matlab algorithm that combines skew and rotation was developed. The results show that point cloud data from the 3D scanner provide detailed models of the external log geometry and accurately describe the log shapes and volumes. Preliminary results from breakdown simulation revealed that the through-and-through sawing pattern yields more than the cant saw pattern and that the increase in yield was almost the same for both species.

Keywords: sawing, log breakdown, tropical species, simulation, 3D scanner

INTRODUCTION

Mozambican sawmills produce large amounts of waste in their conversion processes. Examples of factors that affect the yield are high irregularity of the log shape, ad hoc decisions made prior to sawing, differences in mechanical and physical properties of the logs (sapwood is considered to be waste due to its low durability) and artefacts in the sawing process. Currently, the saw process is labour-intense and time-consuming; and the log positioning and definition of saw pattern depends on the sawyer's skills (Shenga *at al*. 2013).

The recovery of yield and value of logs have being studied using simulation techniques (Dogan *et al*. 1997; Maness and Donald 1994; Gibson and Pulapaka 1999; Nordmark 2005; Shu-Yin and Que-Ju 2005), but similar studies for tropical hardwood species are difficult to find and may not have been published. The known yield values are based on field work interviews. For instance, the yield of different tropical hardwood species varies from 35% (Jambirre) Bunster (2012) to 40% (all species) (Egas *et al*. 2013). In comparison, the yields of Brazilian hardwoods species are 45% - 55% (Iwakari 1990) and in general, 48%, for hardwood (Blackwell and Walker 2006). Thus, to increase the yield and the added value, sawing strategies for tropical hardwood species must be investigated. The vision is to use saw simulations to identify strategies for good log positioning and sawing pattern selection. To create log models based on log shape and a database for simulations, a 3D laser scanner was chosen in a previous study (Shenga *at al*. 2014). This method was chosen due to its practical advantages (no need for controlled, horizontal transport and/or rotation of logs during scanning, lightweight and easy setup) over other common techniques for log shape description (such as 1-D and 3-D optical scanners and X-ray scanners).

The purpose of this study was to create a database of two tropical hardwood species for investigation of saw strategies using simulations. To assess the accuracy of the models, each log top diameter, described as point clouds with XYZ coordinates, was compared with diameters obtained from manual measurements. In this study, preliminary breakdown simulation results were also evaluated.

MATERIALS AND METHODS

To obtain the log outer shape features for the construction of the database, 10 Jambirre (*Millettia stuhlmannii* Taub.) and 5 Umbila (*Pterocarpus angolensis* D. C.) logs were used. The log samples were selected from the most commercially exploited species in Mozambique, where Jambirre is classified as the most crooked species because of its highly irregular shape. Five logs of the straighter and more regularly shaped Umbila species were incorporated as reference logs. The Jambirre logs were scanned without bark whereas the Umbila logs were scanned with bark. Prior to sawing, the logs were measured and graded by sawmill employees according to the rules used in the Mozambican wood industry (Sitoe and Bila 2008). The log shapes were obtained using a 3D phase-shift laser scanner, FARO Focus 3D S-120 (USA) and the data were collected at the Kwekwe sawmill in the province of Cabo Delgado in Mozambique.

Log scanning

The logs were placed about 1 meter above the ground on a wood stand, see Figure 1. To obtain the full shape description of the log, the scans were taken at 5 different positions and heights around the log. The different positions and heights were: (1) the highest position – to scan the upper side of the log; (2 & 3) lower positions – to scan the butt and top end of the log and the lower side of the log; and (4 & 5) middle positions – to scan log ends, the middle and lower side of the log. Checkerboards were placed around the log and on the log stand as reference points to facilitate the automatic reconstruction of the 3D models. The range of each scan was limited to avoid scanning around 360º and to reduce the scanning time. Each scan took 6 minutes and a total of 1 hour was required to scan one log, including the loading and unloading of the log on the stand.

Figure 1: Scanning setup showing the log, stand, reference checkerboards and scan positioning.

Reconstruction of 3D models

The five scans of each log were loaded in SCENE, FARO built in software, for registration, and the scans were merged together with the aid of the checkerboard reference spots. Point cloud data of the surrounding background and the stand were removed manually. The log data were exported in ASCII file format. A cloud Compare software was used to remove unwanted data, to align the log in the XYZ coordinate system and to crop the top and butt ends of each log. The final log outer shape model is described in XYZ coordinates.

Determination of top diameter

The first and the last slices of the model were selected and, using the XY coordinates system, the values of X_{max} and X_{min} were determined (see details of slicing and slice bounding in Shenga *et al*. 2014). The difference between the two values represents the diameter, but due to the shape irregularities more measurements were taken. Diameter values were taken in the x-axis as shown in Figure 2. After each measurement the slice was rotated 15º; overall, the slice was rotated 12 times and the correspondent diameters were recorded. The diameter of each slice (first and last) was determined as the average of the 12 measurements, and the smallest diameter was selected as the top diameter of the log.

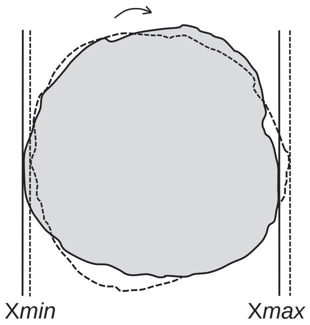
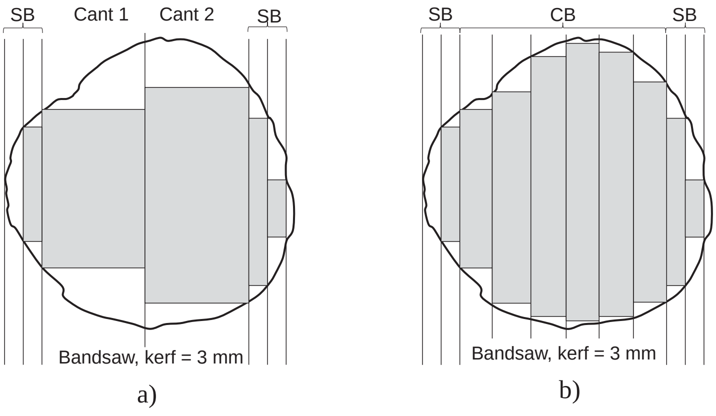


Figure 1: Determination of top diameter of each log. The mean diameter was calculated as the average of 12 measurements, and the smallest diameter was identified.

Definition of sawing simulation parameters

Saw Patterns



a) b)

Figure 3: The most common sawing patterns used to saw tropical hardwood species in Mozambique. a) Cant sawing (CS) and b) Through-and-through sawing (TT).

The cant saw and through-and-through patterns were tested in the simulation study. These sawing patterns are generally used in Mozambique with a simple sawmill setup; a bandsaw or a circular saw with headrigs.

The sawing patterns are shown in Figure 3. Cant sawing (CS) is commonly used to process lumber for export and the main products are cants or planks. In general, the sideboards are considered to be waste because they consist mostly of sapwood. Through-and-through sawing (TT) is used to process lumber for the domestic market, the main products being centreboards. As in CS the sideboards are counted as yield only if they are free of sapwood. Sawing patterns and board thickness for the two strategies are shown in Table 1.

Saw Class

The log sawing class interval was determined using the top diameter of the log as reference. A square was fitted on the top diameter with the minimum diameter as its diagonal. The side of the square represents the cant or plank width. The diameter interval of each sawing class was set to 40 mm, and two cants were taken out on each cant width. The saw class diameter distribution is shown in Table 1.

Table 2: Saw class diameter intervals together with cant and through-and-through sawing patterns showing thickness of sideboards and centreboards

	Diameter (mm)		Board thickness	
Saw class N^o.	Min	Max	Cant Sawing (CS)	Through-and-Through sawing (TT)
1	0	249	25 25 50 50 25 25	25 25 25 25 25 25 25 25
2	250	289	25 25 75 75 25 25	25 25 25 50 50 25 25 25
3	290	329	25 25 100 100 25 25	25 25 50 50 50 50 25 25
4	330	369	30 30 100 100 30 30	30 30 50 50 50 50 30 30
5	370	409	30 50 100 100 50 30	25 50 50 50 50 50 50 30
6	410	449	30 75 100 100 75 30	25 50 50 75 75 50 50 25
7	450	489	50 75 100 100 75 50	25 75 75 75 75 75 75 25

Log Positioning

The simulation algorithm positions the log before sawing taking into consideration skew and rotation. This combination is studied by taking the skew as base, *i.e.* for each skew position the log is sawn along all rotation positions. Figure 4 shows rotation and skew positions. The skew angles were set to -1^o to 1^o at intervals of 0.5^o; and the rotation angles were set from 0^o to 180^o at intervals of 2^o. This process is repeated until all the positions or orientations have been carried out and the sharp-edged volume of sideboards and centreboards is summarized and compared.

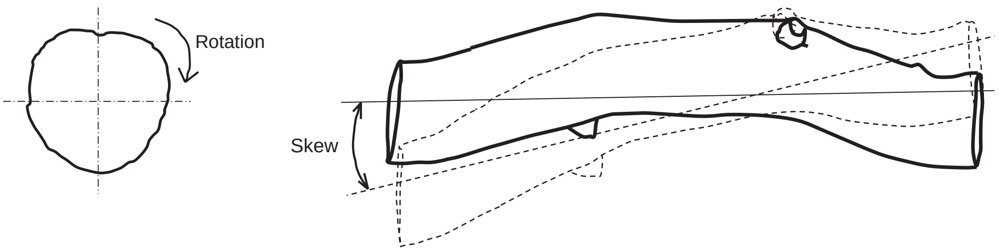


Figure 4: Illustration of rotation and skew positioning of a log.

Calculation of board volume

For cutting patterns CS and TT a maximum rectangle with a width of at least 5 mm and a floating length greater than 20 cm was fitted on each sawn board see Figure 5. The volume from CS cutting was calculated as:

$$V_{CS} = \sum (V_{SB} + V_{cant})$$

and the volume from TT cutting as:

$$V_{TT} = \sum (V_{SB} + V_{CB})$$

where:

$CB, SB, Cant$ = Centreboard, sideboard and cant, see Figure 24.

$V_{SB} = A_{rectSB} \cdot Thick_{SB}$ = Volume of sideboard;

$V_{cant} = A_{rectCant} \cdot Thick_{Cant}$ = Volume of Cant;

$V_{CB} = A_{rectCant} \cdot Width_{CB}$ = Volume of centreboard;

A_{rect} = Area of maximum rectangle fitted on the board or plank;

The volumes of sharp edged boards were summarized for each position (skew and rotation) and the maximum volume of the log was recorded. All volumes were then compared and final results of the simulation gave the maximum volume and associated skew and rotation position.

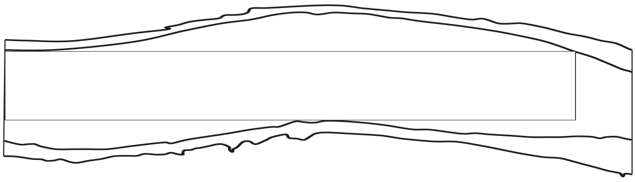


Figure 5: Flat view of sawn board and the fit of a rectangle representing the sawn edge board.

RESULTS AND DISCUSSION

Examples of reconstructed logs are shown in Figure 6. External log features are visible, such as the location of butt and top end, taper, and crook. In addition, surface mantle features are also visible; for instance bark on the Umbila log (Log ID 15) and debranched knots (Jambirre - Log ID 1). The log files and data also include RGB colour information, which was not used in this study.

Log ID 6 Log ID 15 Log ID 1

Figure 6: Example of reconstructed logs.

The accuracy of the reconstructed logs was assessed by comparing measurements given by the 3D models with manual diameter measurements taken in the field. Figure 7 shows the identity line and the correlation between the measured and modelled log diameters. Values below the identity line show that the model overestimates the diameter while the values above the line show that the model underestimates the diameters. In general, the modelled diameters are overestimates but the Jambirre (lower left values) show smaller overestimations. On average, the overestimation is 4% for Jambirre and 7% for Umbila. The difference may be due to the fact that the measurement positions were not the same. The measurements were taken a few centimetres away from the position of manual measurement because the models were cropped. The reason for cropping the log length data was to favour the alignment of the model in the XYZ coordinate system. In addition, the cross sections of the top and butt were not flat surfaces. The greater difference, in the case of Umbila can be explained by the bark thickness, since the manual measurements were made under bark.

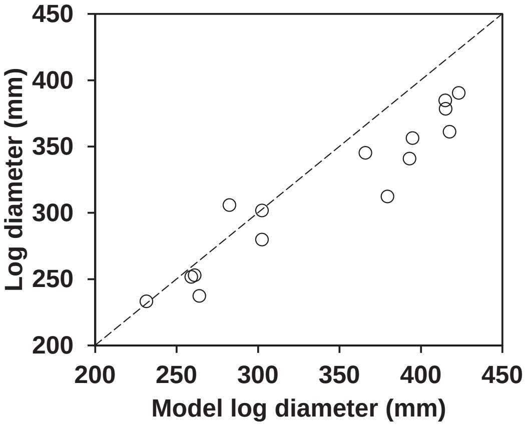


Figure 7: Agreement between log model top diameters and diameters measured manually at sawmill. The identity line is included for reference.

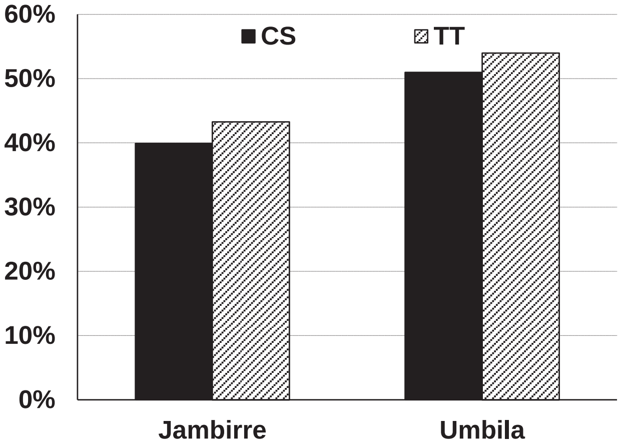


Figure 8: Percentage yield from CS and TT sawing of the two species.

Figure 8 shows preliminary simulation results. The figure shows that the yield using cant sawing (CS) was 39.9% for Jambirre and 51.0% for Umbila; and 43.3% and 54.0% respectively using through-and-through (TT). These results agree with literature, which report yields of around 35% for Jambirre (Bunster 2012) and 40% for all species (Egas *et al*. 2013). Since inner features such sapwood content, knots, rot and etc., were not considered in the algorithm, we believe that the simulated yield may be too high. However, the results can be seen as an indication that the yield increases when through-and-through sawing is used instead of cant sawing.

Figure 9 shows the maximum simulated sawn volume yields for each log and sawing pattern grouped according to species. In all cases, the CS sawing pattern shows a lower volume yield than the TT sawing pattern. The magnitude of the difference in yield between the two sawing strategies varies between logs and species. The difference is between 1.0 and 5.6 percentage points for the Jambirre batch and between 1.9 and 4.5 percentage points for Umbila. The large variation in yield of the Jambirre log group can be explained by characteristics such as crookedness, irregular outer shape and somewhat smaller log diameters. This difference in yield between species suggests that the species should be separated before sawing and that logs should be priced according to species and grade.

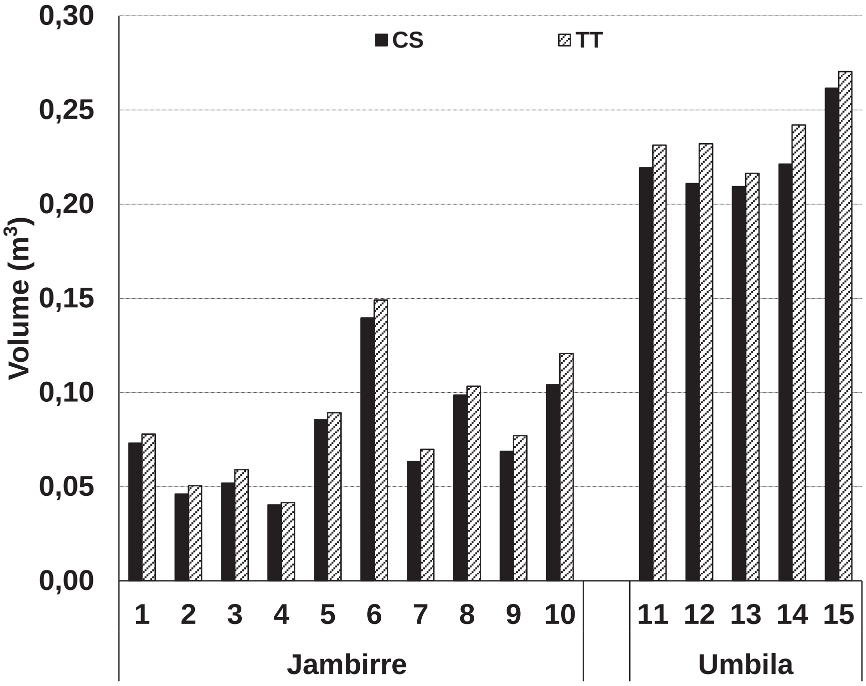


Figure 9: Simulated maximum yield for each log from CS and TT sawing patterns for the two species.

CONCLUSIONS

Models of 15 logs were successfully constructed. The results show that the point cloud data from the 3D laser scanner provides detailed external log geometry that can be used as base for sawing simulation studies. Preliminary results from breakdown simulations revealed that the through-and-through sawing pattern gives greater yield than cant sawing and that the increase in yield is of similar magnitude for both log groups. The logs (Jambirre) with high level of crook and irregular outer shape had a low yield and a large variation in maximum yield compared with the Umbila log group.

REFERENCES

1. Shenga P, Cristóvão L, Broman O (2013) A review of Mozambican wood exploitation - Map of the processing chain. Proceedings of the 21st Wood Machining Seminar, 4-7 August, Tsukuba, Japan, 293-301.
2. Dogan CA, McClain TF, Wicklund SA (1997) Simulation modelling and analysis of a hardwood sawmill. Simulation Practice and Theory 5(5), 387-403
3. Maness TC, Donald WS (1994). The effect of log rotation on value recovery in chip and saw sawmills. Wood and fiber Science 26(4) 546-555

4. Gibson D R, Pulapaka H (1999) An algorithm for log rotation in sawmills. Wood and Fiber Science, 31(2), 192-199
5. Nordmark U (2005). Value recovery and production control in bucking, log sorting, and log breakdown. Forest Products Journal 55, 73-77.
6. Shu-Yin, Z, Que-Ju, T (2005) Modelling lumber recovery in relation to selected tree characteristics in jack pine using sawing simulator Optitek. Annals of Forest Science 62(3), 219-228
7. Bunster J (2012) Management plan model for forest concessions under a simple license (Report), Traforest Lda. Pemba, Mozambique. (in Portuguese)
8. Egas AF, Uetimane EJ, Nhamirre JV, Sitoe EC (2013) Assessment of harvested volume and illegal logging in Mozambican natural forest. http://www.illegal-logging.info/sites/default/files/FAEF_Mozambique_Report.pdf. Accessed 04 October 2014
9. Iwakiri S (1990) Yield and breakdown methods of 20 hardwood species from Amazonas, Brazil. Acta Amazonica 20, 271-281.
10. Blackwell PB, Walker J C (2006) Primary Wood Processing: Principles and Practice. In: Sawmilling (ed.) J.C. Walker, Springer, Dordrecht, Netherlands, 203-250.
11. Shenga PA, Bomark P, Broman O, Hagman O (2014). 3D Phase-shift Laser Scanning of Log Shape. BioResources 9(4) 7593-7605
12. Sitoe A, Bila A (2008) Manual for the preparation and implementation of the management plan of the forest concession. DNTF, Ministry of Agriculture, Maputo, Mozambique (in Portuguese).