DOCTORAL THESIS

Sawing Strategies for Tropical Hardwood Species

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Wood Science and Engineering

LULEÅ UNIVERSITY OF TECHNOLOGY

Doctoral Thesis

Sawing Strategies for Tropical Hardwood Species

Simulation Studies Based on Industrial Conditions in Mozambique

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In memory of my father

Abstract

The harvesting of tropical hardwood species in Mozambique is much greater than the natural regrowth in the forest and the stock is decreasing drastically. It is therefore important to improve the material recovery when the wood is refined (*i.e.* in sawing and further refinement to products such as joinery, furniture etc.) to reduce the waste and to re-utilize efficiently the by-products and increase their added value. The wood-processing industry is an important means to boost the industries in the rural areas and also to generate income for the local communities by creating jobs and business opportunities.

The majority of the logs that could be used for sawmilling in Mozambique are exported as roundwood due to the inability of wood-processing companies to meet the product standards set for export and to generate profit. The inability of the local sawmills to generate profit also fosters illegal logging because of the higher price of roundwood for export, and this contributes to an increase in the number of unlicensed individuals in harvesting. This threatens law enforcement and thus the degradation of the local wood industry. An alternative, to increase the profit and empower the local community, could be to export more refined wood products such as sawn timber, parquet, and veneer instead of roundwood.

The objective of this work was to investigate alternative strategies for sawing tropical hardwood species that could increase the profitability of the Mozambique wood industry in general and of the sawmills in particular. The subject was approached using a database of virtual logs together with a sawing simulator. The thesis considers two main areas: (1) creating the log database with the corresponding algorithms for sawing simulation, and (2) investigations of alternative sawing strategies.

The first task was to build the database of surface-scanned logs and develop the algorithm for the saw simulation. The results are a database of 15 log models describing the log's outer shape containing 10 Jambirre

(*Millettia stuhlmannii* Taub.) and 5 Umbila (*Pterocarpus angolensis* DC.), and the algorithm for the sawing simulation. The algorithm uses "brute force", *i.e.* it determines the volume yields of sawn timber from combinations of all the settings of the log-positioning parameters (offset, skew and rotation) and selects the maximum volume yield. The simulation, using three sawing patterns (cant-sawing, through-and-through sawing and square-sawing) combined with two positioning parameters (offset and rotation), showed that the choice of sawing pattern has a great impact on the volume yield and that square-sawing gave the higher yield than cant-sawing and through-and-through sawing.

The second focus was on alternative sawing strategies; bearing in mind that the highest volume yield is achieved with computerized production systems and that these resources are not yet available in Mozambique. Hence, the objective was to find the positioning methods and parameters that improve the volume yield and that can be set manually. The result have shown that the rotation has the greatest effect followed by offset and skew, and that the volume yield can decrease by between 7.7% and 12.5% from that obtained with the optimal positioning when the logs are manually positioned with a knowledge of the optimal log position. In a horns-down and log bucking study, it was shown that horns-down results in systematic lower yield than optimal positioning. Nevertheless, the results emphasize that horns-down methodology could be of interest in practice if no scanning of logs is available. Bucking of logs to half-length at the sawmill prior sawing showed to be one good way to increase the volume yield, especially for the more crooked logs tested.

It is concluded that there is an unexploited value potential in the wood chain which can be reached using alternative positioning and modern measurement techniques and that the grading of wood will facilitate and improve the sawing process.

Keywords: sawing strategies, tropical hardwood species, simulation, volume yield, log grading, Umbila, Jambirre.

Preface

The work within this thesis has been performed at Division of Wood Science and Engineering at Luleå University of Technology in Skellefteå. The project was funded by the Swedish International Development Agency (SIDA) through the Technology Processing of Natural Resources for Sustainable Development programme. The financial support is acknowledged and deeply appreciated.

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Many thanks to all staff of Luleå University of Technology in Skellefteå, for the help and friendship I have received. Special thanks to Peter Bomark who travelled to Mozambique and helped me with the scanning and with the simulation code, and to Magnus Fredriksson who provided the last part of the simulation code.

Most especially to my parents, to my brothers and sisters; thanks for your moral and economic support.

Last but not least, to you Rosa and to our son Nathan.

"I'm coming home
I'm coming home
Tell the world I'm coming home
Let the rain wash away all the pain of yesterday..."

Thank you for your support and forgive me for not being present in these five years.

Skellefteå, December 2, 2016

Pedro Shenga

List of publications

This thesis is based on the following publications:

Paper I

Ah Shenga, P., Cristóvão, L., & Broman, O. (2013). A Review of Mozambican Wood Exploitation: Map of the Processing Chain. In: *Proceedings of the 21st International Wood Machining Seminar*, Nobuaki Hattori (Ed.), *August 4th - 7th, Tsukuba International Congress Center, Japan.* (pp. 293-301)

Paper II

Ah Shenga, P., Bomark, P., Broman, O., & Hagman, O. (2014). 3D Phase-Shift Laser Scanning of Log Shape. *BioResources*, *9*(4), 7593-7605.

Paper III

Ah Shenga, P., Bomark, P., Broman, O., & Sandberg, D. (2015). Simulation of Tropical Hardwood Processing: Sawing Methods, Log Positioning, and Outer Shape. *BioResources*, *10*(4), 7640-7652.

Paper IV

Ah Shenga, P., Bomark, P., Broman, O., & Sandberg, D. (2016). The Effect of Log Position Accuracy on the Volume Yield in Sawmilling of Tropical Hardwood. *BioResources*, *11*(4), 9560-9571.

Paper V

Ah Shenga, P., Bomark, P., Broman, O., & Sandberg, D. (2016). Log Sawing Positioning Optimization and Log Bucking of Tropical Hardwood Species to Increase the Volume Yield. *(Accepted for publication in Wood Material and Science Engineering)*

The author's contribution to the appended publications

In Paper I, Ah Shenga had the main responsibility for data collection and writing. Guidance and feedback was provided by the co-authors.

In Paper II, Ah Shenga had the main responsibility in data analysis and writing. The data collection was performed together with Bomark. Guidance and feedback was provided by the co-authors.

In Paper III, Ah Shenga had the main responsibility to perform the simulations, analyze the data and writing. Bomark helped in data collection and to develop the algorithm for the sawing simulation. Guidance and feedback was provided by the co-authors.

In Paper IV, Ah Shenga had the main responsibility to perform the simulations, analyze the data and writing. Bomark helped to develop the algorithm for sawing simulation. Guidance and feedback was provided by the co-authors.

In Paper V, Ah Shenga had the main responsibility to perform the simulations, analyze the data and writing. Bomark helped to develop the algorithm for sawing simulation and writing. Guidance and feedback was provided by the co-authors.

Other related publications not included in the thesis

Fredriksson, M., Broman, O., Persson, F., Axelsson, A., & Ah Shenga, P. (2014). Rotational Position of Curved Saw Logs and Warp of the Sawn Timber. *Wood Material Science and Engineering, 9*(1), 31-39.
doi: 10.1080/17480272.2013.853691

Ah Shenga, P., Bomark, P., & Broman, O. (2015). Simulated Breakdown of Two Tropical Hardwood Species. *Pro Ligno, 11*(4), 450-456.

Ah Shenga, P., Bomark, P., & Broman, O. (2015). External Log Scanning for Optimizing Primary Breakdown of Tropical Hardwood Species. In: *Poster proceedings of the 22nd International Wood Machining Seminar*, Roger Hernández and Claudia Cáceres (Eds.), *June 14th - 17th, Quebec City, Canada.*, (pp. 65-72).

Contents

Part I

Chapter 1

Introduction

The forest is one of the major source of livelihood for the majority of Mozambicans, but its management is in general not sustainable, and this endangers its existence due to the uncontrolled and illegal harvesting of timber and also because it is used for the domestic production of charcoal and firewood. Around 62% of the population of Mozambique live in rural areas (Anon., 2016) and most of them use charcoal and firewood as the main energy source for cooking. The uncontrolled logging endangers not only the ecosystem and the fauna but also the wood industry based on forest resources.

Mozambique has about 118 species (Fath, 2002) and of these only 52 species have well documented physical and mechanical properties (Bunster, 2006). Today, around 10 species are commercially exploited (Fath, 2002). The most commercially exploited species vary according to the demand of the international market, but three species, Umbila (*Pterocarpus angolensis* DC.), Jambirre or Panga-panga (*Millettia stuhlmannii* Taub.) and Chanfuta (*Afzelia quanzensis* Welw.), are always in the group of the most exploited species and this increases the risk that their regrowth is hampered. The species most sought after for export are also those that are most used on the domestic market. The demand for tropical hardwood species is greater than the natural regrowth in the Mozambique forests, and the stock is decreasing drastically. It is therefore important to find alternative species for industrial use, to decrease the pressure on the most harvested and naturally grown species, and it is also important to improve the material recovery when the wood is refined (*i.e.* in sawing and further refinement to products such as joinery, furniture etc.).

The use of alternative species or lesser-known species can play an important role in reducing the high rate of deforestation. The common wisdom transmitted since early days is that the locally most used species provide better mechanical properties, and this may hamper the introduction of new species to replace those being most used. Studies made to investigate and to document the lesser-known species in Mozambique have reported that many of these species have properties similar to those of the most commonly exploited species and can be used as a replacement (Bunster, 2006; Ali et al., 2008; Uetimane et al., 2008; Lhate et al., 2010; Cristovao et al., 2011). Efforts should however be made to publish these findings to the community, to the sawmill industry, and to the wood exploiters.

To reduce the deforestation and the illegal logging, the government passed new legislation in 2015 for the use of the Mozambique forest. Some of the measures were to prohibit the harvesting of ironwood (*Swartzia madagascariensis* Desv.) over a five-year period to prevent its endangerment and to stop issuing new forest licenses for logging for a period of two years starting from 2016. Other measures such as increasing the amount of checkpoints and resources to control the harvesting process have also been adopted.

The wood sector contribution is around 4.8% of the Gross Domestic Product (GDP), where 3.3% is roundwood, 1.1% is sawn timber and the remainder as other products such as charcoal and firewood (OEC, 2014). Most of the logs that could be used for sawmilling in Mozambique are exported, mainly to China. China is currently the only viable market for Mozambique wood (roundwood as well as sawn timber) due to the inability of companies in Mozambique to meet the product standards set for export to *e.g.* the Western markets (Ekman et al., 2013). The log prices in China are also relative high compared to the Mozambique market, which complicates the domestic refinement. The inabilities of the local sawmills to generate profit also tends to promote illegal logging because of the higher price of roundwood for export, and this contributes to an increase in the number of unlicensed individuals in harvesting. This threatens law enforcement and thus a degradation of the local wood industry. The wood processing industry is an important factor which can boost the industries in the rural areas and also generate income for the local communities by creating jobs and business opportunities. An alternative way to increase the profits and empower the local community could be to export more refined wood products such as sawn timber, parquet, and veneer to the EU markets instead of roundwood to China.

The wood industry is mostly located close to the main cities (*e.g.* Pemba, Nampula, Quelimane, Beira and Maputo) and this increases the transportation costs because the forests are far from the the cities. Another factor that increases the costs is the handling of heavy and large diameter logs instead of sawn timber. The wood processing industry uses simple machinery that generates large volumes of waste material. The volume losses are also caused by a lack of knowledge of wood properties, sawing strategies and the commercial value of different species. Maybe the most important factor for losses in Mozambique sawmills are the shape of the sawlogs, often having multiple crook which complicates how each log should be sawn to get high yield (see logs studied in Appendix II). This contributes to the under-utilization and also to the indiscriminate harvesting of the forest resource in Mozambique.

The sawmill industry is an early and very important link in the Mozambique forest products value chain. To reverse the current trend of undeveloped processing and the high-volume export of unrefined logs, sawmills must increase their profits by producing products that fulfil the requirements of the international market, and through a sustainable forest management to acquire *e.g.* the Forest Stewardship Council (FSC) certification in order to access the EU market and to be able to deal directly with these markets. To reach that goal the Mozambique sawmill industry must invest in equipment and education to improve the sawing process, and also to utilize efficiently the by-products from the sawing process. As a part of this overall goal for the Mozambique sawmill industry, the work described in this thesis has been focused on a specific area of the sawmill process, namely the optimization of the sawing process to increase the volume yield of sawn timber.

1.1 Aim and objective

The aim of the work has been to increase knowledge of sawing tropical hardwood species, and to improve the preconditions for the Mozambique sawmill industry to develop and increase its competitiveness.

The objective was to develop methods to increase the volume yield of sawn timber, based on industrial conditions of Mozambique.

1.2 Research questions

The thesis presents some issues relating to the way in which the combination of log positioning and sawing patterns can increase the volume yield of sawn timber in Mozambique sawmills. The guiding question was:

Is it possible to increase the volume yield of tropical hardwood species by combining the sawing pattern and log positioning parameters and, if possible, how should it be done?

The objective was to identify, present and analyse a number of parameters that affect the volume yield, and following questions were posed:

- What are the common practices used in Mozambique sawmills, which species are frequently used, and how is the wood sector in Mozambique organized?
- What methods can be used in practice to measure the log shape in Mozambique sawmills in order to create log models that could be used to investigate different sawing strategies?
- With respect to the conditions in Mozambique sawmill industry, how should sawing patterns and log-positioning parameters be evaluated?
- Which positioning parameter have the strongest effects on the volume yield of sawn timber and how the choice of sawing pattern influence the yield?
- How does bucking influence the crook of the logs and does bucking increase the volume yield of sawn timber?

1.3 Limitations

The studies presented here were based on simulations using a limited set of virtual logs (scanned real logs), comprising only their external features. No industrial measurements were performed for validation. The only properties of the virtual logs and of the sawn timber from simulation studies were their geometry. Only two species were used. Other species may differ in shape, which may lead to different conclusions.

1.4 Presentation of appended papers

This section gives a short summary of the appended papers. The links between the papers are shown in Figure 1.1.

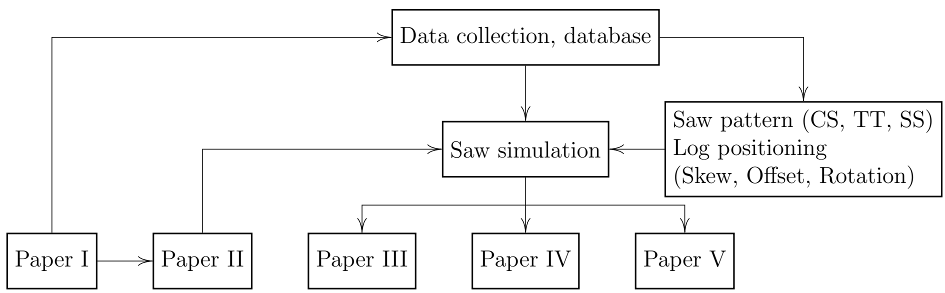


Figure 1.1: The relationship between the work presented in the different papers. For Paper III three sawing patterns (CS, TT and SS) and two log positionings (skew, rotation) were used, while for Papers IV and V two sawing patterns (CS and TT) and three log positionings (skew, offset and rotation) were studied. CS – cant-sawing, TT – through-and-through sawing and SS – square-sawing

Paper I provided the main input for the further studies, and the results were a good help in choosing the sawmill in which to perform the data collection for further studies. In Paper II, a method for data collection was chosen taking into account the findings from Paper I. In Paper III, the data collection was performed and a database was built, the algorithm for simulation of the sawing was developed and a preliminary simulation was performed. In Paper IV, the effect of deviations on volume yield of sawn timber was investigated, and in Paper V, the effect of bucking the logs into two and positioning the log according to the main crook were evaluated.

Paper I: Is a survey to identify the production chain of sawmills in Mozambique and the species that are commonly used. This information was used to identify two species that could represent the majority of logs used for industrial production in Mozambique. The two species were chosen taking into account the most common log features, crookedness and straightness, *i.e.* one species had to be one of the most straight and the other one of the most crooked. During the survey information was also collected regarding the amounts and species in the country as well as their variability, sawing patterns and log positioning practices, grading system and log pricing. The survey was carried out by interviews and site visits in three provinces chosen because of their importance as forest resources.

Paper II: The objective of this study was to choose the method for data collection. From findings in the first study, a 3D-laser scanner was selected. This camera uses the phase-shift principle for measurement. Two logs, Birch (*Betula pendula* Roth.) and Scots pine (*Pinus sylvestris* L.), were used to validate the method. In addition, computer tomography (CT) scanning was used to measure the same logs to validate the 3D-laser scanner measurements. The accuracy of this method was determined by comparing the cross-section areas from 3D-scan data with the corresponding cross section from the CT data. The result of this study shows that the method developed was appropriate for further studies within this project, and that was also a method on a technological level that can be used onsite at sawmills in Mozambique.

Paper III: A database of 15 logs, Jambirre (*Millettia stuhlmannii* Taub.) and Umbila (*Pterocarpus angolensis* DC.), was built up using the 3D-laser scanner, and a saw simulation algorithm was developed in Matlab software. In addition, the variation in volume yield of sawn timber from the logs was investigated using the simulation algorithm. Three sawing patterns (cant-sawing, through-and-through saw and square-sawing) and two positioning parameters (skew and rotation) were used in the study. The simulation showed a good potential for increasing the volume yield of sawn timber, but the study also led to new ideas about how to further increase the volume yield by a refined positioning. This was studied further in Papers IV and V.

Paper IV: Alternative solutions for log positioning that combine data from the saw-simulation algorithm and from common practices at Mozambique sawmills were investigated. The objective was to evaluate the effects of the error positioning and of the crook on volume yield. The idea was to evaluate, using the mark that shows the optimal position given by the saw simulation, how much a sawyer deviates from the optimal position when positioning the log manually. The effect of crook on volume yield was also evaluated by grading the logs on the basis of crook. The results show that rotation is the parameter that most affects the volume yield followed by offset and rotation. The volume yield can decrease by between 7.7% and 12.5% compared with optimal positioning parameters when the log is manually positioned.

Paper V: The objective of this study was to investigate alternative ways of positioning the logs prior sawing. The optimal position method was compared with a traditional horns-down method often used in practice. The importance of log length for sawing yield was also investigated by simply bucking the tested logs into half-length and thereby reduce the crookedness of each log. In comparison with optimal position, sawing according to horns-down, the volume yield decreased by between 5 and 10-percentage points. This stresses the need of having full information of the outer shape of logs (measured with some scanning technique) prior sawing.

Chapter 2

Background

2.1 The forest industry in Mozambique

2.1.1 Forest and forestry

Mozambique has approximately 26.9 million hectares of productive forest for industrial logging, corresponding to 67% of the total forest area (Marzoli, 2008). The commercial species with a high volume are Mopane (*Colophospermum mopane*), Umbila (*Pterocarpus angolensis* DC.), Jambirre or Panga-panga (*Millettia stuhlmannii* Taub.) and Chanfuta (*Afzelia quanzensis* Welw.).

The wood exploitation is performed under government rules, and the exploiters are divided in two groups: the simple license exploiters and the concessions. A simple license is issued only for Mozambicans as individuals or as groups and 500 cubic meters of roundwood are allowed to be harvested annually (today the simple license exploiters are obliged to provide an annual management plan), while a concessions is issued for any Mozambican or foreign individual or companies, and can be exploited for up to 50 years (renewable). A major requirement is that the concession must own a sawmill, and the volume of roundwood to harvest is defined through the management plan that has to be approved yearly by the provincial forest entities.

The forestry law also defines specifications for log harvesting and for logging; for example, the minimum diameter (at breast height) for harvesting varies from 20 cm to 50 cm depending on the log species. In addition, to control the harvesting, the logs are graded as: "Precious", first, second, third, and fourth grade. The Precious grade represents 4% of the total annual logging volume, the first grade 21%, the second grade 44%, the third grade 14% and the fourth grade 17% (Marzoli, 2008). The Precious grade is, of course, the most expensive, and can be exported as roundwood as second, third and fourth grades. The first grade is the most sought after species and their export is allowed only after processing. The other grades (second, third and fourth grades) are used domestically, mostly in the countryside, for the construction of small houses, bridges, canoes, etc. Some concessions have started using some of these species in their sawmill production.

Another example of legal specification is the roundwood processing. The degree of processing is specified by law (Anon., 2007), but sawmills perform only the primary breakdown, which results in un-edged cants or planks with a relative low added value.

2.1.2 The forest products industry

After independence from the colonial regime in 1975, the sawmill industry began to decline due to the lack of skilled labour and the limited market, because sawmills owners and their employees fled the country, and the connection with the international market deteriorated. The situation worsened with the civil war that lasted 16 years (1976-1992). It completely destroyed the sawmill industry because the raw material was not being transported to the sawmills and because the power supply, main roads and railways were disrupted. After the peace agreements in 1992, the sawmill industry started to be revitalized and new forest legislation has been passed and implemented according to the market needs.

With the increase in demand for tropical species on the Chinese market, the export of roundwood also increased, and as a result in 2007, the government introduced rules for wood processing to increase the added value and also to control the deforestation and regulate the logging by grading the roundwood into species, based on the demand. The Chinese market demands roundwood and offers competitive prices for roundwood compared to the sawn timber. As consequence, the sawmill industry has been marginalized due to the prices offered for the roundwood and their inability to generate profit on the domestic market and to fulfil the requirements of the European market regarding forest management, quality of sawn timber and so on. In 2015, the government reinforced the export rules to decrease the deforestation and also to increase added value.

Most of sawmills has reconditioned equipment used before independence, and the majority of sawmill operators are self-taught from the experience of older operators. Education in wood processing is only provided in professional training centres (mostly for carpenters). There are forestry courses at the higher education level, but they are mostly dedicated to forest management.

In 2008, under the SIDA-TechPro program, the Eduardo Mondlane University (UEM) together with the Department of Forest Products at the Swedish University of Agricultural Sciences (SLU) in Uppsala and the Division of Wood Science and Engineering at Luleå University of Technology (LTU) in Skelleftå, started training Mozambicans in the field of wood technology. As a result, four PhD-programs were concluded in four different areas related to wood:

- Ernesto Uetimane Junior (2010). Anatomy, drying behaviour and mechanical properties of lesser used wood species from Mozambique. (http://pub.epsilon.slu.se/2356/)

- Alexandre Charifo Ali (2011). Physical-mechanical properties and natural durability of lesser used wood species from Mozambique. (http://pub.epsilon.slu.se/8079/)

- Inácio Arnaldo Lhate (2011). Chemical composition and machinability of selected species from Mozambique. (http://pub.epsilon.slu.se/8207/)

- Luís Cristóvão (2013). Machining properties of wood: Tool wear, cutting force and tensioning of blades. (http://pure.ltu.se/portal/en/publications/machining-properties-of-wood(c98ad54d-9908-4da2-b762-0c0aaad0c240).html)

In 2013, a Master's degree course in wood technology was started at UEM in collaboration with the two universities.

2.1.3 Production chain

Wood trading in Mozambique has special characteristics: the sale is made as roundwood and the buyers choose where to process for further refinements. A schematic representation of the trade and the production chain is shown in Figure 2.1.

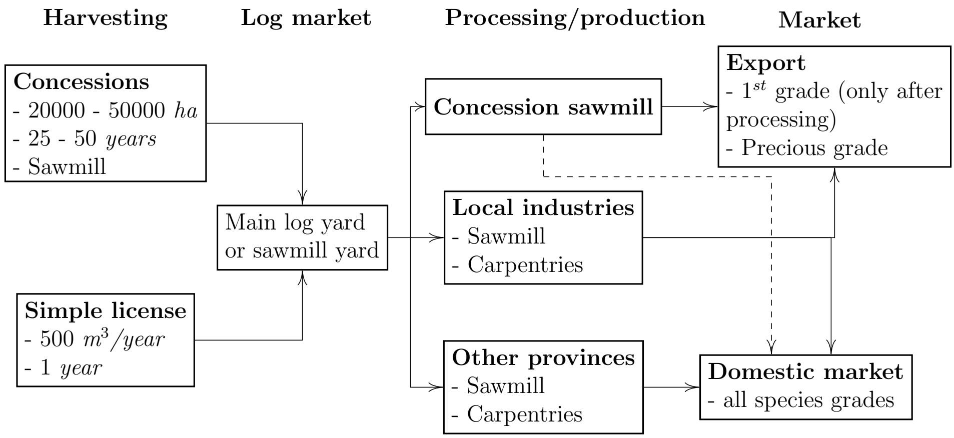


Figure 2.1: Schematic representation of value chain from forest to sawn timber market in Mozambique

There are three main actors in forestry: (1) Mozambicans: simple license exploiters or concession holders whose production is sold internally as roundwood; the forest management is poor (*e.g.* harvesting above the allowable annual cut issued in the licenses, no re-afforestation, etc.); the concession holders have sawmills but do not process the roundwood for export. (2) Chinese: Traders or concessions holders; the concessions are mostly shared with Mozambicans. This group is the main exporter of roundwood and sawn timber. They buy most of the production from the first group and process all the purchased logs and also the logs from their concessions. They also support the simple license exploiters (in exchange they buy most of the harvested logs, at low price) with chain saws, pay the exploitation licenses, transportation, food and so on; the forest management is also poor; (3) Others: These are Europeans, South Africans, Zimbabweans, etc. to some extent shared with Mozambicans (concessions holders). They produce end-user products for the domestic market and export sawn timber to the European market; most of these exploiters comply with the forest management plans.

Around 80% of the harvested timber in Mozambique is exported to China (Ekman et al., 2013). However, the exported wood data are contradictory. For example, OEC (2014) reports that about 69% of the timber exported in 2014 was roundwood, while the annual activities reports (Anon., 2014) reported that the amount of sawn timber exported in 2013 and 2014 was higher than the volume of roundwood. On the other hand, Ekman et al. (2013) reported that the amount of sawn timber exported and registered in Mozambique statistics was lower than the amount of sawn timber imported to China from Mozambique and registered by the Chinese authorities.

Nevertheless, the added value is low since the processing only produces a square or rectangular shape from the roundwood, without observing any standard of quality or dimensions.

2.1.4 Sawmill Industry

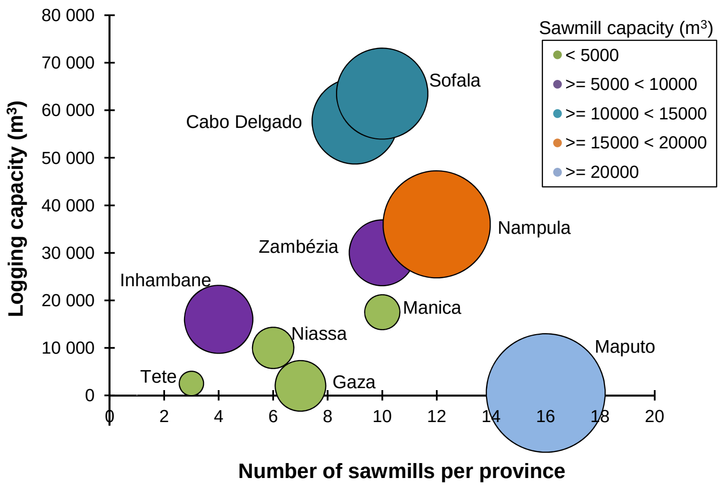


Figure 2.2: Sawmill annual capacity per province (Fath, 2002). The size of the circles indicates the sawmill capacity per province

Most of the sawn timber is produced in small-scale enterprises with an annual production capacity below 2,500 m^3 of sawn timber, and these sawmills are considered to be a driving force for industrialization in rural areas (Fath, 2002).

The production capacity and the logging capacity per province are shown in Figure 2.2. The provinces of Sofala and Cabo Delgado have the highest logging capacity while Maputo has the lowest. Maputo has the highest production capacity.

Sawmills have generally one sawing unit and the equipment commonly used are bandsaws and circular-saw headrigs, as shown in Figure 2.3(a) and 2.3(b). Circular saws are less used due to the large diameter of the logs and also because of the thickness of the sawblade. Sawmills are also equipped with sharpening tools and in some cases with machines or guillotines to produce teeth of the bandsaw blades. A typical sharpener section is shown in Figure 2.3(c). The teeth of circular saw blades are commonly sharpened using hand grinders. The majority of sawmill machines are second-hand and reconditioned and few sawmills have adequate sharpening tool installations.

(a) (b) (c)

Figure 2.3: Examples of common sawmill equipment in Mozambique: a) a headrig with a bandsaw (Cabrussica sawmill, Sofala), b) a circular saw sawmill (David sawmill, Nampula), and c) a sharpener section (Catapu sawmill, Sofala)

The saw strategies are defined by the sawyer or by the person in charge of the sawmill or sometimes by the owner of the logs (sawmills also process logs from simple license exploiters or others). This practice greatly affects the volume yield of sawn-timber since the decision depends entirely on the operator's judgement and abilities, and in many cases it is made with a lack of knowledge of wood species and of the sawing process. The sawing is frequently performed when the logs are green, and air or water is used as lubricant to reduce friction between the wood and the sawblade.

For export, the sawn timber is transported from the sawmills to the harbour and packed in containers for shipment. The sawn timber for the domestic market is often sold directly at sawmills or at the informal markets, 2.4(a) without being dried due to a lack of knowledge both of the drying process and of its importance. If they are available, the drying process uses kilns, but in some cases air drying is also used. Sawmills with drying facilities mostly produce end-consumer products and occasionally export sawn timber or roundwood.

The sawn-timber is further processed for the domestic market at traditional joineries without electricity and using hand tools, Figure 2.4(b). In addition, small sawmills and joineries, Figure 2.4(c), provide services to the traditional carpentries such as sawing, resizing the board thickness, profiling, turning, etc.

(a) (b) (c)

Figure 2.4: The domestic sawn-timber market: a) typical domestic sawn-timber market, b) the traditional an the most common carpentry, and c) typical carpentry that execute works for the traditional carpentries

Chapter 3

Methodology approach

The mission of this project was to study the effect of sawing patterns and of the log positioning on the volume yield of sawn timber from tropical hardwood species, with a special focus on the special industrial conditions which are applicable in Mozambique.

To build up a competitive wood industry in Mozambique, there is a great need for change and development in both the sawmilling and the forestry sectors. If logs of lower grade (crooked and irregular shaped logs) could be processed to a greater extent than today with less waste, that could increase profits, modernize sawmills, and put an emphasis on the secondary processing of the sawn timber. If the present study shows that the Mozambique sawmills would benefit from using log shape measurement prior to sawing, it may provide an incentive for small sawmills to invest in log-scanning techniques and log-positioning devices.

Since the technological level of the Mozambique sawmills (simple sawing equipment, manual log positioning, no data record for sawn timber, no volume measurement devices, etc.) is low, simulation was chosen to investigate the variation in the volume yield of sawn timber because it means that the "virtual" logs can be sawn an unlimited amount of times in a "saw simulator" if compared to the trial sawing in reality.

The strategy was:

1. to select some typical logs for use in investigating the sawing strategies,
2. to scan logs and build a database that describes the outer shape of the scanned logs,
3. to develop the algorithm for simulation of the sawing process, and
4. to execute simulations to investigate the effects of sawing strategies to on the volume yield of sawn timber, and to identify a strategy for maximizing the volume yield.

3.1 Log selection

The features of tropical hardwood logs vary according to species, but there are similarities such as the amount of sapwood and heartwood, the density, the absence of knots in the trunk, crookedness, taper and so on. The most visible feature is the crook, and in most cases it is oriented in more than one direction (see appendix II). The crook varies among the species but it is in general greater than in coniferous species. Although the harvesting is selective, some species are particularly crooked even if the log is bucked to one meter lengths. Thus, the crook was found to be the main parameter to consider when investigating the different sawing strategies. The log length was also used for the log selection.

The species were selected among the most exploited species for the domestic market and for export. Chanfuta (*Afzelia quazensis* Welw.), Umbila (Pterocarpus angolensis DC.), Jambirre (*Millettia stuhlmanni* Taub.) and Messassa (*Brachystegia speciformis* Benth.) are the most predominant. The Messassa specie is exported particularly as railway sleepers to Zimbabwe and it also used on the domestic market. The selection was based preliminarily on data from the Atlas of Wood Species in Cabo Delgado (Bunster, 2011). The atlas contains data for about 300,000 trees in the Cabo Delgado province during the elaboration of management plan inventories. The data presented in the atlas show the quantity of species per number of trees per hectare, the quantity of stems per height and the quantity of stems per quality. Of these parameters, the stem quality was the parameter used in this work. The atlas classifies the stems in three grades: grade 1 is straight logs, grade 2 is one crook, and grade 3 is two crooks or more.

The quantity of stems in terms of quality is shown in Figure 3.1. Jambire was found to be the most crooked species, where only 52% of the species is grade 1 logs, grades 2 and 3 of Jambirre has the highest proportions, which also means that the abundance of crooked logs is higher than in other species. Chanfuta is the species that has the straightest logs followed by Umbila and Messassa. However, these proportions may be different in other parts of the country due to the soil composition, vegetation type and differences in the amount of rain. However, 35% of the logs have some crook, an it is therefore of interest to improve the sawing for these logs.

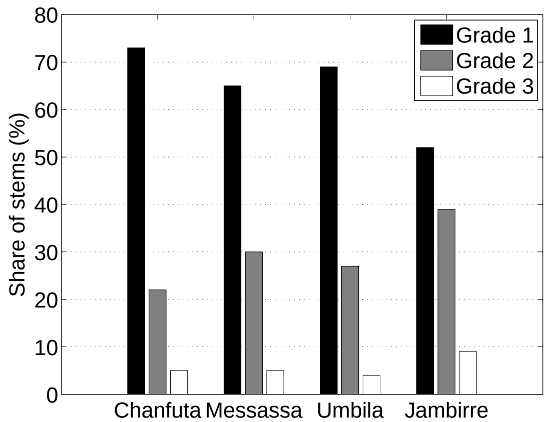


Figure 3.1: Share of stems per grade (Bunster, 2011)

3.2 Log scanning and the database

The project was set so that the scanning had to be performed in Mozambique. To take the logs and perform the scanning in Sweden was not possible because of the costs and the bureaucracy in exporting roundwood. Another reason was the desire to investigate scanning methods for small-scale sawmills for potential use in Mozambique. Thus, a portable method to determine the log outer shape suitable for the Mozambique sawmills had to be used.

The practical limitation was that the log had to be fixed during the scanning because no (or very few) Mozambican sawmills are equipped with conveyors to transport the logs, which is the requirement for traditional scanning techniques such as laser triangulation, X-ray scanning, shadow scanners, etc.

Portable devices have previously been used to measure the log shape and for the data processing. For instance, Keane (2007) described the AutoStemTM software, which imports the data from a laser scanner and processes it automatically for each scan in 3 to 5 minutes. The result from this scanner can be exported to different saw-optimization software packages. Antikainen and Verkassalo (2013) described the acquisition of log shape using structured light analysis (Kinect Sensor from Microsoft) in which the 3D modelling and calculations were performed with a specially developed graphics processing unit. Pinto et al. (2003) used a WoodCim inspector scanning system to reconstruct Maritime pine logs. However, all these methods require controlled, horizontal transport and/or rotation of logs during scanning, a requirement that can be problematic under typical Mozambican conditions.

Within the realm of portable scanners for potential use in structural geometric measurements of stationary objects, three primary ranging technologies are being used in commercial laser scanners: (1) time-of-flight discrete-return scanners, (2) continuous wave phase-shift scanners, and (3) time-of-flight waveform scanners. However, these methods have some drawbacks compared to the methods used to measure the log shape in the saw line. They require more than one scan position to obtain a full description of the object, which results in low acquisition speed. Moreover, the registration of scans is time-consuming and is not sufficiently automated and requires manual operations. Despite these disadvantages, the structural geometric measurement of stationary objects was found to be suitable method for data collection in a Mozambique sawmill environment to build up the database. Although the method used by Antikainen and Verkassalo (2013) has the potential to be used in a Mozambique sawmill environment, it was not used in the present case because it requires rotation of the log during the scan, which was the main limitation.

To obtain a full 3-D description of the log, five scans were taken at different angles from different positions.

3.3 Saw optimization

Optimization has been largely used to analyse sawmill performance worldwide. The optimization methods used in the sawmill industry can be categorized as: (1) Empirical, *i.e.* the recovery is calculated using real sawing. The same amounts of real logs are sawn with different sawing patterns and the results are compared. Such results are the most accurate, but are difficult to compare because each log can only be sawn once. (2) Theoretical, *i.e.* the recovery is calculated using mathematical log models. The yield maximization issue is addressed as the packing problem, *i.e.* the problem is the determination of the maximum amount of sawn timber that can be fitted into a log of a certain cross section diameter. (3) Simulation, *i.e.* the recovery is calculated using scanned log models and different input variables (offset, skew, rotation, curve sawing, saw kerf width etc.). In contrast to the mathematical optimization, the simulation uses the real representation of the log (in some studies inner features were also used to describe the log). The main advantage of simulation studies is that the logs can be sawn an unlimited number of times. In the present work, the main focus was on the simulation method.

Simulations have shown great potential to saw logs efficiently, Todoroki and Rönnqvist (1999) used dynamic programming to describe some procedures to determine the optimal cutting of flitches into graded dimensional boards. Lin et al. (2011) concluded that the log grade, log diameter, species, log crook, and log length affect the value and volume yield of sawn timber. Lin and Wang (2012) studied the choice of the best opening face in the sawing, edging, and trimming of sawn timber, and found that an optimization system for the process stages could significantly improve the value recovery and could also assist mill managers and operators in the daily operation of the sawing process. In an optimization study, Lundahl and Grönlund (2010) showed that an optimal combination of rotation and parallel positioning of the log in the first and second saw-machines of a typical Swedish sawmill could, on average, increase the volume yield by 8.6%. Fredriksson (2014) complemented this study using computed-tomography (CT) data to optimize the positioning of the logs before sawing according to the knot structure in the log, and he reported that it was possible to achieve a gain in sawn timber of up to 21%.

To perform the simulations, many computer algorithms have been developed and used to support and improve the sawing process. For instance, Steele et al. (1987) used the best opening face (BOF) method, where the model first determines the opening face that will produce the smallest acceptable piece of timber and successive cuts are then made and the resultant recovery determined. This process is repeated incrementing the opening faces moving towards the center of the log. When all the reasonable possibilities are examined, the Best Opening Face is chosen. Dogan et al. (1997) developed the simulation or animation model of the sawmill and sorting areas to investigate the replacement of the trimmer in sawmill, to determine the availability of the forklift in sorting area and so on. Gibson and Pulapaka (1999) developed an algorithm for log rotation in sawmills where the arbitrary position was determined through data scanning and the necessary angle of rotation was then calculated to position the logs at horns up or horns down. Nordmark (2005) used simulations to investigate the effect of measurement techniques in bucking and log sorting on value recovery and production control.

In the work described in this thesis, the sawing principle used was similar to that used in BOF.

3.4 Simulations

Simulations were executed to investigate the effect of different sawing strategies involving different sawing patterns and positioning parameters.

The sawing patterns were defined as the result of combinations of practices seen in the field (Paper I), and three sawing patterns were identified as being interesting to study: (1) cant-sawing – commonly used to process sawn timber for export, the main products being cants and sideboards, (2) through-and-through sawing – used to process sawn timber for domestic market, the main products being un-edged centreboards and sideboards, and (3) square-sawing – used in sawmills that produce end-user products.

For positing parameters, offset, skew and rotation were used and following combinations of parameters were set for the studies: Paper III – saw patterns (cant-sawing, through-and-through sawing and square-sawing) and log positioning (skew and rotation); Papers IV and V – saw patterns (cant-sawing, through-and-through sawing) and positioning parameters (offset, skew and rotation).

Chapter 4

Materials and Methods

The studies presented in this thesis are divided as follows: (1) log selection, (2) log scanning method, (3) the database, (4) algorithm for simulation. The steps are described briefly below with more detail in the appended papers.

4.1 Log selection

From a literature study (Paper I), Jambirre (*Millettia stuhlmannii* Taub.) was found to be the most crooked, while Umbila (*Pterocarpus angolensis* DC.) and Chanfuta (*Afzelia quanzensis* Welw.) gave the straightest logs. These species were found to be suitable for investigating the sawing strategies. Thus, to select the species, the findings from a desk study were compared with the results from a visual inspection during the survey made in the Cabo Delgado, Nampula and Sofala provinces. The visual inspection validated the results from the literature, and Jambirre was the species selected to represent the crooked logs and Umbila the straight logs, because Chanfuta was not available in the sawmill were the data collection was performed. The data collection was performed in Pemba, Cabo Delgado Province, this place being chosen because other sawmills were not available.

4.2 Log scanning method

A 3D phase-shift laser scanner was chosen to measure the log shape because of the Mozambican sawmill layout and the log dimensions (Paper II). The experiment was performed in Skellfteå, Sweden. To validate the measurements from the 3D laser scanner, a computer tomography scanner (CT) was used to determine the log shape. Two species were used in this study Birch (*Betula pendula* Roth.) and Scots pine (*Pinus sylvestris* L.) and three measurements were made from different scan positions and heights around the log to obtain the full shape of the log.

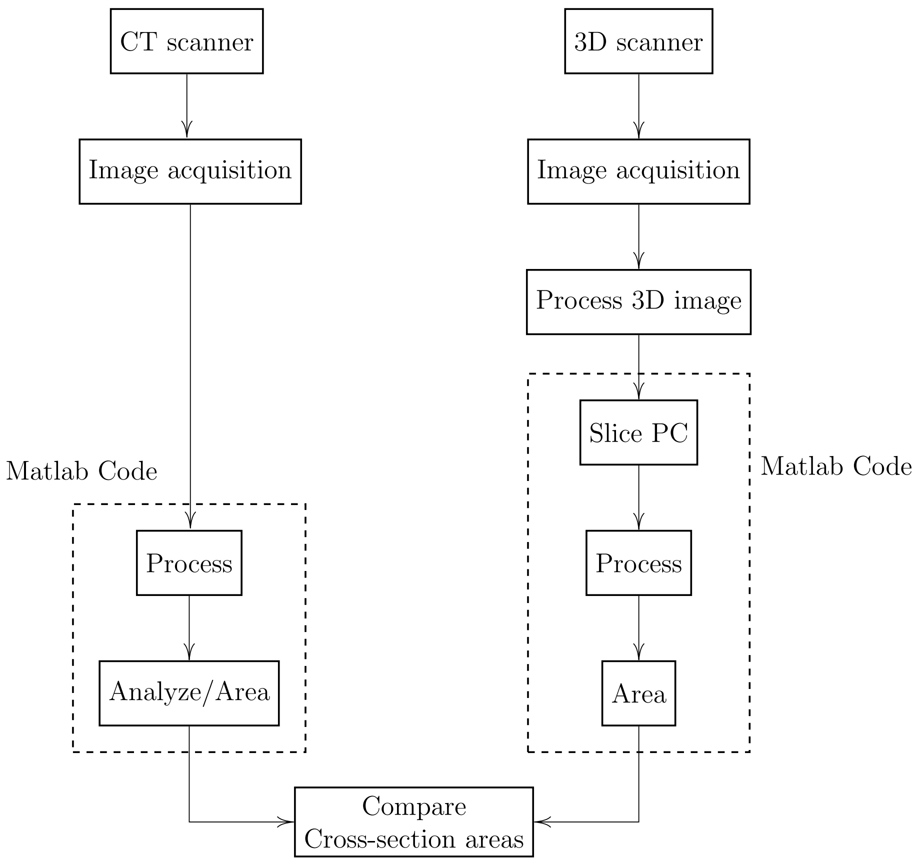
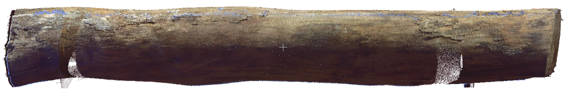


Figure 4.1: Process flow chart of acquisition and processing slices areas from computer tomography (CT) and 3D scanner data

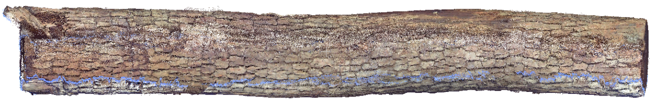
The 3D scanner generated point cloud data, and the CT scanner generated grey-scale slice images (taken every 10 mm along the log length). The point cloud data were processed similarly to the CT-data, sliced 10 mm, and the areas that corresponded to each slice were compared. The sequence of processing is shown in Figure 4.1.

4.3 Database

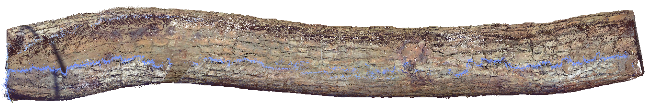
The scanning of logs for the database was performed in Pemba, Cabo Delgado in Mozambique. The 3D laser phase-shift scanner (Faro Focus 3D S-120) was used and five scans were taken around the log to obtain a full description of the log (Paper III). Fifteen logs were scanned, 10 Jambirre (*Millettia stuhlmannii* Taub.) and 5 Umbila (*Pterocarpus angolensis* DC.). The outer shape of each log was described as a point cloud (with XYZ coordinates and RGB colour). Examples of the log models are shown in Figure 4.2. The logs were between 1.8 m and 3.8 m long and had top diameters of between 23 cm and 39 cm.



(a) Log No. 6 - Grade 1



(b) Log No. 15 - Grade 2



(c) Log No. 14 - Grade 3

Figure 4.2: Three examples of reconstructed log models from the 3D-laser scanner. The examples shows the log shape and their grades according to Bunster (2012)

4.4 Sawing simulations

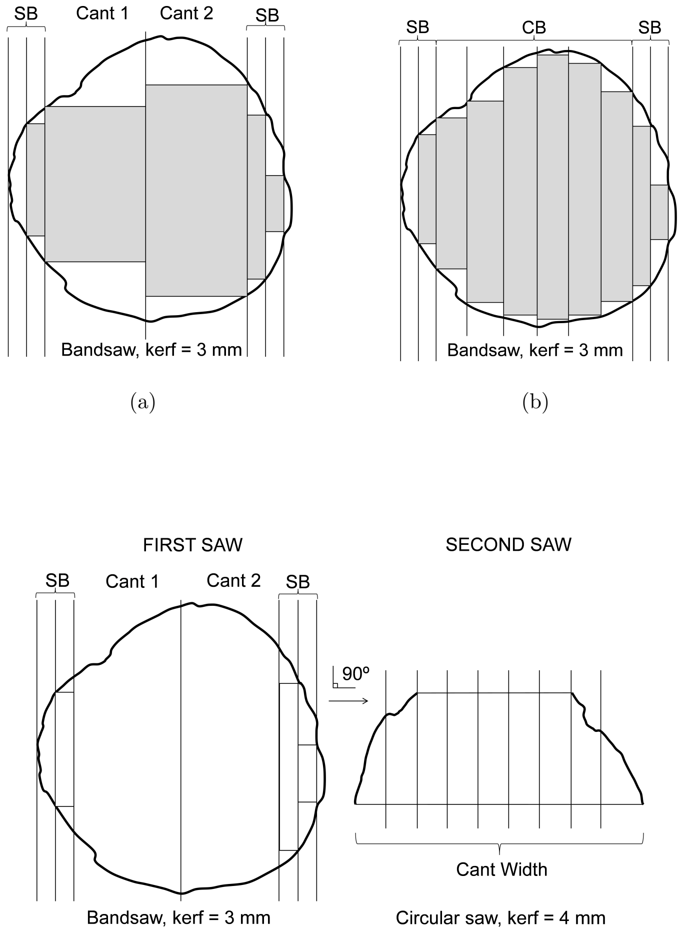
An algorithm was written in Matlab (MathWorks, USA) to simulate the sawing process (see the pseudo-code of the algorithm in Appendix I), consisting of placing pre-defined planes (board thickness from the sawing pattern) and calculating the maximum sharp edged board volumes from each sawing combination. The sawing patterns used for the simulation were cant-sawing, through-and-through sawing and square-sawing (Figure 4.3). In the first step, the top-end of the log was determined by comparing the log-end diameters and then matched to the predefined log-diameter class (Table 4.1). When the sawing pattern had been selected, the log was sawn using different combinations of skew, rotation and offset (Figure 4.4).

In addition, the set-up parameters of the band-saw mill commonly used in Mozambique were used. For cant-sawing and through-and-through sawing, the kerf width was set to 3 mm, and for square-sawing a kerf width of 3 mm was set for the bandsaw (first saw) and of 4 mm for the rip-saw (second saw). To compensate for the shrinkage during drying, 4% was added to the target cross-sectional dimensions regardless of the main direction of the wood.

Table 4.1: Sawing patterns for cant-sawing, through-and-through sawing, and square-sawing, showing the thickness of sideboards and centreboards for each log-diameter class. These sawing simulations have been used in all studies

Log-diameter class (mm)			Sawing patterns		
No.	Min.	Max.	Cant-sawing (CS)	Through-and-through (TT)	Square-sawing (SS)*
1	0	249	25 25 50 50 25 25	25 25 25 25 25 25 25 25	CS+25 (rip-sawing)
2	250	289	25 25 75 75 25 25	25 25 25 50 50 25 25 25	CS+25
3	290	329	25 25 100 100 25 25	25 25 50 50 50 50 25 25	CS+25
4	330	369	30 30 100 100 30 30	30 30 50 50 50 50 30 30	CS+25 or 50
5	370	409	30 50 100 100 50 30	25 50 50 50 50 50 50 25	CS+50
6	410	449	30 75 100 100 75 30	25 50 50 75 75 50 50 25	CS+50
7	450	489	50 75 100 100 75 30	25 75 75 75 75 75 75 25	CS+50

*SS was a combination of cant-sawing (same sawn-timber thickness) and a second sawing stage where the cant was rip-sawn into boards of equal thickness. The board thickness of 25 mm was used when the cant-width $\leq$ 339 mm, and for a cant-height of 50 or 75 mm, but the board thickness was set to 50 mm for a cant-width $\geq$ 340 mm and a cant-height of 100 mm.



(c)

Figure 4.3: Cross-sectional views (top-end of the log) of the sawing-patterns used in the simulation: a) cant-sawing (CS), b) through-and-through sawing (TT), and c) square-sawing (SS). SB and CB are respectively sideboards and centreboards

4.4.1 Log positioning parameters and sawing patterns

The simulation algorithm positions the log before the first cut by skewing, offsetting and rotating the log (Figure 4.4). In each study, the following sawing parameters were used:

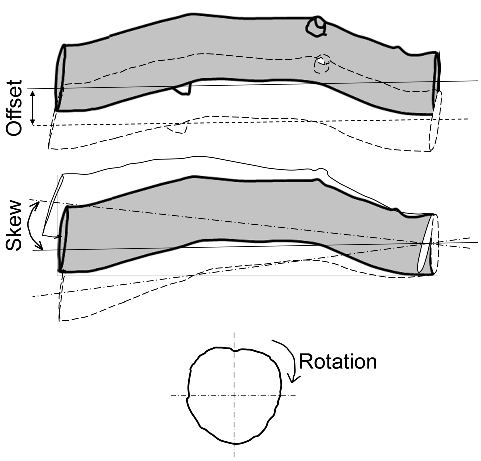


Figure 4.4: Definition of the positioning parameters offset, skew and rotation

In Paper III, the simulations were performed to investigate which sawing pattern gives the highest volume yield of the sawn timber. Three sawing patterns (cant-sawing, through-and-through and square-sawing) were used and two positioning parameters (skew and rotation). The skew was varied from -1° to +1° mm with steps of 0.5° and the rotation from 0° to 180° in steps of 2°.

In Paper IV, two simulations were performed to investigate the most effective positioning parameter and the reduction of volume yield when positioning the log manually, knowing the optimal positioning of the log that gives the highest volume yield of sawn timber.

The optimal positioning was determined using the following sets: two sawing patterns (cant-sawing and through-an-through) and three positioning parameters: offset (-100 mm to +100 mm, steps of 10 mm), skew (-1° to +1°, steps of 0.5°) and rotation (0° to 360°, steps of 5°).

- To investigate the parameter having the greatest effect, the following parameters where used: offset (-30 mm to +30 mm, steps of 1 mm), skew (-0.7° to +0.7°, steps of 0.1°) and rotation (-30° to +30°, steps of 1°). The parameters were varied one at time, *i.e.* fix two and vary one.

- To investigate the reduction in volume decrease, the following parameters were used: offset (± 15 mm), skew (± 0.35°) and rotation (± 15°), the parameters were randomly and simultaneous varied.

In Paper V, the simulations were performed to evaluate the possibility of using crook as a means of positioning, and the possibility of increasing the volume yield of sawn timber using bucked logs. The logs were bucked in half length. The following sawing parameters were used:

- To determine the optimal positioning. Offset (-100 mm to +100 mm, steps of 10 mm), skew (-1° to +1°, steps of 0.5°) and rotation (0° to 360°, steps of 5°).

- Crook-up sawing. Offset (-100 mm to +100 mm, steps of 10 mm), skew (-1° to +1°, steps of 0.5°) and rotation (0°);

Thus, the only difference in settings was in rotation because 0° is horns-down position.

The sawing was performed using cant-sawing and through-and-through sawing for all logs (full-length and bucked logs).

4.4.2 Log crook, grading and bucking

The crook for each scanned log was determined as follows (Figure 4.5): (1) at 10 mm intervals along the length of the log, the geometric centre of the cross section (disc) was determined, *i.e.* the arithmetic mean position of all points that define the outer shape of the log at that position. (2) a straight line was drawn between the geometric centres of the outermost two cross sections of the log (the top and butt ends of the log). (3) the crook of each log was then defined as the maximum distance between the line defined in (2) and the geometric centres of the cross sections.

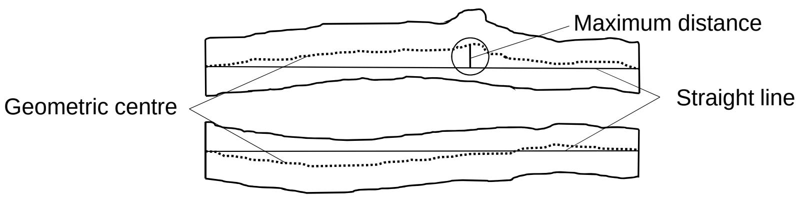
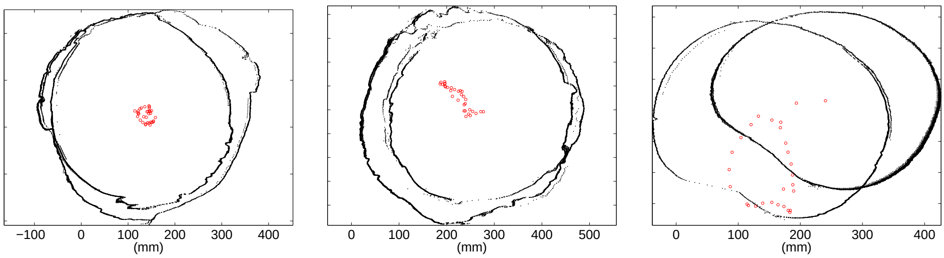


Figure 4.5: Two lateral views of the same log showing the log crook. The curved line (dotted line) represents the geometric centres of cross-sections at 10 mm intervals along the length of the log. The straight horizontal line is the connection of the geometric centres of the two outermost cross-sections. The log crook is defined as the maximum distance between these lines (the highlighted circle)

Examples of the different levels of crookedness are shown in Figure 4.6. The geometric centres of the cross sections along the log are seen as group of dots in the central regions. A fairly straight log has all the geometric centres well centralized, while a crooked log has the geometric centres scattered over the cross section.



(a) (b) (c)

Figure 4.6: The cross-section view of the log periphery at the top-end and butt-end of three logs from the database, and the geometric centres calculated at each 10 mm of the log length (the circles in the central region of the cross sections). The degree of log crookedness is illustrated as the scatter of the geometric centres: a) a fairly straight log, b) a single crooked log, and c) a double crooked or tortuous log

The crooks of the 15 logs in the database were computed and a crook of 60 mm was chosen as the limit, in order to enable the logs to be grouped into two grades, where Grade 1 consisted of those with a crook less than 60 mm and Grade 2 greater than or equal to 60 mm.

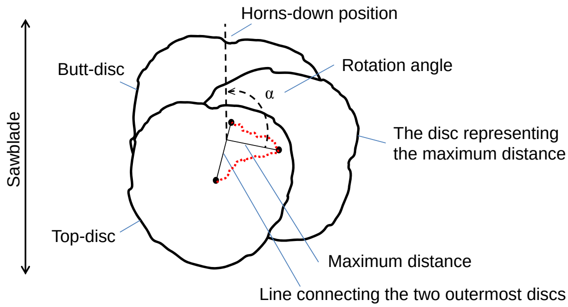


Figure 4.7: Principal procedure used to position the logs in horns-down position. The saw-blade has a vertical position and the log is rotated an angle α so the maximum crook of the log is parallel to the sawblade. Maximum distance is between the "two line" in Figure 4.5

Knowing the size and the position of the crook, each log was rotated to horns-down position using the procedure shown in Figure 4.7. The procedure is similar to that used by Gjerdrum et al. (2001). Examples of the un-rotated and rotated logs are shown in Figure 4.8. For bucking, the logs were divided in half.

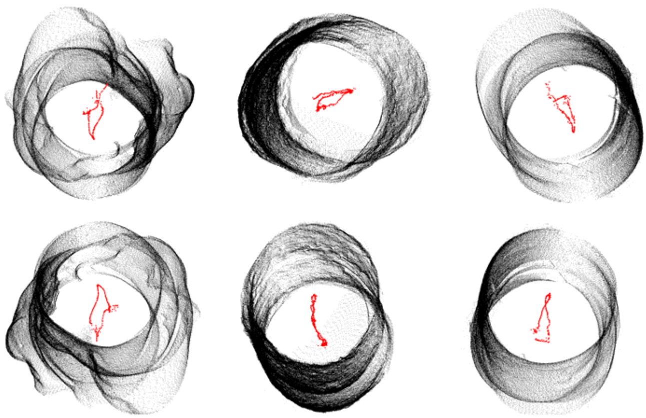


Figure 4.8: Three examples of log models showing the outer shape of the logs, and the geometric centres of the cross-sections at 10 mm intervals along the length of the log (the dots close to the centre). In the first row, the logs are positioned according to the scanning position (random selected positions); while in the second row the same logs are positioned at the horns-down position

4.4.3 Edging and calculation of the board volume

For a given sawing pattern, the volume yields of all the boards or components at each position (offset, skew and rotation) were calculated and all the sawn timber volumes of each log were recorded. The simulator displayed the volumes with the respective offset, skew and rotation positions.

During the edging of the sawn timber in the CS and TT sawing patterns, the board volume was maximized (Figure 4.9). The minimum width accepted was 50 mm, a width module of 5 mm was used, but no length module was used.

The minimum length of a component during square-sawing was set to 200 mm (which is the minimum length of raw material to produce one component of flooring parquet).

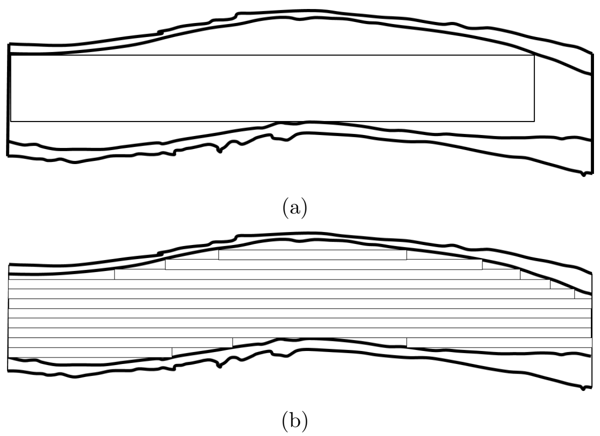


Figure 4.9: a) Flat view of simulated cant from cant-sawing (CS) or board from through-and-through sawing (TT). The rectangle represents the maximum fitted size of a sharp edged board or cant. b) Flat view of simulated board from the second saw in square-sawing (SS). Each rectangle represents a ready-to-use sharp-edged component

Chapter 5

Results and Discussion

Simulation was used because it enables different sawing strategies to be investigated using the same logs several times, which would be impossible if trial sawing were used. Another reason was the costs. Trial sawing in Mozambique with the current sawmill conditions would cost considerable more than to building the database. No validation of the results was performed; the volume yields from simulations were only compared to literature findings. In addition, only the outer features of the logs were considered as the main log characteristics. Other features such as sapwood and heartwood contents, rot, knots and cracks on the top-face and end-face of the log were not considered, although these features would also affect the volume yield, depending on how the quality of the sawn timber is defined.

5.1 Log shape measurement (Paper II)

The cross-sectional areas of the logs determined from point cloud (PC) data showed good agreement with the comprehensive computer tomography (CT) areas, Figures 5.1 and 5.2. However, some differences between the two methods were observed. Possible sources of error in the investigation include errors from the acquisition method itself, errors from the data processing method, and errors due to properties of the object scanned (log surface features such as loose bark, scratches, cracks, etc.).

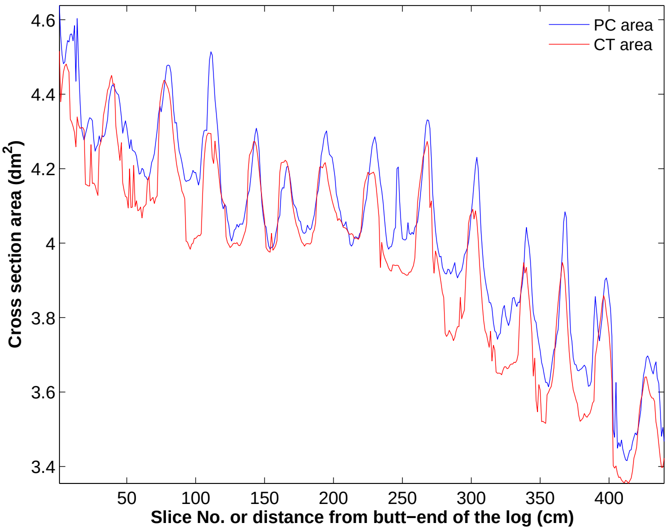


Figure 5.1: Comparison of cross-sectional areas between the 3D scanner (PC) and computer tomography (CT) measurement of the Scots pine log

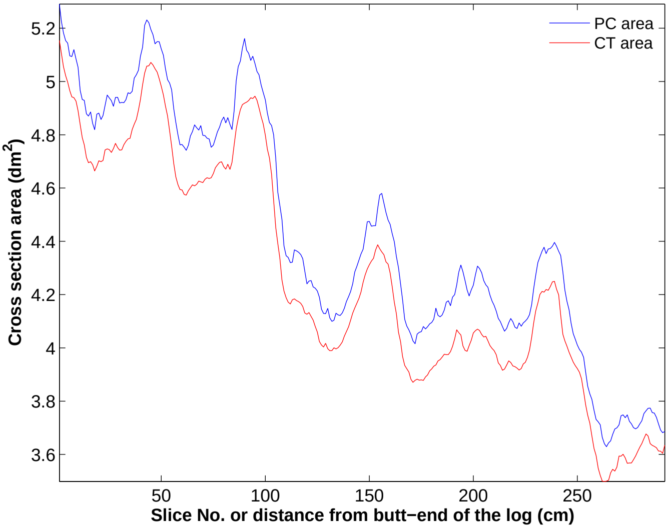


Figure 5.2: Comparison of cross-sectional areas between the 3D scanner (PC) and computer tomography (CT) measurement of the birch log

5.2 Database, saw simulation algorithm and preliminary results (Paper III)

The database was built (see the reconstructed log models in Appendix II) and the sawing algorithm was also developed. The preliminary test revealed that the cant-sawing pattern gave the lowest volume yield for all log grades and the that through-and-through sawing gave a higher yield than cant-sawing regardless of log grade or species, Figure 5.3.

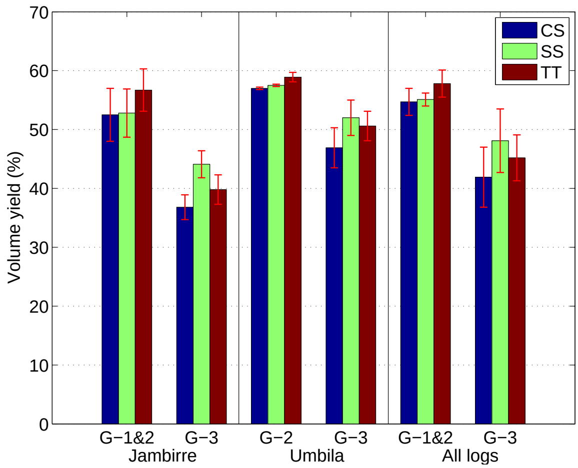


Figure 5.3: Maximum volume yield with optimal positioning (combination of skew and rotation) as an average of all log-diameter classes for different sawing patterns, species and log grades. Bars indicate standard deviation, and CS – cant-sawing, SS – square-sawing, TT – through-and-through sawing, and G – grade

Note that in this study in comparison with study IV and V had two main differences in simulation setup:

1. in paper III the logs were manually graded according to Bunster (2012) instead of the measured log crook (see log crook, grading and bucking in Material and Methods section), and

2. the positioning parameter Offset was not used in paper III but found to be important and therefore incorporated in study IV and V.

The square-sawing (SS) gave the highest yield when Grade 3 logs were sawn. The results also suggest that the straight logs should preferably be sawn with the through-and-through sawing pattern (TT) instead of cant-sawing pattern (CS) with a potentially 3-percentage-point greater volume yield (all logs, in Figure 5.3). The potential for improvement with crooked logs was 6-percentage points with SS instead of CS.

In addition, if a sawmill does not have the equipment for secondary processing, a change from CS to TT is still predicted to improve the volume yield of crooked logs with a potential of about 3-percentage points.

Overall, the preliminary simulation results show that the volume yield can be increased if SS or the TT sawing is used instead of the commonly used CS pattern. Compared to a yield of 40% reported by Mozambican sawmills (Egas et al., 2013), the simulation results (Figure 5.3) show an improvement with optimal positioning for all types of logs except for the Grade 3 logs of Jambirre (CS and TT sawing patterns).

5.3 Effect of deviations in log positioning on volume yield (Paper IV)

The results from the study of the effect on volume yield of deviations in log positioning are shown in Table 5.1. The table shows the average decrease in volume yield when one of the log positioning parameters is varied around the optimal positioning (OP) of the log while the other two are kept at the optimal position, *i.e.* the mean value of all simulations in the interval. The results show that the decrease in volume yield is higher with CS than with TT sawing for both sawing grades.

Table 5.1: Simulated average decrease in volume yield with a positioning error in one parameter while the other two are kept at optimal position (OP). SD-standard deviation

Log crook		**Grade 1**				**Grade 2**			
Sawing pattern		**CS**		**TT**		**CS**		**TT**	
			SD		SD		SD		SD
Decrease in yield (%)	Rotation	-12.7	4.8	-11.5	3.3	-16.9	4.5	-11.9	3.0
	Offset	-9.6	3.6	-8.7	2.9	-14.0	4.2	-7.7	1.7
	Skew	-9.4	3.2	-8.4	2.3	-11.9	3.7	-7.1	1.5

For comparison, the mean decrease in volume yield for all Grade 1 logs when varying the offset was 9.2%, which is slight higher value than that reported by Baltrušaitis and Pranckevičienė (2005) who reported a decrease in volume yield between 2.7% and 8.3%. The reason of this difference may be the high degree of crookedness of the logs used in our study. Table 5.1 also shows that the TT sawing pattern is less affected by errors in positioning, which suggests that this sawing pattern should be used to achieve a high volume yield when there is an error in one of the log positioning parameters.

Overall, the results show that the rotation is the most important parameter affecting the volume yield. A similar conclusion was reported by Todoroki (1995), who investigated the log rotation of crooked logs. The results also show that the offset was the second most important parameter, followed by skew. A similar finding was reported by Wessels (2009), who studied the optimization of the CS of pine logs.

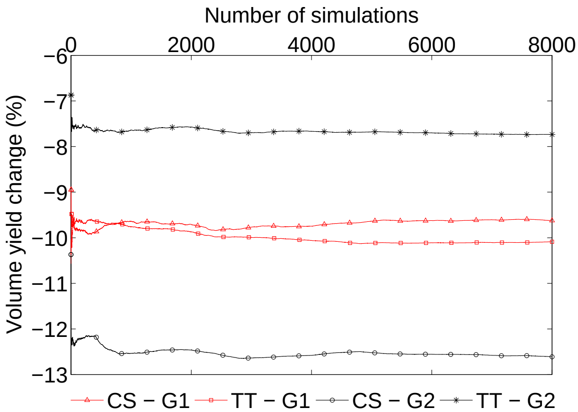
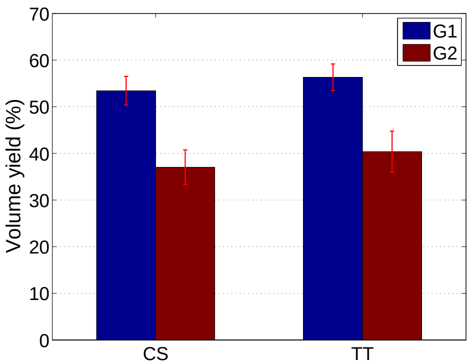


Figure 5.4: The accumulated average decrease in the volume yield for Grade 1 and Grade 2 logs when all three positioning parameters were simultaneously varied randomly around the optimal position (OP). CS – cant-sawing; TT – through-and-through sawing and G – grade

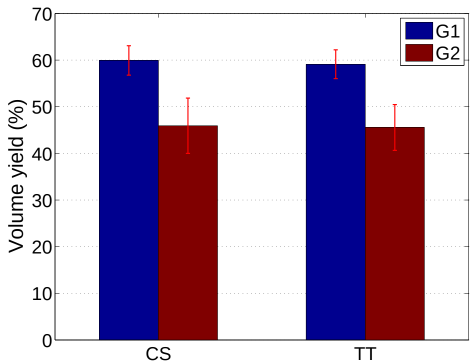
In addition, simulations were done to study a "more practical case" in which a sawmill has full information about the positioning parameters of the logs at OP, but has random errors in all three positioning parameters. Figure 5.4 shows the accumulated average volume yield decrease when offset, skew, and rotation were simultaneously varied randomly around the OP. It should be noted that the investigated interval of variation is narrower than set to determine sawing parameter having the greatest effect, and it was set to considering manual positioning.

The results in Figure 5.4 show that for straight logs (Grade 1) the volume yield decrease is about 9.8% for both sawing patterns, CS being slightly better. For crooked logs (Grade 2), TT sawing pattern had an average decrease in volume yield of about 7.7% whereas the average decrease for CS sawing was about 12.5%.

The large difference in the case of Grade 2 logs is because the effect of non-coincidence of the log centre and the sawing pattern centre in each cross-cut along the log length is more severe in CS than in TT sawing. Thus, TT sawing should be applied when crooked logs are to be sawn.



(a) Data from Paper III



(b) Data from Paper IV

Figure 5.5: Comparison between results in Paper III and Paper IV. For both graphs the logs were here graded according to measured crook: a) Volume yield at OP were offset was not included (Paper III), and b) Volume yield at OP were all three positioning parameters were included (Paper V). CS – cant-sawing; TT – through-and-through sawing, and G – grade

Figure 5.5 compare results of Paper III (where the positioning parameter offset was not included in the simulation study) with results of Paper IV. In Figure 5.5 the logs were graded according to the same grading rule, *i.e* according to crook as in Paper IV. The figure shows that the offset parameter has a clear influence on volume yield. In fact, the offset parameter has got greater impact than the effect of sawing patterns studied. The cant-sawing sawing pattern show to be more sensitive to the offset parameter in comparison with through-and-through sawing pattern.

5.4 Positioning optimization and log bucking (Paper V)

Of the 15 full-length logs, six logs were classified as Grade 1 and nine logs as Grade 2, and after bucking to half length, 22 logs were classified as Grade 1 and eight as Grade 2, Table 5.2.

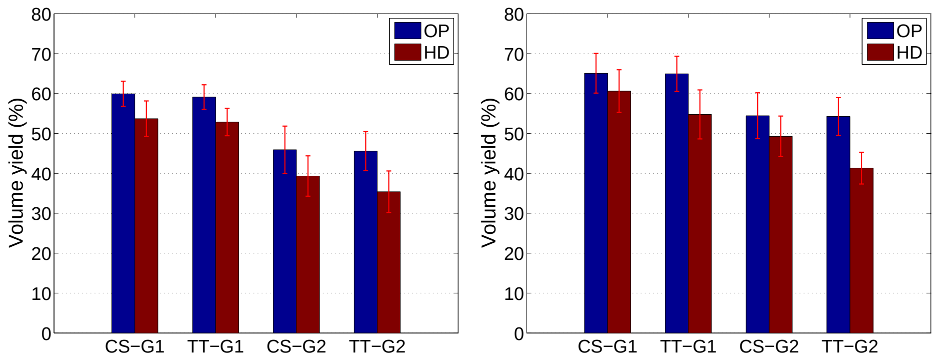
Table 5.2: Grading, crookedness and length of full-length and bucked logs. The full-length log No.1 exemplifies how a Grade 2 log was bucked to give one Grade 1 and one Grade 2 log

Full-length logs						Bucked logs					
Grade 1			Grade 2			Grade 1			Grade 2		
Log No.	Crook (mm)	Length (m)	Log No.	Crook (mm)	Length (m)	Log No.	Crook (mm)	Length (m)	Log No.	Crook (mm)	Length (m)
13	29	3.2	14	90	3.8	6b	20	1.2	10a	60	1.4
6	30	2.5	4	98	2.4	8b	21	1.4	14b	68	1.9
15	39	3.2	7	100	2.3	12b	21	1.6	4b	69	1.2
8	39	2.9	12	101	3.2	11b	26	1.5	5b	81	1.2
11	50	3.1	5	108	2.4	2a	26	0.9	14a	103	1.9
2	50	1.8	3	109	2.4	15a	27	1.6	10b	116	1.4
			10	114	2.8	7b	27	1.1	5a	116	1.2
			9	127	2.7	4a	28	1.2	**1b**	**127**	**1.4**
			1	**190**	**2.8**	6a	29	1.2			
						9a	30	1.3			
						13b	32	1.6			
						13a	32	1.6			
						8a	32	1.4			
						2b	38	0.9			
						7a	38	1.1			
						12a	44	1.6			
						11a	44	1.5			
						15b	44	1.6			
						3a	46	1.2			
						1a	**50**	**1.4**			
						3b	50	1.2			
						9b	52	1.3			

The bucking of the logs in half considerably reduces the crook. An example is given in Table 5.2 for full-length log No. 1, showing that the absolute value of crook is reduced and that bucking has a potential to increase the log quality by reducing the crook. However, short logs may be a challenge in the Mozambique wood industry because the length gluing of components and finger-jointing are not common in practice, and they may thus reduce the productivity of the sawmills. Regarding productivity, we believe that most of the sawmills operate bellow their installed capacity.

The results show the potential of bucking the logs. More important in these findings is the ratio between the crook and the log length, *i.e.* reducing the log length reduces the effect of crookedness and hence increases the volume yield.

The volume yield for optimal positioning and horns-down positioning of full-length and bucked logs are shown in Figure 5.6. The main result from the study of bucking the logs to half-length, is that the yield increases significantly. The volume yield of Grade 1 of bucked logs increased around 5-percentage points in relation to full-length logs, while the volume yield of Grade 2 logs increased around 10-percentage points. These findings show the importance of bucking and also of grading.



(a) Full-length logs (b) Bucked logs

Figure 5.6: Volume yield of sawn timber of the optimal position (OP) and at the horns-down position (HD) of Grade 1 and Grade 2 logs: a) full-length logs, and b) bucked logs. CS – cant-sawing; TT – through-and-through sawing, and G – grade

For horns-down positioning, the results shows that the yield decreases and the magnitude of the decrease is different within the sawing patterns and log grade. Figure 5.6(b) shows that the cant-sawing at horns-down position give a volume yield similar to that of Grade 1 full-length logs at optimal position, which shows the potential of grading and of the horns-down position as well. Although the low volume yield, the horns-down position can be used as alternative to the optimal positioning even though this position may be difficult to identify in Grade 2 logs because of the crook. Overall, the horns-down gives a volume yield around 45%, which is 5-percentage points higher than the mean volume yield in Mozambique today. The difference between horns-down and optimal position in Figure 5.6 show the potential of having full information of log shape and how to position the log based on this information. This information is a strong argument for Mozambican sawmillers to improve their log positioning systems.

Chapter 6

Conclusions

The results shows that there is great potential to improve the volume yield of sawn timber from tropical hardwood species by combining sawing patterns, positioning parameters and grading of logs according to crook. The results also give valuable information about how the positioning, grading and bucking affects the volume yield. The more specific conclusions of the research work are:

- The 3D-scanner provided a detailed description of the log shape and showed good agreement with the reference measurements made with computer-tomography scanner, but the low scanning speed hinders its use in the production line, although the productivity of Mozambique sawmills is low.
- The use of simple and easy methods for log scanning to assist in log positioning prior to sawing could be one way to increase the volume yield in tropical hardwood sawmills in developing countries.
- When the square-sawing and through-and-through sawing were optimized without taking into account the offset, the volume yield was higher than the standard sawing pattern (cant-sawing) frequently used in Mozambique. The square-sawing method gave the highest volume yield when sawing crooked logs, while the through-and-through method gave the highest yield for all types of logs studied.

- The rotation is the log positioning parameter that affects the volume yield the most, and the offset is the second most important positioning parameter, followed by the skew.

- A deviation in the positioning of the log before sawing can reduce the volume yield of sawn timber by between 7.7% and 12.5%.

- For Grade 1 logs, *i.e.* fairly straight logs, the choice between cant-sawing and through-and-through sawing is not important for the volume yield. To achieve as high a volume yield for crooked Grade 2 logs, the cant-sawing pattern should be avoided and through-and-through sawing pattern should be used because cant-sawing is more sensitive to error in positioning.

- Using information that indicates the orientation of the optimal positioning from a proposed scanning station would considerably increase the volume yield.

- Bucking reduces the ratio between the crook and the log length, which reduces the effect of crookedness and hence increases the volume yield.

- Horns-down positioning is an alternative to optimal positioning if logs are bucked and there is no possibility of using optimization tools.

Chapter 7

Future work

Log scanning

One of the objectives was to find methods that could possibly be used in future in a Mozambique sawmill. The method used to scan logs to build the database was suitable for data collection but not for use in a saw line because of the low scanning speed and the fact that more than one scanning position is required. A structural light method was tested using small logs and the results were promising, but tests with full log size an length is necessary to perform. The idea is to place two Kinect sensors (Kinect Sensor from Microsoft) side-by-side on the top of a headrig and to scan while rotating the logs (the log carriage should be capable of mechanically rotating the logs).

Database

To complete the database, inner features of the logs must be added in the log models. The initial idea was to map the defects of each board or flitch taken by the 3D scanner and include the features in the log models. Flitches of 8 logs were scanned but the analysis has not yet been done. The next step is to retrieve the features from the scanned flitches and add them to the log models. The 8 logs were sawn using through-and-through sawing patterns with 25 mm thick flitches and scanned at one position.

Sawing simulation

The sawing simulation algorithm determines the optimal positioning by calculating all combinations of the positioning parameters, which is time-consuming and unrealistic for production. For instance, to determine the optimized positioning of 15 logs, the simulation took about 72 hours. Thus, the algorithm has to be improved to reduce the number of iterations or use optimization algorithms. The results reported in this thesis have to be validated with a real sawing.

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Part II

APPENDIX

Appendix I - Pseudo-code of the algorithm used for sawing simulation (for this specific case, the sawing pattern used was cant-sawing)

```
Initialize sum of calculated volumes to zero
number of files equal to 15 (number of logs)
for number of files do
  Determine mean top-end diameter from 7 measured angles
  for measured angles do
    Calculate the log length
    Calculate number of slices
    Determine top-end diameter
    Bound dimension of the slices
  end for
  Determine the mean diameter of the top-end of the log (DimMin)
  Set parameters for skew
  Set parameters for rotation
  Set parameters for Offset
  for Offset do
    for Skew do
      for Rotation do
        calculate the log length
        calculate number of slices
        Determine top-end diameter
        Bound dimension of the slices
        Set the saw kerf thickness
        if DimMin < 249.99 then
          use Sawing Pattern 1
        else if DimMin ≥ 250 and DimMin < 289.99 then
          use Sawing Pattern 2
        else if DimMin ≥ 290 and DimMin < 329.99 then
          use Sawing Pattern 3
        else if DimMin ≥ 330 and DimMin < 369.99 then
          use Sawing Pattern 4
        else if DimMin ≥ 370 and DimMin < 409.99 then
          use Sawing Pattern 5
        else if DimMin ≥ 410 and DimMin < 449.99 then
          use Sawing Pattern 6
        else if DimMin ≥ 450 and DimMin < 489.99 then
          use Sawing Pattern 7
        end if
        Get the output of sawn boards defined with XY coordinates
        Calculate the edged volume of sawn board
        Calculate the board thickness
```

```
            if centerboard or sideboard then
                Calculate the volume of edged board
            end if
            Sum the calculated volumes
            Prepare output to save the data
        end for
    end for
  end for
  save data in txt file format
end for
```

Appendix II - Log Models

Log models after 3D-scanning and reconstruction, and graded according to Bunster (2012).

Log 1. Jambirre, Grade 3

Log 2. Jambirre, Grade 2

Log 3. Jambirre, Grade 3

Log 4. Jambirre, Grade 3

Log 5. Jambirre, Grade 3

Log 6. Jambirre, Grade 1

Log 7. Jambirre, Grade 3

Log 8. Jambirre, Grade 3

Log 9. Jambirre, Grade 3

Log 10. Jambirre, Grade 3

Log 11. Umbila, Grade 3

Log 12. Umbila, Grade 3

Log 13. Umbila, Grade 2

Log 14. Umbila, Grade 3

Log 15. Umbila, Grade 2

Part III

Paper I

A Review of Mozambican Wood Exploitation - Map of the Processing Chain

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A Review of Mozambican Wood Exploitation - Map of the Processing Chain

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ABSTRACT
Mozambique is one of the countries with large forest coverage in the southern part of Africa and the forest is the livelihood of many Mozambicans. Exploitation of the forest resource is made for firewood, charcoal and wood production for local use, but also for export of sawn lumber and round wood. It is important for the country and its wood-processing industry to reach a state of sustainable wood exploitation. The objective of this work is to map the situation of the Mozambican forest exploitation considering the wood processing chain: harvesting, reforestation, sawing, grading, market and export. The investigation was carried out in three important provinces from a wood production perspective. Interviews were conducted with persons involved in the wood processing chain. The results were compared with data such as provincial reports and the National Forest Inventory. The interviews showed that the current wood exploitation is not fully in accordance with the forestry rules and laws. One major problem is the low level of reforestation activities. Other examples of problems that threaten the goal of sustainability are the lack of human, financial and material resources. The presence of illegal cutting and non-declaration of harvested logs shows the need for increased control. Among 118 tree species found growing in the country, only a few are processed for commercial purposes. One major reason is the lack of knowledge of machining properties. The demand for those few species is high and around 74% of the wood production is exported and traded as sawn lumber or round wood. The market for high-level processed products for export is low, and that means sawmills have few incentives to invest in equipment for further processing. The domestic market works differently, with local entrepreneurs doing the secondary processing and delivering all kinds of products to the customers.

Keywords: *processing chain, Mozambique wood exploitation, tropical species*

INTRODUCTION
Mozambique has great potential to become one of the larger lumber producers in the southern part of Africa. The country has approximately 26.9 million hectares of productive forest for industrial logging (Marzoli, 2008). The forestry sector is seen as underperforming in terms of resource management and the competitive wood processing industry (Ogle *et al.*, 2005).

However, the exploitation of wood today is mostly for export as pre-processed lumber and round wood, which in turn contributes to the national income.

Mozambican wood species are characterized overall as being a very dense material, with logs having a non-uniform shape, both of which factors affect their yield and machinability. The conversion rate is very low, around 30% (Chitará, 2003). As a result, the price of the final products is greatly affected by rapid dulling of cutting tools, low lumber yield and the high costs of equipment and transportation. Thus, investment in sawing equipment and further processing is low because the lumber is mostly exported with low added value (Mackenzie, 2006; Chitará, 2003).

Few companies exploit and manufacture wood products for domestic consumption. Some companies manufacture high quality end-consumer products and sell them at high prices which are unaffordable for many Mozambicans. Thus, most products are provided by small carpentries and are sold on informal markets at low prices and, with low quality. Defects such as cracks, rots, warp and poor surface quality are commonly found in these products. Due to this, imported wood products are gaining space in the domestic market despite their high price. Also, imported products are seen as having more attractive designs and better finishes than the domestic products.

Recently, the domestic consumption of processed wood products is showing a slight increase mainly in construction and the furniture sector, but the situation is still unsatisfactory. Therefore, the trend is that the Mozambican tropical species are losing market share over other materials such as steel, aluminium and *pine* beams from abroad. Given these conditions, improved knowledge of wood processing and marketing of these hard-to-cut species is needed and would enable the country to reach a state of sustainable wood exploitation, providing more jobs and boosting the economy.

The objective of the present study is to map the exploitation process from harvesting through to the manufacture of final products, highlighting the reforestation, harvesting, sawing, grading and commercialization, with the aim of better understanding the wood processing chain in Mozambique.

MATERIALS AND METHODS

The data was collected in the three provinces of Cabo Delgado, Nampula and Sofala. The provinces were selected from the perspective of the importance of each on wood production. The data consists of literature findings and results from interviews conducted in the study. Interviews took place with concessions owners, simple licence explorers, sawmill owners, carpentries owners, technicians of the National Directorate of Land and Forest (DNTF) and the Provincial Directorate of Forest and Wildlife.

The interviews conducted and recorded were with 9 concessions owners, 3 simple licence explorers, 4 carpentries owners, 3 technicians from the Provincial Services of Forest and Wildlife (SPFFB), 1 technician from DNTF, 2 technicians from the Forest Inventory Unit of the Agriculture Ministry and one forest consultant. The interviews were held to determine the state of art of the wood processing chain: harvesting, reforestation, sawing, grading and market.

RESULTS AND DISCUSSION

Current situation of wood production

In Mozambique, wood exploitation is carried out by licensed companies or individuals, here named concession and simple licence exploiters, respectively. Table 1 illustrates the number of exploiters registered in 2011. It can be seen that Sofala province has the highest number of concessions among the three investigated provinces. According to the interviews, this may be due to the abundance of the most sought-after species combined with access to port facilities. Also, most of the concessions in Sofala are located along the main road, which facilitates the transport of logs or sawn products.

Table 1 Number of concessions and simple licence exploiters. Source: SPFFB (2011)

Province	Concessions	Simple licence
Cabo Delgado	17	73
Nampula	10	55
Sofala	26	70

Cabo Delgado and Sofala province have high numbers of simple licence exploiters. It was found during the interviews that most simple licence owners work indirectly for concessions due to a lack of their own capacity and funds, *i.e.*, the concession owners pay the annual licence and provide chainsaws and other tools. As compensation, the simple licence owners sell all the harvested logs at a low price. This practice increases the rate of deforestation, since their ultimate goal is to harvest more for higher profits.

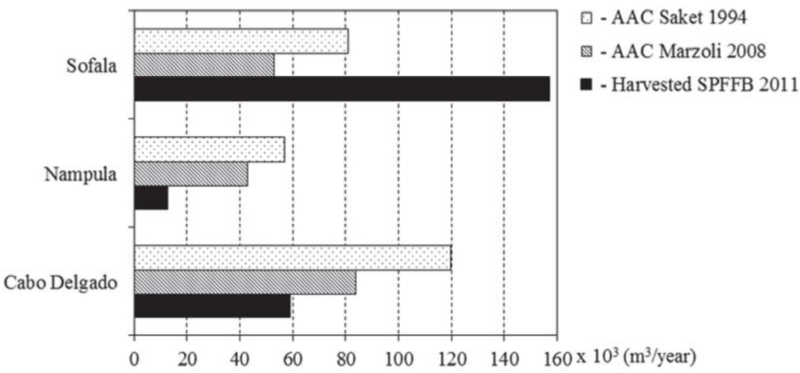

Fig. 1 Annually admissible cut in 1994 and 2008 versus amount of wood harvested in 2011. Sources: Saket (1994), Marzoli (2008) and SPFFB (2011).

It is quite difficult to compare data from different sources and years as attempted in this study; however, Fig. 1 shows that Cabo Delgado and Nampula are harvesting less than the recommended figures as regulated by the state. However, Sofala is harvesting about 50% above the recommended annually admissible cut (AAC). Interviews revealed that the recommendations are not being observed by Sofala SPFFB. Instead, the SPFFB is using informal local forest reports and management plans as a base to approve volumes to be harvested annually. This explains the high amount of wood harvested in 2011 in that region. Also, the reported results for Cabo Delgado and Nampula may be misleading, since not all harvested logs are declared and there are many non-licensed cutters working for concession owners, buyers or exporters.

Most marketed species

According to the Mozambican forest law, the species are graded into five classes: precious, 1st, 2nd, 3rd and 4th. Of these classes, 1st class species are the most exploited and this is the only class that is not accepted for export without pre-processing.

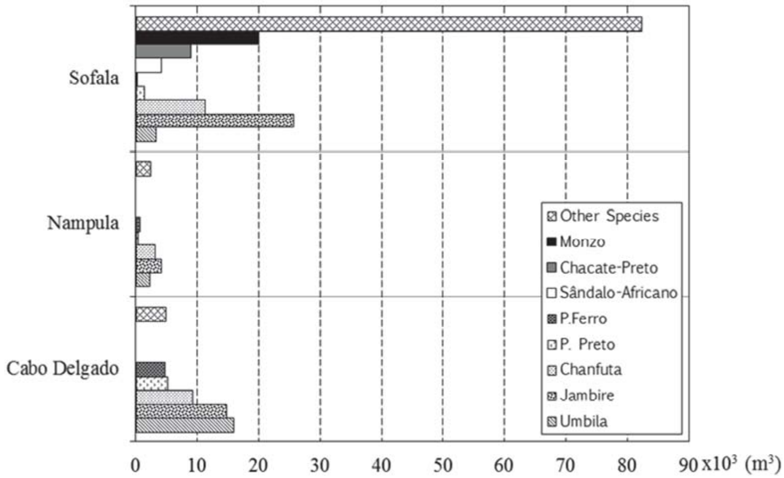

Fig. 2 The most harvested species in the investigated provinces. Source: SPFFB (2011)

From the three provinces, the following species are commercially exploited: Umbila *(Pterocarpus angolensis* DC.*),* Jambire *(Millettia stuhlmannii* Taub.*),* Chanfuta *(Afzelia quanzensis* Welw*),* Pau ferro *(Swartzia madagascariensis* Desv.*)* and Pau preto *(Dalbergia melanoxylon* Guill. & Perr.*),* Sândalo-Africano *(Spirostachys africano* Sond.*),* Chacate-Preto *(Guibourtia conjugata* J.Léonard*)* and Monzo *(Combretum imberbe* Wawra) (see Fig. 2). According to the interviews and literature, the most sought-after species are: Umbila, Jambire and Chanfuta. Chacate-Preto and Sândalo-Africano belong to the precious class, and the others to the 1st class. The graph shows also that many other species are exploited. Most of them are used for internal consumption and belong to the 2nd, 3rd and 4th classes.

Production chain

Harvested logs are transported to the main landing site or to sawmills, which are commercialized. Fig. 3 shows a schematic representation of the production chain. Most of the harvested volume is exported as pre-processed and a lesser amount as round wood. Nevertheless, the added value is low since the processing is only made to produce a square or rectangular shape, without observing any standard of quality or dimensions. The domestic market absorbs the rest of the harvested logs.

The processing for exportation is carried out at concession sawmills and local industry sawmills and the most processed are the 1st class species.

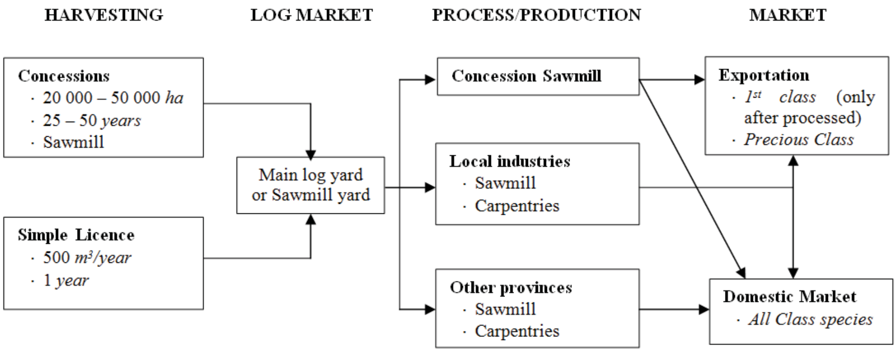

Fig. 3 Schematic representation of wood production chain in three provinces

Harvesting

Harvesting is mostly done with the aid of chainsaws. Handsaws and chisels are not allowed. However, due to the lack of inspections, some wood-cutters and illegal cutters are still using these hand tools. Most illegal cutters operate and live in the licensed areas. They cover for this activity by taking advantage of a law which states that the population living in these areas is allowed to exploit forest resources for non-commercial purposes. Although efforts have been done to minimize the illegal cutting, the SPFFB's are concerned because many licensed operators collaborate with local illegal cutters, resulting in low declaration of harvested logs.

The logs are commonly transported by trucks and tractor trailers.

Sawing and drying methods

The Mozambican law of forest and wildlife states that the concession owners must possess technical resources and industrial equipment to process or transform logs *i.e.*, concession exploiters must have a sawmill.

Sawmills are constituted mostly by single units and the equipment most commonly used is band saws and circular saws, as shown in Fig. 4 and Fig. 5. Circular saws are less used in sawmills, which may be due to the large diameter of the logs and because the cutting width increases with increased sawblade diameter. In general, sawmills are equipped with sharpeners, spring set machines and blade tensioners and in some cases with machines or guillotines to produce teeth. In Fig. 6 a typical sharpener section is shown. The tips of circular saw blades are commonly sharpened using hand grinders. Normally, the machines are bought second-hand and few sawmills have adequate sharpening tool installations. In addition, there is a lack of saw doctors to improve the performance of cutting tools.

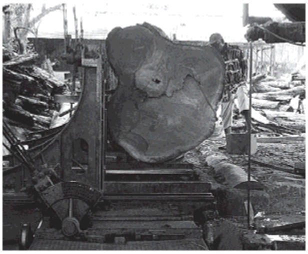

Fig. 4 Bandsaw sawmill. (Cabrussica sawmill/Sofala)

Fig. 5 Circular sawblade sawmill. (David sawmill /Nampula)

Fig. 6 Sharpener section. (Catapu sawmill /Sofala)

During sawing, the breakdown strategies are defined by machine operators or by superiors and sometimes by the owner of the logs. This affects greatly the yield since the decision depends entirely on the operator’s judgment and abilities, and in many cases is made with a lack of wood and process knowledge. The production of inferior quality and waste is common and the productivity is rather low in Mozambican sawmills. The sawing is mostly done when the logs are green and air or water is used as lubricant to reduce friction between the wood piece and the sawblade, also reducing the heat.

Fig. 7 Informal lumber market

Fig. 8 Traditional carpentry

Fig. 9 Resizing of board thickness

The sawn timbers are transported from sawmills and immediately packed in ship containers for export. The lumber for domestic use is often sold at sawmills or at informal markets without being dried due to the lack of knowledge both of drying techniques and their importance, and of drying facilities and storage space. Fig. 7 shows a common informal lumber market. A few sawmills dry their lumber using kilns and some use air-dried storage. Sawmills with drying facilities mostly produce final consumer products and occasionally export planks, boards or round wood.

In Mozambique, the manufacture mostly takes place in traditional carpentries without a power supply and the equipment used is hand tools (Fig. 8). Small sawmills (Fig. 9) provide services to the carpentries such as sawing, resizing the thickness of boards, profiling, turning, etc.

Grading methods

The grading methods used by the loggers are not the same and are normally set by the buyers. The offer of wood, amount of orders, diameter measurement method used, in combination with the grading rule applied, also affect the grading system. One main grading rule is based on the diameter value, as shown in Table 2. Here, different diameter values are used to set the grade for the same species; for instance, Umbila and Jambire use different diameter values to define the same grades.

Table 2 Examples of two different grading systems used in the investigated provinces

Grading rules 1

Species:	Umbila, Jambire	Chanfuta
	1st grade: Ø ≥ 40 cm	1st grade: Ø ≥ 60 cm
	2nd grade: 37≤ Ø ≤ 39 cm	-
	3rd grade: 34≤ Ø ≤ 36 cm	-

Grading rule 2

Species:	Umbila, Mutiria, Muanga and Jambire	Pau ferro
	Grade A: Ø = 40 cm	Class A: Ø = 35 cm
	Grade B: Ø = 34 cm	Class B: Ø = 30 cm
	Grade C: Ø = 30 cm	Class C: Ø = 20 cm

In addition to the above-mentioned, the interviews revealed that two diameter measurement methods are commercially used (Fig. 10). These two methods are also different from the one used and defined by SPFFB, where the bark thickness is included in the diameter measured.

a) *b)*

Fig. 10 Diameter measurement used commercially. Method a) Grading rule 1; b) Grading rule 2

In the first commercial method (Fig. 10-a), the diameter is obtained by measuring two cross-sections starting from the border between the sapwood and heartwood to the outer limit of the sapwood. Hence this method does not consider half of the thickness of the sapwood. The second method (Fig. 10-b) defines the diameter as the average of 4 measurements taken on the cross-section and with this method the full thickness of the sapwood is considered. For both methods, the thickness of the sapwood must be less than 7 cm.

Reforestation

Reforestation is difficult to perform in tropical forests due to the complex biodiversity. This makes it difficult to choose the techniques, methods and regeneration material to use in a specific area. Many policies are designed to safeguard the reforestation, but the lack of inspection or dissemination contributes significantly to deforestation. The interviews revealed that the reforestation is not being done properly, and only a few concession owners have started reforestation. The reasons given by the wood exploiters are lack of monitoring, plant material and technical support regarding the methods of reforestation. Furthermore, the high cost for reforestation fees was mentioned as an argument against undertaking reforestation activities.

The wood loggers are aware of the consequences that may arise from deforestation. They claim that they have already paid for it through the annual licence fee and also that it is impracticable to perform reforestation because the planting period coincides with the rainy season.

CONCLUSIONS

The aim of this study was to review the Mozambican exploitation process from harvesting to the manufacture of final products. The results revealed that the wood industry faces many challenges before reaching a state of sustainable wood exploitation, but also many opportunities to utilize this renewable resource better and hence to contribute significantly to the national income. The interviews showed that the forest and wood exploitation was not being conducted fully in accordance with forest exploitation rules and laws. Efforts are being made to adopt sustainable exploitation but the results are still unsatisfactory. Factors such as the lack of skilled human and material resources, the presence of illegal cutters, and non-declaration of harvested products are greatly affecting Mozambique’s wood exploitation. In addition, sawmills have low productivity and are producing large amounts of waste as a result of poor processing and decision-making. Sawn products in Mozambique rarely follow any standards for dimensions, grade or surface quality. The products manufactured by carpentries are of low quality and are unable to compete with imported products despite their low price.

The demand for wood is concentrated on three species in the investigated regions: Umbila, Jambire and Chanfuta. These wood species are not only those most wanted by the export market, but also the most heavily used domestically.

Therefore, it is urgent to develop knowledge's of the utilization, applicability, and marketing of other species to reduce the demand for these wood species.

In a future study, different strategies to break-down tropical species will be considered.

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Paper II

3D Phase-Shift Laser Scanning of Log Shape

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3D Phase-shift Laser Scanning of Log Shape

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In this paper, a portable scanner to determine the 3D shape of logs was evaluated and compared with the measurement result of a computer tomography scanner. Focus was on the accuracy of the shape geometry representation. The objective is to find a feasible method to use for future data collection in Mozambique in order to build up a database of logs of tropical species for sawing simulations. The method chosen here was a 3D phase-shift laser scanner. Two logs, a birch log with bark, and a Scots pine log without bark were scanned, resulting in 450 cross sectional "images" of the pine log and 300 of the birch log. The areas of each point cloud cross section were calculated and compared to that of the corresponding computer tomography cross section. The average area difference between the two methods was 2.23% and 3.73%, with standard deviations of 1.54 and 0.91, for the Scots pine and birch logs, respectively. The differences in results between the two logs are discussed and had mainly to do with presence of bark and mantle surface evenness. Results show that the shape measurements derived from these methods were well correlated, which indicates the applicability of a 3D phase-shift laser scanning technology for gathering log data.

Keywords: Outer shape; Log measurement; 3D scanner; CT scanner

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INTRODUCTION

Various methods are being used around the world to determine log shape to help sawyers optimize the value and volume yield of logs. The yield of processed softwood lumber can be improved with knowledge of the outer shape and inner features of logs prior to sawing (Grace 1993; Oja *et al*. 1998). Knowledge about the effect of such measurements and controls applied to tropical hardwood sawmills processes is incomplete. This is especially true for small hardwood sawmills in developing countries. The methods and techniques used are suitable for large sawmills, almost all of which require longitudinal conveyor transport of logs. This requirement is seldom satisfied at sawmills in developing countries. As a consequence, research about optimization potential and log positioning in small scale hardwood sawmills is hard to find. The vision of our future research is to study the impact of sawing patterns and log positioning, applying the best opening face (BOF) to study the value and volume yield of some tropical species and products in Mozambique. If future research show that Mozambican sawmills would benefit by using log shape measurement prior sawing, it may give incentives for small sawmills to invest in log scanning techniques. A brief description of the Mozambican wood processing industry follows.

The potential to improve the sawmill industry is great, as around 80% of logs are exported to Asian countries. The most common species exported are Umbila

(Pterocarpus angolensis D. C.), Jambirre *(Millettia stuhlmannii* Taub.), and Chanfuta *(Afzelia quanzensis* Welw.) (Shenga *et al*. 2013). Today, requirements of exported sawn products are low because the market price of processed wood is lower than that of round wood in these markets (Ekman *et al*. 2013). The cause of this peculiar situation is twofold: First, Mozambican forest law does not allow export of round wood (some species are exempt from this). Second, the link between Mozambique and the export markets is made by Asian companies, whose preference is round wood for their domestic wood processing industries. As a consequence, most of the wood is exported as blocks to fulfill the minimum requirements of Mozambican forest laws.

Unfortunately, the current export situation gives sawmills few incentives for investment in further processing capabilities. Finding complementing or new markets or decreasing the use of intermediaries (hence doing business directly with their markets) could improve the current export market situation. If actions to improve the market integration are made, it can be assumed that requirements of wood products will rise, as will requirements of the wood processing operations. In such a situation, Mozambican sawmills must be capable of producing and offering products with changed or stricter quality requirements. A second assumption is that the Mozambican wood raw material itself, coming from dense and high-valued species, could if correctly handled, processed, and marketed, be sold and exported as high-quality lumber that meets the specifications of any market.

Mozambican sawmills are characterized by simple equipment. Often, a band headrig with low production capacity and a low level of automation is used. The high-density logs that are processed are fairly short (2 to 3 meters) but of large diameters and irregular outer shapes. Skilled sawyers are rare, and the salary for a sawyer is often low. The employees at sawmills are often self-taught with no formal education regarding the tasks of their work. Ad hoc solutions are often used, resulting in great waste and low efficiency in the use of raw materials. Knowledge of how to apply different breakdown strategies to reach high value and volume yield of the sawn products is, overall, lacking.

To increase Mozambican knowledge of how to process tropical species in an efficient way, significant research is required. The strategy of our future research will be to scan logs in Mozambique prior to sawing, store the empirical data in a database, and execute simulations and test different production strategies. This setup will make it possible to saw the "virtual" logs an unlimited amount of times in a saw simulator. The alternative is to do a large amount of exhaustive empirical test sawings. To accomplish this, we need a methodology to determine the outer shape of logs prior to sawing which is portable and suitable for the low tech situation at Mozambican sawmills. The equipment must be lightweight, easy to use, and suitable for outdoor scanning. A practical limitation is that the log must be still during scanning because no (or very few) Mozambican sawmills are equipped for conveyor transport of logs suitable for traditional scanning techniques.

Different techniques for the measurement of log shape and processing of the corresponding data exist. Keane (2007) describes a software AutoStem^{TM}, which imports data from a laser scanner and processes it automatically for each scan in about 3 to 5 min. The result can be exported to different saw optimization software packages with an outer shape description of every decimetre. Bhandarkar *et al.* (1999) investigated a system for the detection and rendering of internal log defects using computer tomography (CT). Antikainen and Verkasalo (2013) described the acquisition of log shape using structured light analysis in which the 3D modeling and calculations were performed with a developed graphics processing unit. Pinto *et al.* (2003) used a WoodCim® inspector scanning system for the reconstruction of Maritime pine logs when sawing. All methods mentioned above require controlled, horizontal transport and/or rotation of logs during scanning, a requirement that can be problematic under typical Mozambican conditions.

Within the realm of portable scanners for potential use in structural geometric measurements of stationary objects, three primary ranging technologies are being used in the area of commercial laser scanners: (1) Time-of-flight discrete-return scanners; (2) Continuous wave phase-shift scanners; and (3) Time-of-flight waveform scanners. Time-of-flight discrete-return scanners pulses laser energy and measure the discrete time-of-flight of a return echo. They provide high accuracy even at large range (effective range is kilometers). The pulse frequency is usually around 100 thousand points per second. Phase based scanners emit a constant wave laser with its intensity modulated at a number of frequencies. They measure shifts in phase of the returned modulations to determine range. The phase based scanners can sample at much higher frequencies than time-of-flight scanners, around 1 million points per second, effective range is less than 100 meters. A phase based scanner is usually cheaper and lighter than a similar time-of-flight scanner. Time-of-flight waveform scanners record the full time trace of energy that is returned after a laser pulse has been emitted from the instrument. The key difference is that in the case of full waveform instruments, the full intensity trace is recorded for future analysis (Newnham *et al*. 2012). Terrestrial laser scanners (TLS) have been used for stand measurement and shape reconstruction (Simonse *et al.* 2003; Thies *et al.* 2004; Watt and Donoghue 2005; Maas *et al.* 2008; Dassot *et al.* 2012; Hilderbrant and Iost 2012; Kelbe *et al.* 2013).

However, TLS methods have some drawbacks if compared to the methods used to measure log shape in saw line. They require more than one scan position to get a full description of the object, which result in low acquisition speed. Moreover, the registration of scans is time-consuming and not automated enough requiring manual operations. Despite these disadvantages, TLS was found suitable for data collection for Mozambican sawmill environment. The phase-shift scanner was chosen for this study due to its benefits compared to Time-of-flight scanners.

Working principle for 3D phase-shift laser scanners

A sinusoidal, modulated laser beam is emitted and its reflection from an object is analyzed in order to determine the phase shift. The phase difference is proportional to the time taken by the laser to go to and from the object, and this time is proportional to the distance travelled. Laser technology is highly effective because the light wave is reflected from all solid surfaces with limited divergence, regardless of the nature of the obstacle. Thus, if f is the modulation frequency and T_l the phase shift, the distance d can be calculated according to following formula:

$$d = c \cdot T_l / 4 \cdot \pi \cdot f \qquad (1)$$

where c is the speed of light. The measurement result is a point cloud of measurement spots that can be used to construct 3D volumes.

Studies regarding the transformations of 3D volumes have been made using a variety of different algorithms. Thomas *et al.* (2006) investigated the detection of defects in hardwood using circles fit with a generalized M-estimation method. Hilderbrant and

Iost (2012) used a polygon method considering the azimuth angle position to calculate the volume of a stem from point cloud data collected by TLS. In the latter method, the coordinates are put in order and a medial line is traced through them. The increase of angle and the area of the cross section are calculated as the sum of the triangles formed by the points. Two examples of other methods used to determine cross sectional areas are the Pratt method and the Shadow area method. The Pratt method is based on direct least-squares analysis, which fits a line between the scattered points and gives the center coordinates and the radius of the cross section for area calculations (Pratt 1987). In the Shadow area method, or two axis shadow scanning principle, the cross section is simplified into four coordinates resulting in an oval representation, and its area is calculated as the area of an ellipse using the major and minor axes of the cross section (Green 1993). These methods were tested, and the first method yielded a conical or cylindrical shaped log (obtained using parametric plotting). It was affected by the distribution of points in the cloud, whereas the second gave more details of the outer shape. Unfortunately, diameter values were sensitive to the positioning of the log during scan when using the second scanning method.

Computer tomography (CT) scanner

A CT scanner consists of an X-ray tube and a detector (photographic film, semiconductor, or array) that rotates around the object being measured. When a high-energy beam generated by the X-ray tube passes through an object, measurements of the attenuation of the X-ray emission are generated and collected by a detector. These measurements allow for the generation of a two-dimensional image of a slice or section through a three-dimensional object. In wood, mass attenuation is approximately constant, which allows for reliable calculation of its density. Such density images can be used to calculate numerous qualities of a cross section such as its diameter, area, and others. Computer tomography has frequently been used for research on log features (Oja *et al.* 1998; Nordmark 2003; Rinnhofer *et al.* 2003; Skog and Oja 2009).

Objective

The aim of this study was to test the applicability and accuracy of a 3D phase-shift laser scanner for measurement of the outer shapes of logs. The evaluation was made by comparing the measurements from the 3D scanner with those from a CT (X-ray) scanner. This study was limited to only two logs, one without bark (straight) and one with bark (crooked and irregular outer shape). Focus was on the outer shape representation and not the absolute value of *e.g.* diameter, volume *etc*. Due to its small sample, this study should be seen as preliminary and indicative. The test results will guide us in the suitability of using the 3D phase-shift laser scanner for future data collection in Mozambique and possibilities to investigate the effects of BOF, breakdown strategies, and log positioning in Mozambican hardwood sawmills.

EXPERIMENTAL

Materials

A 3D phase-shift laser scanner, FARO Focus 3D S-120 (USA), was selected for testing. For the evaluation, two logs were used: a three metre birch log (*Betula pendula* Roth.) and a four and a half metre Scots pine log (*Pinus sylvestris* L.). To test the behavior of the 3D laser scanner for different surfaces, the birch log was scanned with bark, while the Scots pine log was scanned without bark (industrially debarked). Both logs were also scanned with a CT scanner (SOMATOM AR. T, Siemens AG; Germany), and the results were compared.

Methods

For each centimetre of the log, a cross sectional image of the log was gathered using the CT scanner. The length of the logs defined the number of resulting cross sections (300 for the three metre birch log and 450 for the four and a half metre Scots pine log). The CT scanner was set to produce 16-bit grayscale images. The image size was 512 x 512 pixels for a window size of 400 x 400 square millimeters, corresponding to a voxel size of 0.781 x 0.781 x 10 cubic millimeters.

The logs were then scanned individually with the 3D scanner from three positions. Figure 1 illustrates one of the scanning positions. Three spherical reference points were placed around the logs to allow precise registration of the scans. The range of the scans in the horizontal and vertical directions was limited to avoid scanning the surroundings and to speed up the operation. The position of the scanner with relation to the log determined the range setup. Each scan lasted around 6 minutes and describes millions of points with XYZ coordinates and RGB values. The point cloud (PC) data was registered, and unwanted information was removed using the Faro scanner software (SCENE version 5.2). The logs were then aligned in the XYZ coordinate system using CloudCompare (version 2.5.4.1) and saved in ASCII format before being imported into Matlab (MathWorks, USA) for calculation of cross sectional areas and comparison analysis.

The data were processed separately for each profiling method (as shown in the flow chart in Fig. 2) and then compared. The calculation of cross sectional area was done in Matlab using a Polygon method (Hilderbrant and Iost 2012).

Fig. 1. Setup for data acquisition. (1) Reference points; (2) 3D phase-shift laser scanner; (3) Computer tomography scanner and (4) the Scots pine log.

A description of how the images from the CT scanner and the PC data from the 3D scanner were manipulated and analyzed is presented in Fig. 2.

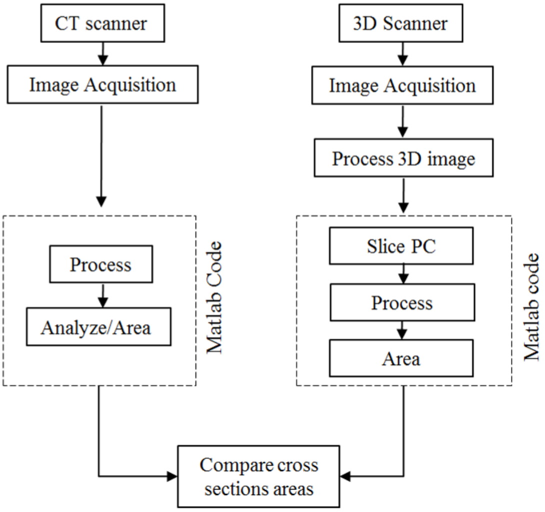


Fig. 2. Process flow chart of acquisition and processing for computer tomography (CT) and 3D scanner data.

CT data

The sequence of greyscale images, or cross sections, was loaded and processed for area determination as shown in Fig. 2 (left column). The results are shown in Fig. 3. The basic steps of data analysis were as follows: (1) The data (original data from CT scanner in .IMA format) was transformed to a file readable by Matlab. The result of this transformation is a file in a .tif format; (2) The transformed data was converted into an image (*mat2gray*), as shown in Fig. 3a; (3) A *median* filter (7 x 7) was applied, as shown in Fig. 3b; (4) Thresholding was applied to the filtered image resulting in a binary image, as shown in Fig. 3c. The threshold level was different for each cross section, with an average of 0.3; and (5) The cross sectional areas were determined, as shown in Fig. 3d, using the *regionprops* command. These values were saved in a worksheet.

PC data

The laser scans were registered with the help of the built in 3D phase-shift laser scanner software (SCENE), were aligned onto a XYZ coordinate system in CloudCompare 2.5.4.1, and were processed using a Matlab algorithm. Figure 2 (right column) shows a sequence of the process, and Fig. 4 shows an example of a cross section of point cloud data and its associated boundary description.

The point cloud data was first cropped to achieve the same log length as the CT data, and was sectioned in the same way as the CT cross sections (10 mm distance). The number and position of each cross section were tuned to be the same as in the CT case. The Matlab algorithm used is described as follows: (1) The data was loaded and color information was removed (the color information was not used in the test); (2) A size output was acquired by calculating the length of the log; (3) The distance between cross sections was set (x = 10 mm) and the number of cross sections was determined; (4) The points in Cartesian coordinates were converted to polar coordinates for each cross section and sorted according to increasing angle; (5) The area of each cross section was calculated using a polygon formula,

$$A = [(x_1 + x_2)\cdot(y_1 - y_2) + (x_2 + x_3)\cdot(y_2 - y_3) + \ldots + (x_n + x_1)\cdot(y_n - y_1)]/2 \qquad (2)$$

where n is the number of vertices; and (6) The area values were saved in a worksheet file.

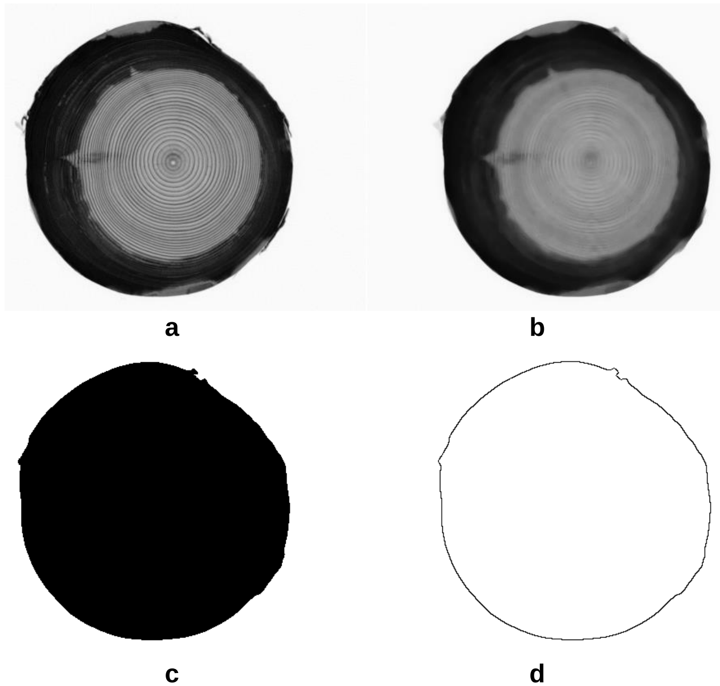


Fig. 3. Steps for determining the cross sectional area of CT images (Scots pine log): (a) original grayscale image; (b) filtered image; (c) threshold image; and (d) description of cross sectional boundary.

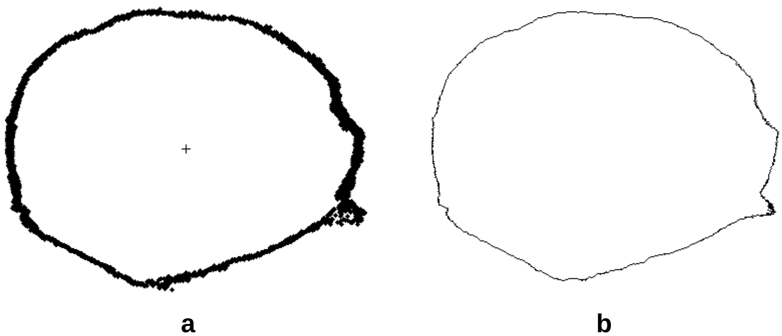


Fig. 4. Examples of cross sectional areas determined via 3D scanner data (birch log): (a) point cloud (PC) describing the boundary of the cross section; and (b) line fit to describe its boundary.

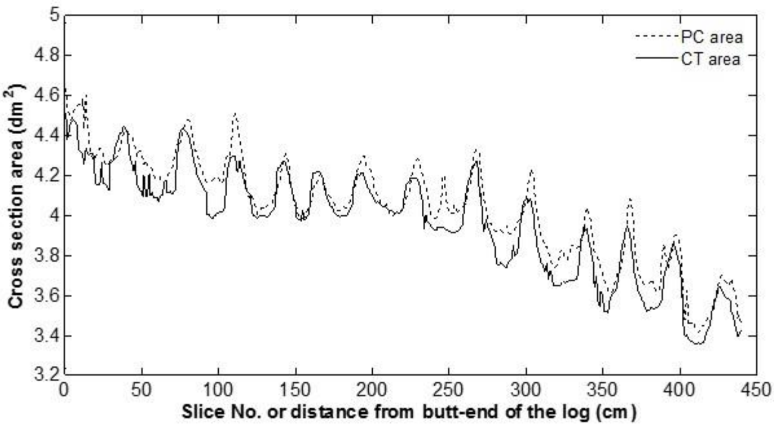
Finally, the cross sections of the CT slices and the corresponding cross sections from the 3D scanner were plotted in the same coordinate system for comparison. The average area difference and standard deviation were calculated.

RESULTS

Figures 5a and 6a show a longitudinal representation of the reconstructions of the two logs from point cloud (PC) data. In the 3D representation (which was difficult to show in manuscript format), external logs features were visible, such as the location of the butt and top ends, taper, and crook. Additionally, the surface mantle features were also visible; for instance, the presence of loose bark on the pine log and debranched knot marks and the presence of lichen on the birch log.

The 2D reconstruction of the Scots pine log, as shown in Fig. 5a, shows a white surface along the log, revealing incomplete data. This phenomenon was detected on the top and bottom of the log and could have been avoided by improved positioning of the 3D scanner. The lower left side of the log is also white but this is not missing data; rather, this was due to reflections of direct sunlight.

a



b

Fig. 5. (a) Reconstruction of point cloud data of the Scots pine log; and (b) comparison of cross sectional areas between data from the 3D scanner and computer tomography. The point cloud (PC) areas are represented with dotted line (- - -) and computer tomography (CT) areas with a continuous line (—).

For visual comparisons, the graphs in Figs. 5b and 6b show the cross sectional areas and their respective locations along the length of the logs. The CT areas were systematically smaller than the PC areas (note the offset between the solid and dotted line). This difference in area between the CT and PC scans was somewhat smaller for the

Scots pine logs than the birch log. The graphs also show the shape of the logs, the location of butt and top end, the taper, and the location of knot whorls.

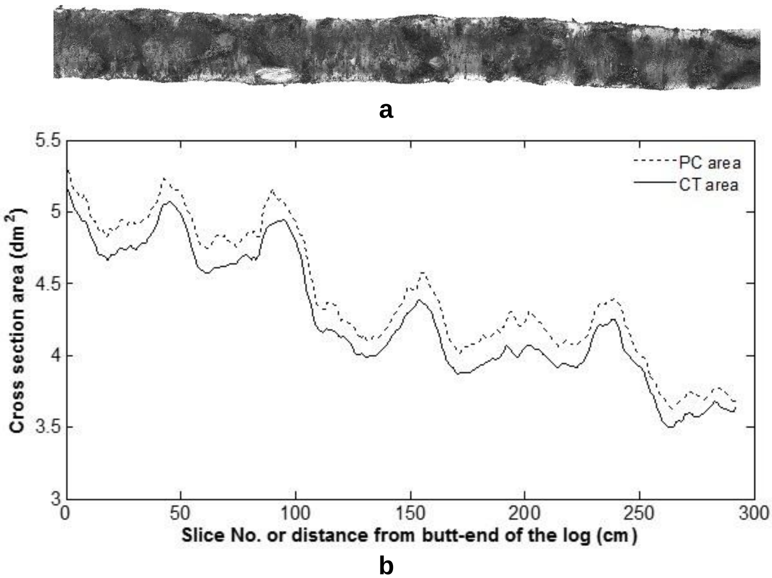


Fig. 6. (a) Reconstruction of point cloud data of the birch log; and (b) comparison of cross sectional areas between data from the 3D scanner and computer tomography. The point cloud (PC) areas are represented with dotted line (- - -) and computer tomography (CT) areas with a continuous line (—).

The average difference between the areas determined using the two methods was 2.23% and 3.73%, with standard deviations of 1.54 and 0.91, for the Scots pine and birch logs, respectively.

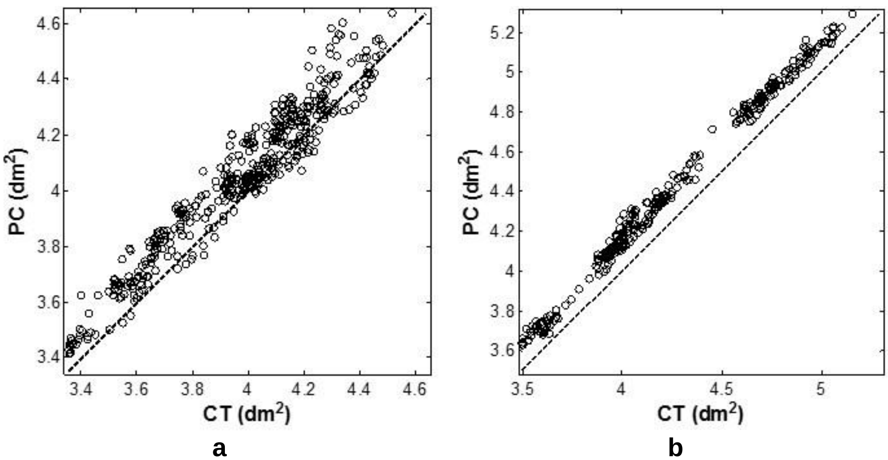


Fig. 7. (a) Scots pine data and (b) birch data. The plots shows that the CT and PC are correlated with r = 0.962 and r = 0.997 for pine and birch data, respectively

Despite the systematic difference between the results of the two methods, the measurements are correlated with r = 0.962 and r = 0.997 for pine and birch data, respectively. Figures 7a and 7b show the relation of data with an identity line. The systematic measurement error of the two logs is revealed by the closeness of points to the identity line. Pine data are more spread out but closer to the line, revealing higher standard deviation and smaller error between two methods, Fig. 7a. Whereas the small spread and the larger shift from the identity line of the birch data reveals lower standard deviation and bigger error, Fig. 7b.

DISCUSSION

Overall, the cross-sectional areas determined from point cloud (PC) data showed good agreement with the comprehensive computer tomography (CT) areas. However, some differences between the two methods were observed. There are some possible sources of error in the performed investigation including errors from the acquisition method itself, errors from the data processing method, and errors due to properties of the object scanned (log surface features like loose bark, scratches, cracks, and others). In Fig. 5b, some of these errors occasionally resulted in larger CT areas than PC areas. Furthermore, the same phenomenon is represented by values under the identity line, Fig. 7a. This may be a result of improper lengthwise matching of cross section positions caused by missing data at the butt and top ends of the logs (because of the device used to hold the logs during scan). The overlaps could be avoided by using fixed reference points on the log for both scan methods. Moreover, Fig. 8 shows an example of one cross section that was not fully described by the PC *i.e.,* representing missing data. The linear approximation that describes the PC boundary depends on the distribution of points along the scanned surface, meaning that irregularities on the surface of a log affect the point cloud measurement results.

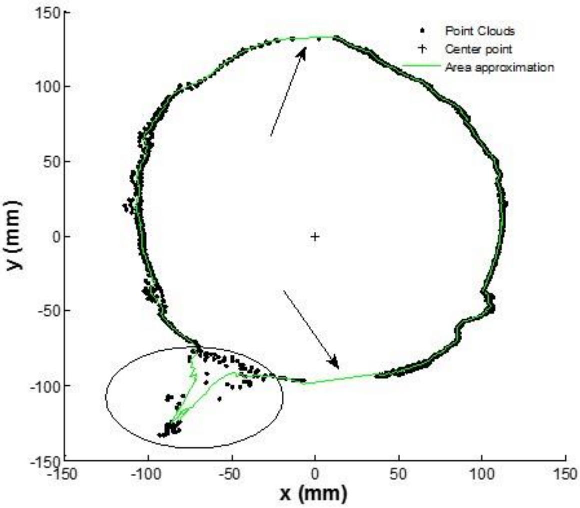


Fig. 8. Example of a Scots pine cross section from the point cloud data that shows missing data from the scanning indicated by arrows. The ellipse indicates an instance of loose bark being considered as part of the cross section.

Despite the absence of some data, the area estimation was not severely affected (Fig. 5b). Figure 8 also shows that loose bark was considered as part of the cross section, which of course affects the area estimations.

The somewhat more crooked birch log had few irregularities on the mantle surface, and the point cloud results agreed with properties of the real log as shown in Fig. 7b. The standard deviation value was low, only 0.91. The Scots pine log had many defects on the mantle surface such as cracks, scratches, and loose bark. Some of these defects increased the standard deviation and the data spread as shown in Fig. 7a. This spread reveals surface irregularities and was caused by industrial harvest, handling, and debarking.

The difference in area values seen in the birch plot, Fig. 6b, reveals a large systematic error, which might be caused by the presence of bark and lichen attached to the surface. This can be handled by subtraction when scanning logs with bark. Here, the average of the area difference can be used to remove the bark thickness mathematically if it is known. In practice, if the PC method should be used for diameter or volume estimation of logs, the systematic error shown here could be reduced by a calibration operation.

Differences in the cross sectional areas of the Scots pine and birch logs are in agreement with the results found in related works. Lerch *et al.* (2008) reported 2% inaccuracy when taking anthropometric measurements with a 3D body scanner and a CT scanner; Hildebrant and Iost (2012) reported a 1% difference when measuring a PVC (polyvinyl chloride) pipe stem model. Furthermore, previous studies made using a terrestrial laser scanner to measure stems provided results that agree with our findings. Dassot *et al.* (2012) reported accuracy to within 10% when estimating the volume of the stem of trees and to within 30% when estimating that of tree branches. Kelbe *et al.* (2013) reported an accuracy of 12.5% with a 4.5% overestimation when reconstructing 3D stem models using low-cost TLS.

One way to improve the PC data acquisition is to avoid point cloud outliers. This can be achieved by cleaning the logs mantle surfaces prior scanning or by using improved methods for data processing before the area calculation, for instance the method described by Thomas *et al.* (2004). Despite these deficiencies in data acquisition and that only two logs were measured, the study show that a 3D phase-shift laser can be used for log geometry measurement. With experience from this preliminary test we recommend this methodology to be tested on a larger sample of logs, compared with other existing scanners to clarify the accuracy in and suitability for log volume measurement.

CONCLUSIONS

1. The point cloud data provide a detailed description of a logs external geometry and shape and showed good compliance with the reference measurement made with computer tomography.
2. The impact of the systematic error incurred with point cloud measurement can be reduced or handled by calibration operations (not investigated here). The error can also be reduced by cleaning up the mantle surface prior scanning and thus avoiding outliers in the point cloud measurement.

3. The test results show that the 3D phase-shift laser scanner is feasible to use for our future data collection in Mozambique aiming at investigating effects of BOF, breakdown strategies, and log positioning in Mozambican hardwood sawmills.

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Paper III

Simulation of Tropical Hardwood Processing - Sawing Methods, Log Positioning, and Outer Shape

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Simulation of Tropical Hardwood Processing – Sawing Methods, Log Positioning, and Outer Shape

Pedro Ah Shenga,* Peter Bomark, Olof Broman, and Dick Sandberg

To increase understanding of breakdown strategies for Mozambican timber, simulations were carried out using different sawing patterns that can be alternatives to the low degree of refinement performed for export today. For the simulations, 3D models of 10 Jambirre and 5 Umbila logs were used. The log shape was described as a point cloud and was acquired by 3D-laser scanning of real logs. Three sawing patterns (cant-sawing, through-and-through sawing, and square-sawing) were studied in combination with the log positioning variables skew and rotation. The results showed that both positioning and choice of sawing pattern had a great influence on the volume yield. The results also showed that the log grade had an impact on the sawing pattern that should be used for a high volume yield. The volume yield could be increased by 3 percentage points by choosing alternative sawing patterns for fairly straight logs and by 6 percentage points for crooked logs, compared to the worst choice of sawing pattern.

Keywords: Yield; Value; Positioning; Saw method; Millettia stuhlmannii; Pterocarpus angolensis

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INTRODUCTION

Extensive studies regarding the sawing of raw material from temperate zones can be found in literature, but studies of the sawing of tropical hardwood species, particularly from Miombo woodlands, are rare. The Miombo woodlands cover the central region of Zimbabwe and extend into Mozambique, southern Zambia, and Malawi. In Mozambique, the Miombo woodlands cover approximately two-thirds of the natural forest area, and timber from these woodlands is an important resource for the Mozambican sawmills industry. The Miombo species have a particularly irregular outer shape (crook in all directions, ovalness, and "bumpiness" as a result of large branches), and therefore the trunks are bucked to fairly short logs at harvesting. The log requirements for sawing are in general an average diameter of about 70 cm and a length of 2 to 3 meters. The lengths used are kept short to reduce the effect of log crookedness on the volume yield of sawn timber. At the harvesting site, logs that are too crooked and do not fulfill the size requirements, having a low proportion of heartwood or a large number of knots or other defects, are often left behind in the forest.

Logs are in general graded into four classes (Sitoe and Bila 2008; Bunster 2012): Grade 1 - logs with a very low degree of crook, Grade 2 - logs with one pronounced crook, Grade 3 - logs with more than one crook, and Grade 4 - logs that contain rot and/or have a length less than 1 meter. There is also a minimum diameter for harvesting. This diameter is measured at breast height and is 40 cm for the most commercial species. The Miombo species in Mozambique is processed in sawmills with a simple layout of bandsaw or circular-saw headrigs. Small-scale firms produce relatively small volumes of sawn timber for the domestic markets, and most of the logs are processed for export. For export, the logs are sawn into blocks or cants consisting mainly of heartwood, with little processing as possible in order to fulfill the national regulations, which merely require some degree of processing of the logs before export.

The sawmill work in Mozambique is largely a manual operation with no kind of technical support for transporting logs or sawn timber during the sawing process or for positioning the log (skew and rotation) in the saw machine to determine the position of the first cut. The manual positioning operations and the non-optimal choice of sawing pattern often results in large amounts of waste in the sawing (Ah Shenga *et. al* 2013). For economic reasons, and also for increased sustainability, there is thus a need to increase the volume yield in the sawing process, especially from logs with an irregular and crooked shape, *i.e*. logs of grades 2 or 3. There is also a need to increase the use of low-grade logs that are often left in the forest. Log shape measurement and simulation techniques could be a way to improve the understanding of how to manage a sawing process in general, and thereby increase the use of raw material in the process.

Several computer simulation models have been developed to study the volume yield and value recovery of sawn timber (Dogan *et al*. 1997; Gibson and Pulapaka 1999; Nordmark 2005; Shu-Yin and Que-Ju 2005; Lin *et al*. 2011). Todoroki and Rönnqvist (1999) used dynamic programming to describe some procedures to determine the optimal cutting of flitches into graded dimensional boards. Lin *et al*. (2011) concluded that the log grade, log diameter, species, log sweep, and log length affect the value and volume yield of sawn timber. Lin and Wang (2012) studied the choice of the best opening face in sawing, edging, and trimming of the sawn timber, and found that an optimization system for the process stages could significantly improve the value recovery and could also assist mill managers and operators in the daily operation of the sawing process. In an optimization study, Lundahl and Grönlund (2010) showed that an optimal combination of rotation and parallel positioning of the log in the first and second saw-machines of a typical Swedish sawmill could on average increase the volume yield by 4.5 percentage points. Fredriksson (2014) complemented this study by using computed-tomography data to optimize the positioning of the logs before sawing according to the knot structure in the log, and he showed that it was possible to achieve a gain of the sawn timber of up to 21%.

Similar studies related to the sawing process of tropical hardwoods are scarce. Iwakari (1990) reported a volume yield of 45 to 55% when sawing Pau Rainha (*Brosimum rubescens*) and Macaranduba (*Manilkara huberi*) from Brazil. These tropical hardwood species have some similarities to the Miombo species such as high density, large diameters, and large proportions of heartwood. Volume yield data of some logs species from Mozambique were presented by Egas *et al*. (2013), who carried out interviews at sawmills, where they assessed the volume yield to be about 40%.

To build up a competitive wood industry in Mozambique there are great needs for change and development in both the sawmilling and the forestry sector. If logs of lower grade (crooked and irregular shaped logs) could be processed to a great extent with less waste, this could be one way to increase profits, to modernize sawmills, and also to put an emphasis on the secondary processing of the sawn timber.

The overall aim of the present study has been to show how the volume and value yields can be improved in the sawing of logs from the Miombo woodlands, specifically in Mozambique.

The objective of this study was to investigate how the volume yield of two miombo species was affected by log positioning, selection of breakdown strategy, and an additional secondary processing step. The study focuses on the sawing of crooked logs with an irregular shape.

MATERIAL AND METHODS

This study investigates the impact of crook, sawing pattern, and log positioning on volume yield by a simulation of the sawing process based on the outer shape of 15 logs that had been scanned, and the data were further processed in a log database. All the logs were also sawn with a single specific sawing pattern, and the results were used as a reference for the simulation.

The Log Database

The logs were selected from among the most exploited species from a log yard at a local sawmill. A total of 10 Jambirre (*Millettia stuhlmannii* Taub.) and 5 Umbila (*Pterocarpus angolensis* D.C.) logs were selected for the database, where 11 of the logs had a high degree of crook (Grade 3) and the other four logs were straighter (Grades 1 or 2). Results are shown in Table 1.

The logs were measured and graded by sawmill employees according to the rules used in the Mozambican wood industry (Bunster 2012). Figure 1 shows some typical log shapes.

Fig. 1. Three examples of log shapes and their grades according to Bunster (2012). Log numbers according to Table 1

The log shape was obtained using a three-dimensional (3D) phase-shift laser scanner, FARO Focus 3D S-120 (FARO 1981), and the data used the outer shape of the logs as 3D models described by point clouds. The scanning was performed in Cabo Delgado, Mozambique, at the Kwekwe sawmill. The log models were cropped on both ends to reduce problems with missing scan data.

To limit the size of the database and increase the speed of the sawing simulations, each log was characterized at every 10 mm by log-discs. Additional information regarding the processing of point cloud data to build up a log model is given in Ah Shenga *et al*. (2014).

Table 1. Description of the Log Database

Log No.	Species	Grade*	Top diameter** (cm)	Butt diameter** (cm)	Length (cm)
1	jambirre	3	31	33	275
2	jambirre	2	24	32	177
3	jambirre	3	25	28	244
4	jambirre	3	23	26	240
5	jambirre	3	31	36	244
6	jambirre	1	36	36	248
7	jambirre	3	28	31	229
8	jambirre	3	25	34	286
9	jambirre	3	30	35	266
10	jambirre	3	34	43	282
11	umbila	3	38	42	309
12	umbila	3	39	41	317
13	umbila	2	35	41	320
14	umbila	3	36	40	376
15	umbila	2	38	43	324

* Grade 1 - logs with a very low degree of crook, Grade 2 - logs with one pronounced crook, Grade 3 - logs with more than one crook, and Grade 4 logs containing rot and/or that have a length less than 1 meter.
** The manual measurement was made using the average of two perpendicular diameters.

Breakdown Strategies for Use in the Simulation

The breakdown strategy for this study was to try to find a way of sawing that *a)* increases the volume yield of sawn timber, especially from crooked logs, and *b)* also increases the degree of refinement directly at the sawmill or close to its production site. This target should in practice be reached using the same type of production equipment that is used today, *i.e*. a bandsaw or circular-saw headrig.

Today sawmills use cant-sawing and through-and-through sawing patterns (Fig. 2) to process the logs to sawn timber for both export and the domestic market. The cant-sawing method requires simple equipment, and the sawn timber is exported with low added value. The sawn timber from through-and-through sawing is in general processed further at sawmills or at separate joineries to fabricate consumer products such as furniture, interior fittings, or joinery for house building.

As a result of a combination of practices seen in the field, three sawing patterns were identified as being interesting to study (Fig. 2):

- Cant-sawing (CS): This method is commonly used to process sawn timber for export, the main products being cants and sideboards.
- Through-and-through sawing (TT): This method is used to process sawn timber for the domestic market. The main products are un-edged centerboards and sideboards.
- Square sawing (SS): This method is commonly used in sawmills that also produce end-user products. In this process, two cants and a number of sideboards are normally produced in the first stage, and after 90° rotation the cant is rip-sawn.

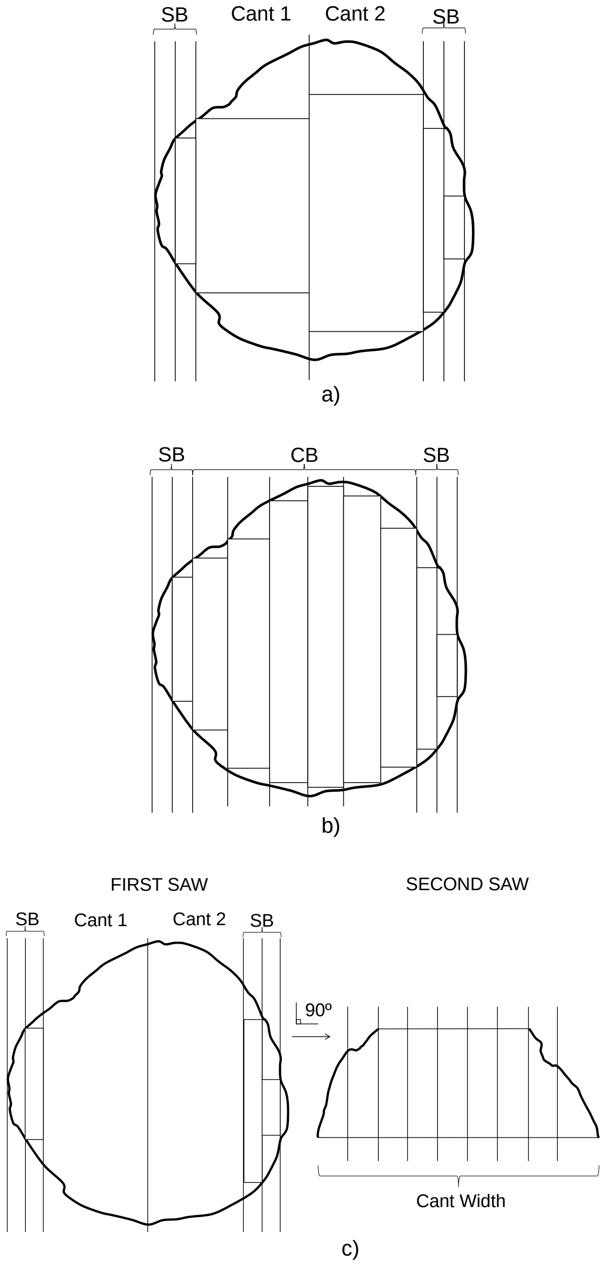

Fig. 2. Cross-sectional views (top-end of the log) of sawing-patterns used in the simulation: a) cant-sawing (CS), b) through-and-through sawing (TT), and c) square-sawing (SS). SB and CB are respectively sideboards and centerboards

Depending on the top-diameter of the logs, the dimensions of the sawn timber for the three sawing patterns were selected according to Table 2. All the sawn timber was manufactured sharp-edged in the simulation, although this is not the general practice at a Mozambican sawmill. The reason for this decision was that different grading rules regarding wane for sawn timber are used in Mozambique, and the rules are also applied differently depending on the market. To avoid uncertainty in the study, the simulation procedure was therefore set to include only sharp-edged sawn timber.

When executing the simulations, the resulting positioning of a log that maximizes the yield is in this study was defined as the Best Opening Face (BOF) direction for the specific log and sawing pattern. For the second stage in square-sawing (Fig. 2c, right), the dimensions of the sawn timber were set as follows:

- For a cant width ≤ 339 mm: the board thickness was set to 25 mm and the cant-height to 50 or 75 mm, and
- For a cant width ≥ 340 mm: the board thickness was set to 50 mm and the cant-height to 100 mm.

Prior to the simulation, log-diameter classes were defined based on the top-diameter of the log and the diameter interval for each class was set to 40 mm. For each log-diameter class, a fixed sawing-pattern was decided for cant-sawing, through-and-through sawing, and square-sawing (Table 2).

Table 2. Sawing Patterns for Cant-sawing, Through-and-through Sawing, and Square-sawing, Showing the Thickness of Sideboards and Centerboards for Each Log-diameter Class

Log-diameter class (mm)			Boards thickness (mm)		
No.	Min	Max	Cant-sawing (CS)	Through-and-through sawing (TT)	Square-sawing (SS)*
1	0	249	25 25 50 50 25 25	25 25 25 25 25 25 25 25	CS + 25 (rip-sawing)
2	250	289	25 25 75 75 25 25	25 25 25 50 50 25 25 25	CS + 25
3	290	329	25 25 100 100 25 25	25 25 50 50 50 50 25 25	CS + 25
4	330	369	30 30 100 100 30 30	30 30 50 50 50 50 30 30	CS + 25 or 50
5	370	409	30 50 100 100 50 30	25 50 50 50 50 50 50 30	CS + 50
6	410	449	30 75 100 100 75 30	25 50 50 75 75 50 50 25	CS + 50
7	450	489	50 75 100 100 75 50	25 75 75 75 75 75 75 25	CS + 50

* SS was a combination of cant-sawing (same sawn-timber thicknesses) and a second sawing stage where the cant was rip-sawn into boards of equal thickness. A board thickness of 25 mm was used when cant width ≤ 339 mm, and for a cant height of 50 or 75 mm, but the board thickness was set to 50 mm for a cant-width ≥ 340 mm and a cant-height of 100 mm.

Simulation

A MATLAB algorithm was developed to simulate the sawing process. First the algorithm determined the top-end of the log and matched the top-diameter to the predefined log-diameter class. The sawing process consists in placing planes previously defined by the board thickness of each sawing pattern (Table 2). When the sawing pattern had been selected, the log was sawn using combinations of skew and rotation. In addition, the set-up parameters of the band-saw mill were used (commonly used in Mozambique). For cant-sawing (CS) and through-and-through sawing (TT), the kerf width was set to 3 mm, and for square-sawing (SS) a kerf width of 3 mm was set for the bandsaw (first saw) and 4 mm for the rip saw (second saw). To compensate for the shrinkage during drying, 4% was added to the target cross-sectional dimensions regardless of the main direction of the wood. The main steps used by the algorithm are described as follows:

Determination of top diameter and definition of log volume

The first procedure of the simulation was to determine the top-end of each log. Using the cross section of the first and the last log discs of each log (log-discs with a thickness of 10 mm), the difference X_{max} - X_{min} (Fig. 3) at every 15º rotation angle (0, 15, 30,… 135, 150, 165) were determined. The log diameter was calculated as the average of the calculated measurements. The first and last log-disc diameters were then compared and the lowest average diameter was assigned as the top diameter of the log. The top-diameter was then used to match a log to a specific log-diameter class in Table 2.

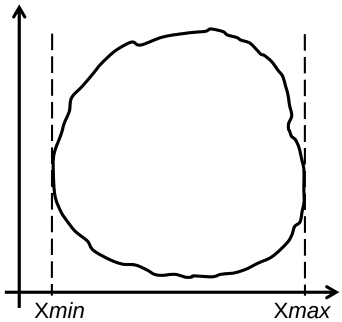

Fig. 3. Principle for determination of the diameter of the log. The value (X_{max} - X_{min}) was calculated for every 15° rotation step, and the log diameter was defined as the average of the calculated measurements

The volume of each log was determined by using the volume integration formula, Fig. 4.

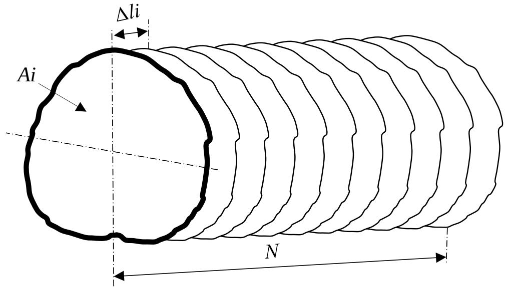

Fig. 4. The volume of each log was calculated as the sum of the volume of each log-disc with the thickness Δl_i according to the volume integration formula (Eq. 1). A_i is the cross-sectional area of each log-disc with the thickness Δl_i (=10 mm) and N – number of discs in each log

Figure 4 represents a calculation employing Eq. 1,

$$V = \sum_{i=1}^{N} (A_i \cdot \Delta l_i) \quad (1)$$

where A_i is the cross-section area of the i^{th} log-disc determined using Green's theorem (Arfken *et al*. 2012), Δl_i is the thickness of each disc (10 mm), and N is the number of discs representing the log.

Log positioning

The simulation algorithm positions the log before sawing by skewing and rotating the log (Fig. 5). The positioning was made using the skew as base *i.e.*, the log was first skewed at a certain angle and then rotated and sawn; when this sawing was completed, the log was rotated and then again sawn until all rotation positions were completed, and so on until all combinations of skew and rotation were completed.

In skewing, the top-end of the log had a fixed position and the butt-end was skewed at angles from -1° to 1° at intervals of 0.5°, which represents a maximum shift of the butt-end of ± 35 mm for a 2 m long log. The rotation angles were set from 0° to 180° at intervals of 2°.

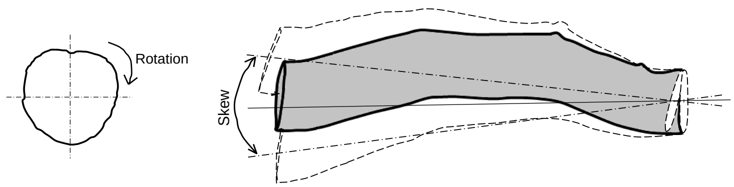

Fig. 5. Rotation and skew orientation: to the left a cross-sectional view of the log and to the right a length-wise view of the log with the top-end indicated in white

Edging and calculation of board volume

For a given sawing pattern, the volume of all the boards or components at each positioning (skew and rotation) were calculated and the maximum and minimum sawn timber volumes from the log were recorded. At the end, the simulator displayed the two volumes with its comprehensive skew and rotation positions.

During the edging of the sawn timber from the CS and TT sawing patterns, the board volume was maximized. The minimum width accepted was 5 cm, a width module of 5 mm was used, but no length modules were used (Fig. 6). The volume of sharp-edged boards (cants and sideboards) was calculated for the following,

Cant-sawing sawing (CS) $$V_{CS} = \sum (V_{SB} + V_{cant}) \quad (2)$$

Through-and-through sawing (TT) $$V_{TT} = \sum (V_{SB} + V_{CB}) \quad (3)$$

where $V_{SB} = A_{rectSB} \cdot Thick_{SB}$ is the volume of sideboards, $V_{cant} = A_{rectCant} \cdot Thick_{Cant}$ is the volume of the cants, $V_{CB} = A_{rectCant} \cdot Width_{CB}$ is the volume of centerboards, and A_{rect} is the area of the maximum rectangle fitted to the board. CB, SB, and Cant are centerboards, sideboards, and cants, respectively.

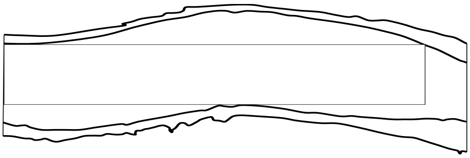

Fig. 6. Flat view of simulated cant from cant-sawing (CS) or board from through-and-through sawing (TT). The rectangle represents the maximum fitted size of a sharp edged board or cant.

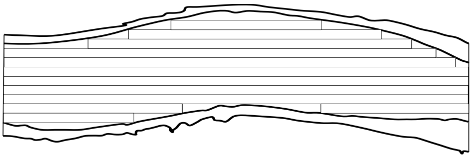

Fig. 7. Flat view of simulated board from the second saw in square-sawing (SS). Each rectangle represents a ready-to-use sharp-edged component.

For the SS pattern (sideboards and ready-to-use components), the volume was given by,

$$V_{SS} = \sum (V_{SB} + V_B) \quad (4)$$

where $V_{SB} = A_{rectSB} \cdot Thick_{SB}$ is the volume of sideboards, and V_B is the volume of ready-to-use components.

The minimum length of a component was set to 20 cm (which is the minimum length of raw material to produce one component of flooring parquet). Figure 7 shows an example of sawn products obtained when using SS.

RESULTS AND DISCUSSION

This simulation study was limited in the sense that it only includes the outer shape information from 15 logs of two species. No other sources of variation that may play a role in a real sawing situation were considered. Nevertheless, the influence of sawing pattern and log positioning on the volume yield of sawn timber should be of general interest, since the same logs were sawn many times simulating different processing conditions. Comparing this work to a real sawing situation, one should bear in mind that the simulation result is an overestimation, since the sapwood content and inner features of logs were not considered. On the other hand, the simulations considered only sharp-edged sawn timber, which reduces the volume of sawn timber considerable when crooked logs are sawn, compared to the practical sawing situation where a certain amount of wane is often allowed.

Figure 8 shows the maximum volume yield at the optimal position (combination of skew and rotation) as an average of all log-diameter classes, and grouped according to sawing pattern, species, and log grade. The volume yield from cant-sawing (CS) was here used as reference in comparison to the other two saw methods because it is the most frequently used sawing pattern in Mozambique.

The results show that the CS pattern gave the lowest volume yield for all log grades and that the through-and-through sawing (TT) gave a higher yield than CS regardless of log grade or species. Square-sawing (SS) gave the highest yield when grade 3 logs were sawn. Thus the results indicate that, when aiming for a high volume yield, straight logs should preferably be sawn with TT instead of CS with a potential of a 3 percentage points greater volume yield (all logs, in Fig. 8). The potential for improvement with crooked logs was 6 percentage points with SS instead of CS. In addition, if a sawmill does not have the equipment for secondary processing (SS) a change from CS to TT is predicted to still improve the volume yield of crooked logs with a potential of about 3 percentage points.

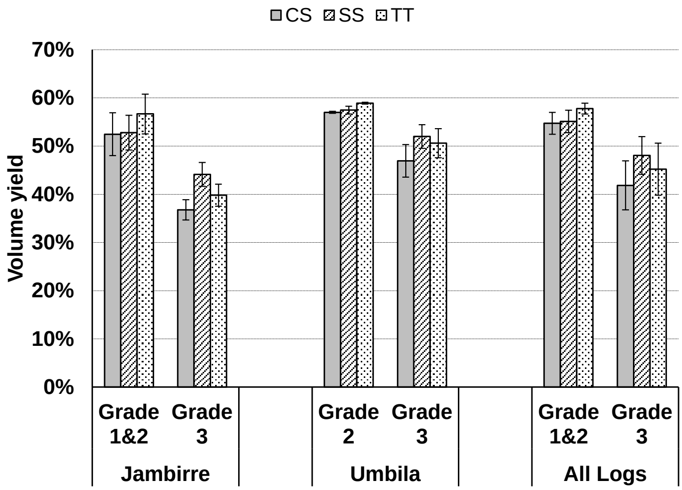

Fig. 8. Maximum volume yield with optimal positioning (combination of skew and rotation) as an average of all log-diameter classes for different sawing patterns, species and log grades. Bars indicate standard deviation, and CS – cant-sawing, SS – square-sawing, and TT - through-and-through sawing

The simulations also showed that crooked and irregularly shaped logs (grade 3) will give a lower volume yield than the straighter and even-shaped logs.

Figure 9 shows the maximum and minimum volume yields (at the optimal and worst positioning) as an average of all log-diameter classes, grouped according to sawing pattern and species. The average difference between maximum and minimum volume yield for all sawing patterns was 15 percentage points. The CS pattern showed the greatest difference between maximum and minimum volume yield, followed by the TT and SS methods. The trend was the same for all log grades and it indicated that the standard CS pattern is the most sensitive to incorrect log positioning and that the SS pattern is the best in that respect. Overall, the results stress the importance of positioning the log prior to sawing to find the best opening face that will maximize the volume yield.

With regard to the species, Fig. 9 shows that with optimal positioning, Jambirre logs had volume yields of 40% (CS), 46% (SS), and 43% (TT) and Umbila logs 51% (CS), 54% (SS), and 54% (TT). This between-species difference is partly explained by the fact that the Umbila logs had not only larger diameters but also less irregular outer shapes than the Jambirre logs. Figure 8 also shows that the difference in volume yield between CS and SS patterns was somewhat larger on the smaller crooked Jambirre logs than on the straighter and larger Umbila logs. This stresses the need to choose the saw pattern at a Mozambican sawmill according to grade and species.

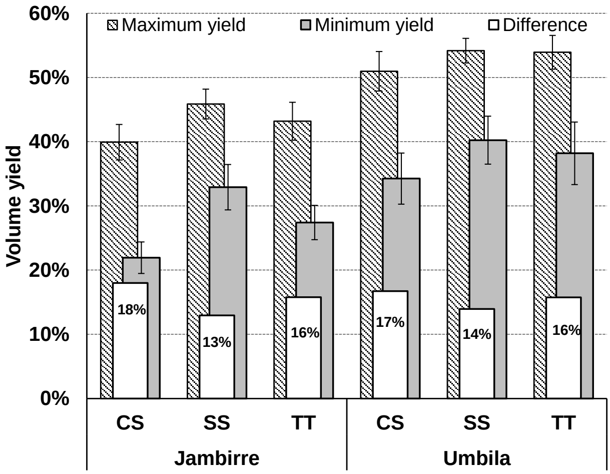

Fig. 9. Average volume yield with optimal and worst positioning and the difference for cant-sawing (CS), square sawing (SS), and through-and-through sawing (TT). The range of investigation was set to ±1° in skew and every 2º increments in log rotation. Bars indicate standard deviation, and CS – cant-sawing, SS – square-sawing, and TT - through-and-through sawing

Overall, the simulation results show that the volume yield can be increased if square sawing (SS) or through-and-through sawing (TT) is used instead of the commonly used cant-sawing pattern (CS). In comparison with the yield of 40% reported by Mozambican sawmills (Egas *et al.* 2013), the simulation results (Fig. 8) show an improvement with optimal positioning for all types of logs except the grade 3 logs of Jambirre (CS and TT sawing patterns). Analyzing the logs according species, it can be seen that only one group (Jambirre, CS) gave a yield as low as 40% with optimal positioning. All the sawing methods and log types gave yield less than 40% with the worst positioning of the logs. This stresses the importance of executing good positioning prior to sawing. Unfortunately no data are available that show how well a Mozambican sawyer usually positions the logs prior to sawing. Most of the operations are done manually and without any supportive technique such as log shape measurements or computer optimization.

CONCLUSIONS

1. For tropical hardwood characterized by an irregular outer shape and crookedness, log positioning and sawing patterns are important for sawn timber volume, *i.e.* volume yield. The results of this study show that the use of simple and easy methods for log scanning prior to sawing to assist in log positioning could be one way to increase the volume yield in tropical hardwood sawmills in developing countries.
2. The alternative sawing patterns studied gave a better yield than the standard sawing pattern normally used in Mozambique. The square-sawing method gave the highest volume yield when sawing crooked logs, while the through-and-through method gave

the highest yield for the fairly straight grade 1 and grade 2 logs. The improvement in volume yield by choosing the best sawing pattern was 3 percentage points for grade 1 and 2 logs and 6 percentage points for grade 3 logs.

3. The study also shows the importance of proper log positioning prior to sawing. In the optimal position, *i.e.* with the best opening face, the volume yield could reach 40 to 46% for crooked logs and 51 to 54% for fairly straight logs.

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Paper IV

The Effect of Log Positioning Accuracy on the Volume Yield in Sawmilling of Tropical Hardwood

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Pedro Ah Shenga, Peter Bomark, Olof Broman and Dick Sandberg

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The Effect of Log Position Accuracy on the Volume Yield in Sawmilling of Tropical Hardwood

Pedro Ah Shenga,* Peter Bomark, Olof Broman, and Dick Sandberg

This study investigated the effect of the positioning of the log before sawing on the volume yield of sawn timber from tropical hardwood species. Three positioning parameters were studied, the offset, skew, and rotation, combined with two sawing patterns of cant-sawing and through-and-through sawing. A database consisting of two tropical hardwood species with very different outer shapes, jambirre (*Millettia stuhllmannii* Taub.) and umbila (*Pterocarpus angolensis* DC.), was used to simulate the sawing process. The result of the simulation revealed that, according to the combined effect of offset, skew, and rotation positioning, the positioning of the log before sawing is extremely important to achieve a high volume yield of sawn timber. The positioning parameter that has the highest effect on the volume yield is the rotation, and the variation in the volume yield associated with a deviation in the positioning can reduce the volume yield of sawn timber by between 7.7% and 12.5%.

Keywords: Log positioning error; Tropical species; Skew; Offset; Rotation

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INTRODUCTION

In 2015, the Mozambican government approved a new decree that reinforces the need for processed lumber locally and puts a five-year ban on the harvest of ironwood (*Swartzia madagascariensis* Desv.). This decree adds value by reducing the list of species allowed to be exported as roundwood and by limiting the collection of species that are mainly harvested for roundwood export. The increasing need for sawn timber on the domestic market is pushing sawmills to modernize the sawing process to fulfill the new quality requirements for their products. Thus, sawmills have to switch from producing so-called "cants" to producing sawn timber or components for use in products such as furniture, doors, and windows. A cant, also referred to as a block, is defined as a log that is roughly sawn on at least one side.

The majority of Mozambican sawmills perform only a primary breakdown, where the logs are converted into cants or sawn timber with rough dimensions. This process leads to a high volume of waste, and consequently a low added value. The current economic situation of the country, and of the industry in general, does not stimulate investments in new sawmill technology. One way to improve the volume yield and the quality of the sawn timber is to develop and invest in equipment for log shape measurement without drastically changing the sawmill equipment that is used today, *i.e.*, bandsaws and circular-saw headrigs. Scanning devices and log feeder equipment can then be used to determine the log's outer shape. This can be used to calculate the optimal positioning of the log, and thereafter to adjust the position of the log *via* rotating, skewing, and offsetting, to achieve the maximum volume yield of sawn timber. This approach may be too expensive for most sawmills, but an alternative solution is to build the scanning station separate from the saw line, so that anyone can scan logs upon payment. At the scanning station, the logs are scanned, the optimal positioning is determined, and the log is marked to indicate the optimal log orientation. These two scanning alternatives are illustrated in Fig. 1.

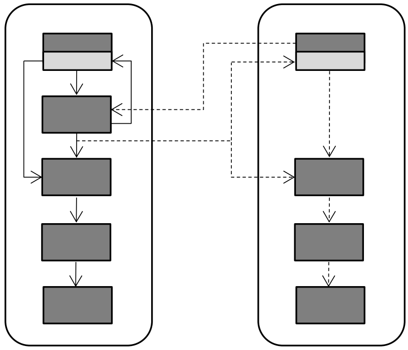

Fig. 1. The schematic representation of a proposed Mozambican sawmill layout with a log-scanning station: a) as an integrated part of the saw-line and b) as an external scanning station where the sawmill uses log-shape data from the scanning station

The detaching of the scanning station from the saw line may reduce the equipment costs, but the log turning and feeder devices may still be onerous for a common sawmill. This makes it interesting to consider the possibility of positioning the log manually, using the positioning data from the scanning station. Regardless of the simplicity of the equipment used in Mozambique, to process the tropical hardwood species, the processing of the hardwood is in general difficult because of the large diameters and considerable irregularities in the logs. Many studies to increase the volume yield of hardwood have been conducted (Richards *et al*. 1979; Meimban *et al*. 1992; Lin and Wang 2012; Schajer 2016). There have also been extensive studies regarding the effects of log positioning, mainly for the softwood species from the "boreal region." For instance, Lundahl and Grönlund (2010) found that the average volume yield can be increased by applying the optimal combination of rotation and parallel positioning, in cant-sawing and through-and-through sawing. Wessels *et al.* (2011) developed an algorithm, the tentacle algorithm, to find an optimal or close-to-optimal positioning solution by a limited number of iterations. They found that the tentacle algorithm performed better than the other evaluated algorithms in terms of the mean volume yield obtained. However, studies of the individual effects of each of the positioning parameters (offset, skew, and rotation) are scarce, especially for tropical species. For instance, Baltrušaitis and Pranckevičienė (2005) investigated the effect of offset logs with top diameters in the range of 14 cm to 32 cm. Berglund *et al*. (2013) and Fredriksson (2014) investigated the optimization of log positioning, but the effect of each sawing parameter was not discriminated. Tulokas and Vuorilehto (2007) investigated the effect of rotation in automatic log positioning equipment.

Being able to determine the optimal log orientation before sawing is one step forward to improving the volume yield of sawn timber, but there are many factors that can influence the final result. In the suggested production models (Fig. 1), the marking of the optimal position on the log may introduce errors. Another important and challenging step is managing the proper position of the log on the headrig for logs with a very irregular shape or a large diameter. The present study was therefore performed to assess the effect of deviation from the optimal rotation, skew, and offset, and how these errors impact the volume yield.

The objective was to investigate the effect of a deviation in the log positioning, around the optimal position, on the volume yield of sawn timber. Further, the effect of the log shape, *i.e.*, straight logs or logs with a very irregular shape, on the volume yield when the log positioning deviates from the optimal position was also studied.

EXPERIMENTAL

To investigate the effect of positioning error, *i.e.*, the deviation in log positioning (offset, skew, and rotation) around the position that gives the highest possible volume yield of sawn timber, sawing simulations were performed based on scanned external shapes of logs from two tropical hardwood species.

Materials

A database of 15 logs of two tropical hardwood species, jambirre (*Millettia stuhllmannii* Taub.) and umbila (*Pterocarpus angolensis* DC.) was used. The logs were between 1.8 m and 3.8 m long and had a top diameter of between 23 cm and 39 cm. Ah Shenga *et al.* (2015) developed the database in an earlier study, and in the database, the outer shape of each log is described as a point cloud acquired using a 3D-laser scanner.

The main reason for selecting these species was that this study wished to examine the effect of log shape on how the positioning accuracy influences the volume yield. Umbila is generally straight, and jambirre is crooked. For this study, the 15 logs were graded into two groups using crookedness as the criterion.

Log crookedness

The crook for each scanned log was determined in the following way: (1) at every 10 mm along the length of the log, the geometric center of the cross section was determined, *i.e.*, the arithmetic mean position of all points that define the outer shape of the log at that position; (2) a straight line between the geometric centers of the outermost two cross sections of the log (the top and butt end of the log) was defined; and (3) the crook for each log was then calculated as the maximum distance from that line to the geometric centers of the cross sections.

Examples of the different levels of crookedness are shown in Fig. 2. The geometric centers for the cross sections along the log, which can also be seen as an estimation of the pith location, are seen as dots in the central regions. A fairly straight log has all the geometric centers well centralized, while a crooked log has the geometric centers scattered all over the cross section view.

Log grades

The crook of the 15 logs in the database was computed, and a crook of 60 mm was chosen as the limit, which allowed the logs to be grouped into two grades. Grade 1 logs consisted of those with a crook of less than 60 mm and Grade 2 greater than or equal to 60 mm.

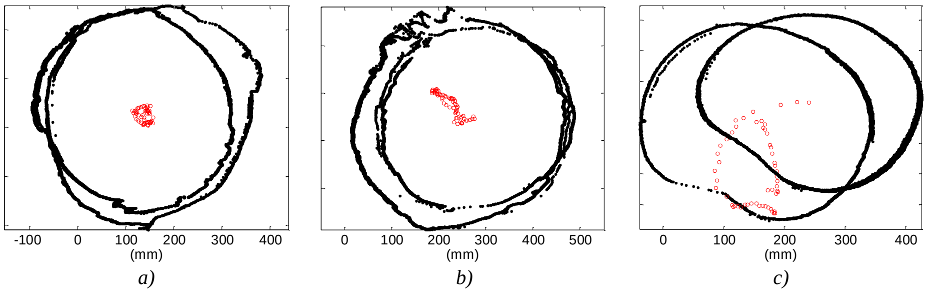

Fig. 2. The cross-section view of the log periphery at the top and butt end of three logs from the database, and the geometric centers calculated at each 10 mm of the log length (the circles in the central region of the cross sections). The degree of log crookedness is illustrated as the scatter of the geometric centers: a) a fairly straight log, b) a single crooked log, and c) a double crooked or tortuous log

Methods

The models of the scanned logs were used to simulate the sawing and to calculate the volume yield of sawn timber. Two sawing patterns, cant-sawing and through-and-through sawing (Fig. 3), and three positioning parameters, offset, skew, and rotation, (Fig. 4), were used for the simulation. The sawing patterns commonly used in Mozambique sawmills are cant-sawing that is used to process sawn timber for export, and through-and-through sawing that is used to produce sawn timber for the domestic market.

Details about the two sawing patterns used are listed in Table 1, showing the setup for the virtual sawmill about board thickness for each log diameter class. The sawn timber was sharp edged (*i.e.*, no wane), and the volume of the sawn timber was calculated as the sum of the sharp edged board volumes. The volume yield calculations were based on the scanned outer shape log volume (Ah Shenga *et al.* 2015). The edging was determined by fitting a maximum rectangle onto a board (Fig. 5), with a modular width of 5 mm. The length of the board was set as floating, but a minimum length was set to 20 cm (minimum length of parquet flooring piece). To compensate for the shrinkage that occur during drying of the green sawn timber, a 4% increase in board dimension was added to the target cross-sectional dimensions (Table 1), regardless of the main direction of the wood.

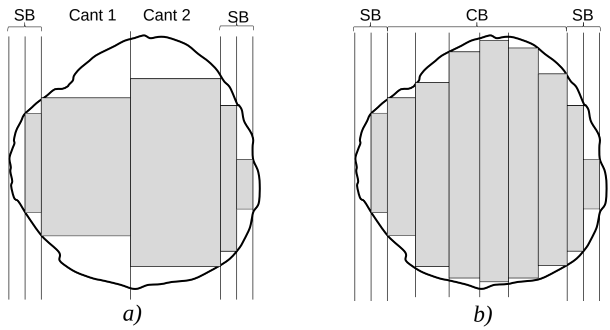

Fig. 3. Sawing patterns used in the study: a) cant-sawing and b) through-and-through sawing. The grey areas represent sharp-edged centerboards and sideboards

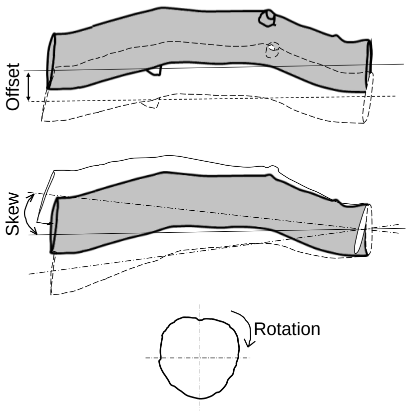

Fig. 4. Definition of the positioning parameters of offset, skew, and rotation

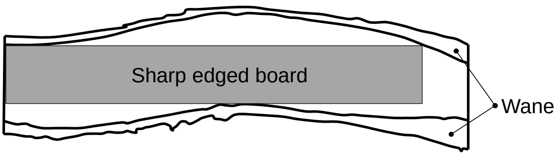

Fig. 5. Flat view of a sawn board showing the principle for the edging procedure. The rectangle in the middle represents the maximum dimensions of a sharp edged board that can be achieved from a cant or an un-edged board

Table 1. Sawing Patterns for Cant-sawing and Through-and-through Sawing, Showing the Thickness of Sideboards and the Centerboards or Cants for Each Log Diameter Class (top diameter)

Log diameter class (mm)			Sawing pattern (mm)	
No.	Min.	Max.	cant-sawing	through-and-through
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, 25
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

Note: The grey marked values represent the thickness of sawn timber or cants for cant-sawing and centerboards for through-and-through sawing patterns, respectively. The width of sawn timber is defined by the maximum edged board fitted on sawn timber during edging

Three independent simulations were performed with following objectives: (1) to determine the optimal positioning (OP) for each log, *i.e.*, the combination of the positioning parameters that resulted in the highest volume yield of sawn timber; (2) to evaluate the effect on the volume yield of a deviation in one positioning parameter at a time around the

OP; and (3) to evaluate the effect on the volume yield when all three positioning parameters were set to have random deviation around the OP.

The code and simulation were carried out using Matlab software (MathWorks, USA). The code routine for the last two simulations were similar to the code used to determine the OP, but with changes in the intervals.

Simulation of optimal positioning (OP)

To determine the OP, the logs offset was set to vary from -100 mm to 100 mm in steps of 10 mm, skewed from -1° to 1° in steps of 0.5° and rotated 360° in steps of 5°. A total of 7665 combinations of the positions were tested for each log, and at each combination the volume of the sharp edged boards was calculated. The position that gave the highest volume yield was defined as the OP, and used as the input and reference position in the subsequent simulations.

Influence of one positioning parameter at a time

To evaluate the effect of the deviation in each of the positioning parameters around the OP, the offset was varied from -30 mm to 30 mm in steps of 1 mm. The skew was varied from -0.7° to 0.7°, in steps of 0.1° and the rotation was varied from -30° to 30° in steps of 1°. These simulations were executed by varying one positioning parameter at a time keeping the other two parameters fixed at OP values. For example, to test the effect of the deviation in rotation, the skew and offset were locked at the OP values, while the rotation was varied ± 30°. Figure 6 shows how the rotation was changed around the OP.

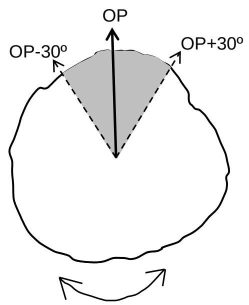

Fig. 6. Cross-sectional view of a database log showing the principle for the rotation variation around the optimal positioning (OP). The volume yield was calculated when the log was rotated OP-30º and OP+30º (grey area), around the OP in increments of 1°

Random variation in all positioning parameters

To estimate how a deviation in the positioning parameters influences the total volume yield in a more practical situation, the variation intervals were limited for each position parameter, and the log positioning for the volume yield simulations were randomly selected. A simultaneous deviation in each positioning parameter around the OP was used, such that the offset was varied ± 15 mm, the skew ± 0.35°, and the rotation ± 15°. The interval of the rotation parameter was chosen within the standard deviation interval of 10° to 15°, which was reported by Tulokas and Vuorilehto (2007) when investigating the automatic log rotation of softwood. The interval ranges set for offset and skew parameters are believed to be realistic in practice.

Twenty randomly selected positions within these intervals were simulated for each log, resulting in 8,000 simulations for each log, and the cumulative mean value for the volume yield for each log grade and each sawing pattern was calculated.

A standard t-test was used to evaluate results from the simulations.

RESULTS AND DISCUSSION

Table 2 shows the average volume yield from cant-sawing and through-and-through sawing patterns when the three positioning parameters (offset, skew, and rotation) were simultaneously optimized to find the log position that gave the maximum volume yield. The optimal position (OP) is then the position of the log that gives the maximum volume yield, and the ideal situation is when the log is positioned at the OP with a minimum of deviation. Unfortunately, because of large irregularities in many of the logs, the OP was difficult to determine visually. To analyze the importance of the log crook and the irregular outer shape, the logs were graded in two grades before the simulations. Six of the logs were classified as Grade 1, and nine of the logs were classified as Grade 2.

The result in Table 2 show a large difference in volume yield at OP for the two log grades (around 14 percentage points).

The difference in volume yield between grades is mainly due to the crookedness of the logs. In the more straight logs, Grade 1, the log center and the sawing pattern center coincide in each cross-section along the entire log while in Grade 2 logs there is a deviation between the log center and the pattern center along the log.

Table 2. Simulated Volume Yield of Sawn Timber at Optimal Position (OP) when Varying all Positioning Parameters Simultaneously

Log crook	Grade 1		Grade 2	
Sawing pattern	**CS**	**TT**	**CS**	**TT**
Volume yield at OP* (%)	59.9	59.1	45.9	45.6
Standard deviation	4.46	4.36	8.39	6.94
Average Volume yield at OP** (%)	59.5		45.8	
p value (CS ~ TT)	0.46		0.71	
p value (CS1 ~ CS2 / TT1 ~ TT2)	< 0.0001			

* Optimal mean volume yield when varying one positioning parameter at time.
** Optimal mean volume yield of each log grade.
CS – cant sawing, TT– through-and-through sawing, Grade 1 – logs with crook less than 60 mm and Grade 2 greater than 60 mm.

Within the groups with same log grade, the results show no significant difference between the cant-sawing and the through-and-through sawing patterns (Table 2, p value > 0.05). However, the result shows that there is a difference in volume yield between log grades, *i.e.*, the Grade 1 logs gives higher volume yield than Grade 2 logs regardless of sawing pattern used (Table 2, p value < 0.0001).

Table 3 shows the average decrease in volume yield when one of the log positioning parameters is varied at a time around the OP of the log, *i.e.*, the mean value of all simulations in the interval. The results show that the decrease of volume yield of cant-sawing is higher than on the through-and-through sawing.

For comparison, the mean decrease in volume yield for all Grade 1 logs when varying the offset was 9%, which is a higher than reported by Baltrušaitis and Pranckevičienė (2005) who showed a decrease in the volume yield between 2.7% and 8.3%. The reason of this difference may be caused by the high degree of crookedness of the sampled logs used on our study.

Table 3. Simulated Average Decrease in Yield when Having Positioning Error in One Parameter and Keeping the Other Two at OP

Log crook		**Grade 1**				**Grade 2**			
Sawing pattern		**CS**		**TT**		**CS**		**TT**	
			SD		*SD*		*SD*		*SD*
Decrease in yield (%)	Rotation	-12.7	*4.8*	-11.5	*3.3*	-16.9	*4.5*	-11.9	*3.0*
	Offset	-9.6	*3.6*	-8.7	*2.9*	-14.0	*4.2*	-7.7	*1.7*
	Skew	-9.4	*3.2*	-8.4	*2.3*	-11.9	*3.7*	-7.1	*1.5*

CS – cant-sawing, TT – through-and-through sawing, SD – standard deviation (%)

The Table 3 also shows that the through-and-through sawing pattern is less affected by the errors in positioning, which suggests that this sawing pattern should be used to achieve a high volume yield when having error in one of the log positioning parameters.

Figures 7 and 8 show how the volume yield is decreasing when the positioning parameters are varying around the logs OP. Naturally, the volume yield decreases when the deviation from the OP increases. The larger slope of the curves, the more sensitive is the volume yield to deviation in the positioning parameters.

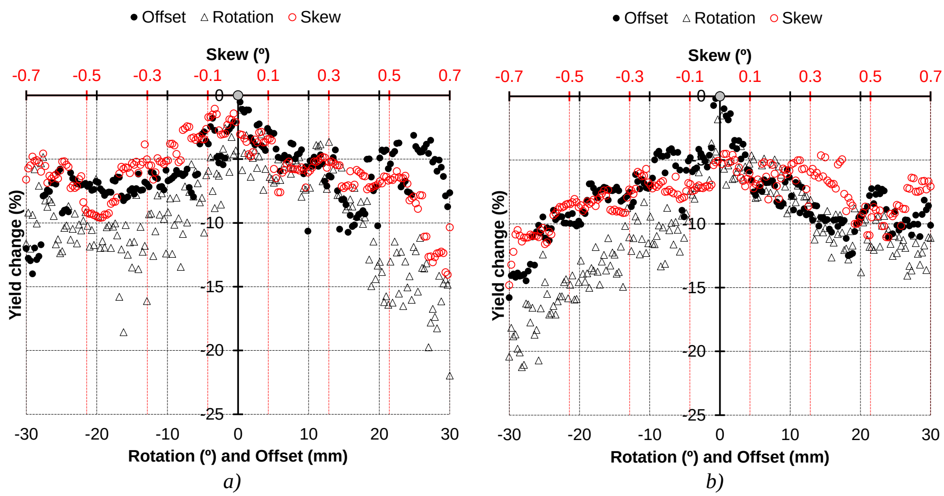

Fig. 7. The effects on the volume yield of sawn timber from deviations in the offset, skew, and rotation around the optimal position (OP) when varying one parameter at a time. Each dot is the mean value of six Grade 1 logs that were sawn according to: a) a cant-sawing pattern, and b) a through-and-through sawing pattern. The change in the volume yield is the percentage of reduction based on the maximum volume yield at the OP. The OP is indicated with the grey circle in the origin of the plot

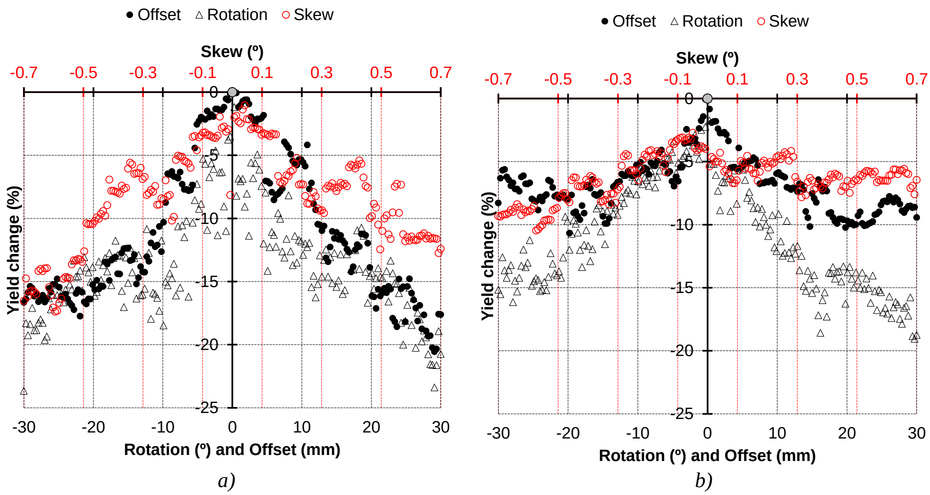

Fig. 8. The effects on the volume yield of sawn timber from deviations in the offset, skew, and rotation around the optimal position (OP) when varying one parameter at a time. Each dot is the mean value of nine Grade 2 logs that were sawn according to: a) a cant-sawing pattern, and b) a through-and-through sawing pattern. The change in the volume yield is the percentage of reduction based on the maximum volume yield at the OP. The OP is indicated with the grey circle in the origin of the plot

Overall, the figures confirm the results in Table 3, showing that the rotation is the most important parameter for the volume yield. Similar conclusion was reported by Todoroki (1995), who investigated the log rotation effect of crooked logs. The result also show that the offset was the second most important parameter followed by skew. Similar finding was reported by Wessels (2009) who studied the optimization of the cant-sawing process for pine logs.

The largest change in volume yield can be seen when Figs. 7a and 8a are compared, showing a difference in performance for cant-sawing when applied on straight logs (7a) and on crooked logs (8a). Another trend is that the volume yield decrease for cant-sawing is more scattered than for the through-and-through sawing which also can be seen in Table 3 (SD values). A large scatter means that the volume yield is sensitive to small variation in a log positioning parameter.

Figure 9 shows the accumulated average volume yield decrease when offset, skew, and rotation were simultaneously varied randomly around the OP. These simulations were done to show a "more practical case" in which a sawmill has full information about the positioning parameters of the logs at OP, but having random errors in all three positioning parameters at the same time. It should be noted that the investigated interval of variation is narrower than in Figs. 7 and 8, and it was set to considering manual positioning. The results in Fig. 9 show that for straight logs (Grade 1) the volume decrease is about 9.8% for both sawing patterns, cant-sawing being just slightly better. For crooked logs (Grade 2), a very large difference in volume yield decrease could be seen where through-and-through sawing had an average decrease in volume yield of about 7.7% compared to 12.5% in cant-sawing.

The larger difference of the decrease in Grade 2 logs is because the effect of non-coincidence of the log center and the sawing pattern center in each cross-cut along the log length is more severe when using cant-sawing than through-and-through sawing. Thus, the through-and-through sawing should be applied when crooked logs are sawn.

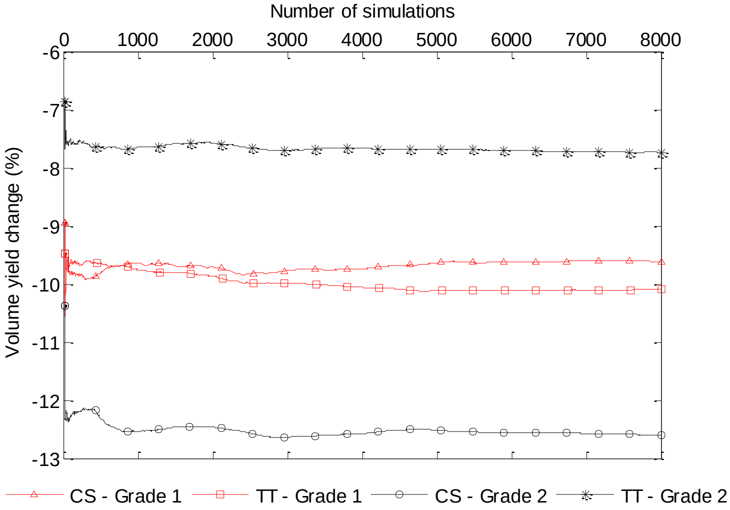

Fig. 9. The accumulated average decrease in the volume yield of sawn timber for Grade 1 and Grade 2 logs when all three positioning parameters were simultaneously and randomly varied around the OP. CS – cant-sawing, TT – through-and-through sawing

To give some volume yield numbers based on our study, and compare the predictions to reality, the following calculation was made. Consider that a sawmill has obtained access to the optimal positioning parameters of each log and using manual positioning with random error in each parameter, similar to the simulation results shown in Fig. 9. The volume yields of the sawmill were calculated in relation to the volumes yields at the optimal positioning from the simulation 1, when varying simultaneously all positioning parameters (Table 2, grade 1 – 60% and grade 2 – 46%). The calculation gives volume yields of 54% for Grade 1 and 41% for Grade 2 logs what is larger volume yield than the 35% of volume yield reported in Mozambique today. The 35% is based on measurements through surveys.

The results of this study show that it is possible to considerably improve the volume yield and that there are strong arguments to put emphasis on improvements in log positioning systems and technique to reduce the positioning errors with aid of measurement and controlled positioning devices at Mozambique sawmills. The idea presented here, a scanning station in which logs can be marked to indicate the optimal position of the log and the position of the first cut could be a possible solution to increase the yield and an important task for future.

This study is somewhat limited by the fact that the sample consisted of only 15 logs, but considering that the log shape is in focus in the study, the results is a good indication of the potential of log positioning and selection of sawing pattern to increase the volume yield of tropical timber.

CONCLUSIONS

1. The rotation is the log positioning parameter that most affects the volume yield, and the offset is the second most important positioning parameter, followed by the skew.
2. The variation in the volume yield associated with a deviation in the positioning of the log before sawing can reduce the volume yield of sawn timber between 7.7% and 12.5%
3. For Grade 1 logs *i.e.*, fairly straight logs, the choice between the cant-sawing and the through-and-through sawing pattern is not important for the volume yield. To achieve as high volume yield for crooked Grade 2 logs, the cant-sawing pattern should be avoided and through-and-through sawing pattern being used.
4. The results indicate that the use of data indicating the orientation of the optimal positioning from a proposed scanning station would considerably increase the volume yield.

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Paper V

Log Sawing Positioning Optimization and Log Bucking of Tropical Hardwood Species to Increase the Volume Yield

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LOG SAWING POSITIONING OPTIMIZATION AND LOG BUCKING OF TROPICAL HARDWOOD SPECIES TO INCREASE THE VOLUME YIELD

Abstract

The sawmill industry is a very important link in the Mozambique forest products value chain, but the industry is characterized by undeveloped processing technology and high-volume export of almost unrefined logs. The low volume yield of sawn timber has been identified as a critical gap in the technological development of the industry. To improve the profitability of the industry, there is thus a need to develop methods and techniques that improve the yield. In this paper, different positioning of logs prior to sawing and the possibility of increasing the volume yield of crooked logs by bucking the logs before sawing have been studied. A computer simulation was used to study the cant-sawing and through-and-through sawing of the logs to determine the volume yield of sawn timber from the jambirre (*Millettia stuhlmannii* Taub.) and umbila (*Pterocarpus angolensis* DC.) species. The optimal position, i.e. the position of the log before sawing that gives the highest volume yield of sawn timber for a given sawing pattern when the positioning parameters, offset, skew and rotation, are considered, gave a considerable higher volume yield than the horns-down position. By bucking very crooked logs and using the horns-down positioning before sawing, the volume yield can be of the same magnitude as that obtained by optimal positioning on full-length (un-bucked) logs. The bucking reduces the crook of the logs and hence increases the volume yield of sawn timber.

Keywords: roundwood, sawmilling, headrig, jambirre, Millettia stuhlmannii, umbila, Pterocarpus angolensis, offset, skew, rotation

INTRODUCTION

Sawmilling in Mozambique is performed using simple equipment consisting of single units of bandsaws and circular-saw headrigs which commonly results in a low volume yield of sawn timber and a low productivity. Most of the harvested roundwood is exported as un-edged planks although there are regulations about a higher degree of refinement of the roundwood before export.

The major reason to exporting un-edged planks is the lack of enforcement of the approved legislation for roundwood harvesting and processing, where the regulations stipulate a greater refinement of the logs. Another reason is the high cost of processing at locally owned sawmills. Foreign traders of wood have also invested in their own sawmills in Mozambique to process the purchased roundwood at a lower price than the local sawmill can offer, and also because they can operate their own production. These sawmills are majority operated by Chinese and they only employ Mozambicans for low paid manual work, which reduces the transfer of knowledge to the local labour. When Mozambicans are operators, there is always a sawmill supervisor from the foreign trader showing them how to operate.

The annual production capacity in Mozambican sawmills is low, around 2,500 m^3 (Fath 2002), and the capacity to supply refined products from the sawn timber is not well developed. The transport system is also not well developed, and this increases the price of sawn timber for domestic use. Transport has become one of the most expensive components of a forest operation, and one that it is difficult for operators to circumvent (Mackenzie 2006). The local construction and joinery industry are supplied mostly by small domestic traders who buy logs in small quantities and convert them into un-edged boards at processing-to-order sawmills. During the sawing of these logs, the choice of sawing pattern and the positioning of the logs are decided by the owner of the logs, *i.e.* the sawyers make suggestions and the final decision is made by the owner. The common practice is to position the logs using the external features of the logs such as crook, cracks and rot. The most important parameter, both for quality and to achieve a high volume yield of sawn timber, is the crook orientation. The log is usually positioned so that the most pronounced crook is facing up or down *i.e.*, parallel to the sawblade. Defects visible on the surface of the logs are rare because damaged logs are avoided during the harvesting.

Despite the simplicity of the equipment used in the sawmills, it is possible to increase the volume yield of sawn timber, but sawmills must first define the target market depending on the product requirements (board dimensions, quality of wood, moisture content, etc.) and this may include strategies to meet the requirements for sustainable forest management in order to obtain *e.g.* the Forest Stewardship Council (FSC) stamp. To improve production economy, sawmills must adopt methods and equipment to increase the volume yield of sawn timber. Such methods and processing equipment are well known in the sawmill industry worldwide, but their implementation is expensive and requires skilled labour which could be an obstacle in Mozambican sawmills. To encourage sawmill owners to implement new methods and techniques in their sawmills, it must be shown that it is possible to increase the sawing efficiency using the available equipment. The use of sawing patterns other than the sawing-around and cant-sawing patterns that are mostly used to process roundwood for export has been shown to be a possible way to increase volume yield when sawing tropical hardwood species (Ah Shenga *et al.* 2014). Ah Shenga *et al.* (2016) have suggested a log-scanning procedure adapted for the situation in Mozambican sawmills that may help sawyers to easily find the optimal log positioning before sawing.

The method commonly used for positioning logs before sawing is to choose the "facing up or facing down positioning method", also known as the crook-up or horns-down positioning. This means that the most pronounced crock of the log is positioned parallel to the saw-blade and sideboards are sawn free from both sides of the log. Thereafter, the log is rotated 90º and more sideboards are sawn. The remaining blocks (cant) are finally sawn into planks. This practice is commonly used to process coniferous species where the crook is mainly oriented in one plane. Although this positioning method provides acceptable performance, many studies have shown that the horns-down position does not give the highest volume yield of sawn timber. Lundahl and Grönlund (2010) reported that a volume yield increase of 8.6% can be achieved by using "optimized log positioning" instead of horns-down positioning when sawing Scots pine, and Wessels (2009) reported a volume yield increase between 0.7% and 3.5% if optimal log positioning was used. For many tropical species, the crookedness is very large and commonly orientated in two or more directions. To determine the optimal position of such a log before sawing is a delicate task.

In a previous study, Ah Shenga *et al.* (2015) described methods to measure the external log features, to determine the crook of "multi-crooked" logs, and to use this information to position the log before sawing to achieve the maximum volume yield of sawn timber. In that study, it was possible, using a database of the scanned logs, to determine the volume yield at the optimal log positioning. However, the acquisition of the measurement equipment and the positioning devices in the short and medium term is still too costly for many Mozambican sawmill owners, and it appears that the use of simple equipment will endure. However, it is important to ensure a sustainable wood processing and minimize the generation of waste.

The objective of the present study has been to find ways to increase the volume yield of sawn timber when sawing logs of tropical species, and the positioning of the log prior to sawing has been in focus. Thus, the so-called optimal positioning has been compared with the horns-down position prior to sawing and the possibility of increasing the volume yield of crooked logs by bucking the logs before sawing was also studied.

MATERIAL AND METHODS

For this study, a database of log models was used in a simulation procedure. The log models describe the outer shape of a log in a point-cloud data format. The data were collected in the Pemba province in Mozambique, using a 3-D laser scanner (Ah Shenga *et al.* 2014). 10 jambirre (*Millettia stuhlmannii* Taub.) and 5 umbila (*Pterocarpus angolensis* DC.) logs with a length between 1.8 m and 3.8 m and top diameters between 23 and 39 cm were used.

A computer simulation was used to simulate the cant-sawing and through-and-through sawing of the logs and determine the volume yield in the following situations:

1. Optimal positioning of the log before sawing, *i.e.* the combination of offset, skew and rotation (defined in Figure 1) that resulted in the highest volume yield of sawn timber,
2. the horns-down position, and when
3. bucking of the logs before sawing to half their length, and thereafter sawing with optimal positioning and horns-down positioning.

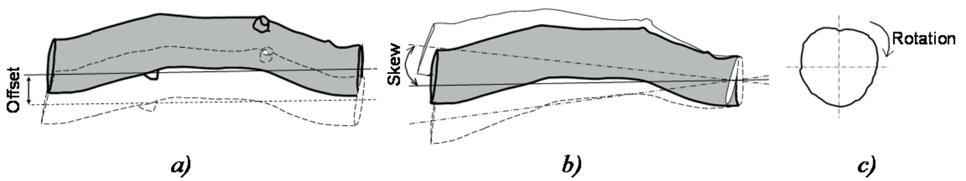

Figure 1. Definition of the positioning parameters of a log: a) offset (parallel displacement), b) skew (angular displacement of the top end), and c) rotation (cross-section view).

In the simulation, the log was sawn with the top-end first, and a virtual straight line between the geometric centres of the top and butt ends of the logs was used as reference when positioning the logs. To determine the optimal positioning, the offset, skew and rotation were simultaneously varied to test all combinations: offset was varied form -100 mm to +100 mm in steps of 10 mm around the reference line, the skew was varied from -1º to +1º with in steps of 0.5º with the butt-end of the log fixed, and the rotation was varied from 0º to 360º in steps of 5º. To determine the maximum volume yield in the horns-down position, only the offset and skew were varied while the rotation was set to the horns-down position.

A student's t-test was used to assess the significance of the difference in mean volume yield between the optimal and horns-down positions.

Log crook and log grade

The crook orientation for each log was determined as follows: (1) at 10 mm intervals along the length of the log, the geometric centre of the cross section (disc) was determined, *i.e.* the arithmetic mean position of all points that define the outer shape of the log at that position. (2) a straight line was drawn between the geometric centres of the outermost two cross sections of the log (the top and butt ends of the log). (3) the crook of each log was then defined as the maximum distance between the line defined in (2) and the geometric centres of the cross sections, Figure 2.

The logs were classified according to crook into: Grade 1, logs with a crook less than 60 mm, and Grade 2 with crook greater than or equal to 60 mm. This grading setting did not follow any specific regulation, but a crook of less than 60 mm is considered to be fairly straight in Mozambique.

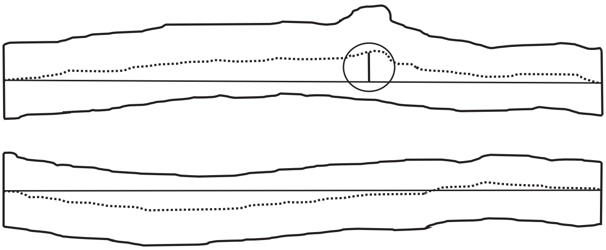

Figure 2. Two lateral views of the same log showing the log crook. The curved line (dotted line) represents the geometric centres of cross-sections at 10 mm intervals along the length of the log. The straight horizontal line is the connection of the geometric centres of the two outermost cross-sections. The log crook is defined as the maximum distance between these lines (the highlighted circle).

Rotate to horns-down position

With the size and position of crook defined, each log was rotated to the horns-down position. Figure 3 shows the procedure used. More details of the procedure can be found in Gjerdrum *et al.* (2001). Examples of the un-rotated and rotated logs of the different levels of crookedness are shown in Figure 4. The geometric centres of the cross sections along the log are seen as group of dots in the central regions.

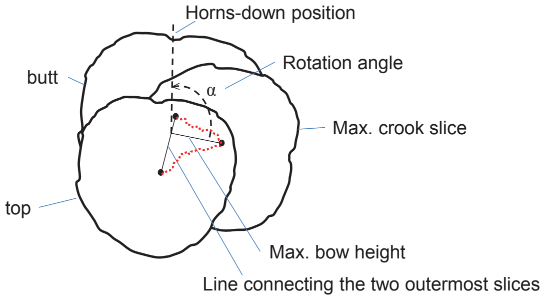

Figure 3. Principal procedure used to position the logs in horns-down position. The saw-blade has a vertical position and the log is rotated an angle α so the maximum crook of the log is parallel to the saw-blade.

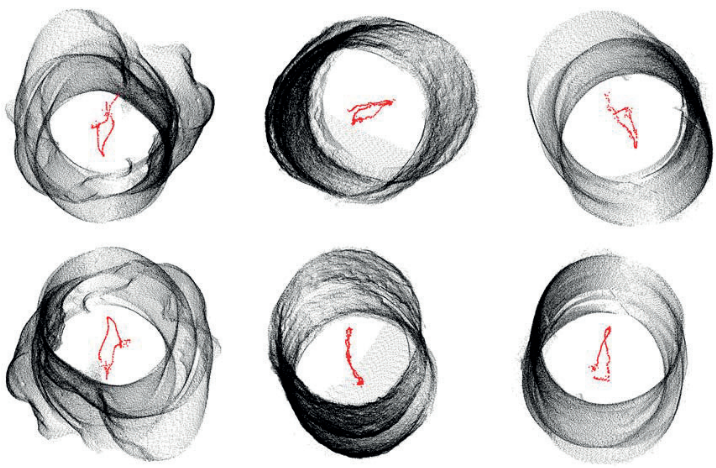

Figure 4. Three examples of log models showing the outer shape of the logs, and the geometric centres of the cross-sections at 10 mm intervals along the length of the log (the dots close to the centre). In the first row, the logs are positioned according to the scanning position (random selected positions), while in the second row the same logs are positioned at the horns-down position.

RESULTS AND DISCUSSION

Of the 15 full-length logs, six logs were classified as Grade 1 and nine logs as Grade 2, and after bucking, 22 logs were classified as Grade 1 and eight as Grade 2, Table 1. The bucking of the logs in half considerably reduces the crook. An example is given in Table 1 for full-length log No. 1, showing that the absolute value of crook is reduced and that bucking has a potential to increase the log quality by reducing the crook. However, short logs may be a challenge in the Mozambique wood industry because the length-wise joining of short components and finger-jointing are not common in practice, and they may thus reduce the productivity of the sawmills. Regarding productivity, we believe that most of the sawmills operate bellow their installed capacity.

Table 1. Grading, crookedness and length of full-length and bucked logs. The full-length log No.1 exemplifies how a Grade 2 log was bucked to give one Grade 1 and one Grade 2 log.

Full length logs						**Bucked logs**					
Grade 1			Grade 2			Grade 1			Grade 2		
Log No.	Crook (mm)	Length (m)	Log No.	Crook (mm)	Length (m)	Log No.	Crook (mm)	Length (m)	Log No.	Crook (mm)	Length (m)
13	29	3.2	14	90	3.8	6b	20	1.2	10a	60	1.4
6	30	2.5	4	98	2.4	8b	21	1.4	14b	68	1.9
15	39	3.2	7	100	2.3	12b	21	1.6	4b	69	1.2
8	39	2.9	12	101	3.2	11b	26	1.5	5b	81	1.2
11	50	3.1	5	108	2.4	2a	26	0.9	14a	103	1.9
2	50	1.8	3	109	2.4	15a	27	1.6	10b	116	1.4
			10	114	2.8	7b	27	1.1	5a	116	1.2
			9	127	2.7	4a	28	1.2	1b	127	1.4
			1	190	2.8	6a	29	1.2			
						9a	30	1.3			
						13b	32	1.6			
						13a	32	1.6			
						8a	32	1.4			
						2b	38	0.9			
						7a	38	1.1			
						12a	44	1.6			
						11a	44	1.5			
						15b	44	1.6			
						3a	46	1.2			
						1a	50	1.4			
						3b	50	1.2			
						9b	52	1.3			

The simulated volume yields of sawn timber for the two positioning methods and the two sawing patterns are shown in Figure 5. The cant-sawing (CS) pattern gives a higher volume yield than the through-and-through (TT) sawing pattern for both full-length and bucked logs. In the study reported by Ah Shenga *et al.* (2014) using the same log models, CS was however found to be the least productive sawing method. In contrast to the present study, the offset parameter was in that case not used to improve the volume yield, and the grading was made according to species (Bunster 2012), and this is the main cause of the difference. The decrease in volume yield from CS to TT of full-length logs was 2% to 6%, whereas for bucked logs the decrease was between 8% and 14%. This may also be due to the saw-kerf width, i.e. in TT sawing the share of saw-kerf is larger than in the CS method. The effect of saw-kerf was investigated by Pinto *et al.* (2002)

and they found that, on average, 1 mm saw-kerf decreases the volume yield of sawn timber by about 3%.

The optimal positioning and horns-down positioning of full-length logs are shown in Figure 5a. There was a significant difference ($p < 0.02$) in volume yield between the two positioning methods, the mean volume yield with optimal positioning being higher than the yield in the horns-down positioning. For Grade 1 logs, the horns-down positioning gave a volume yield 10% (mean of two sawing patterns) less than the optimal positioning. For Grade 2, logs the volume yield decreased by 14%.

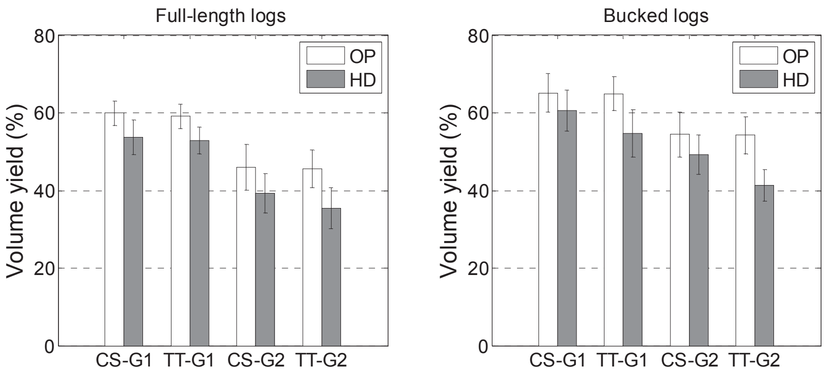

Figure 5. Volume yield of sawn timber of the optimal position (OP) and at the horns-down position (HD) of Grade 1 and Grade 2 logs: a) full-length logs, and b) bucked logs. CS – cant-sawing, TT – through-and-through sawing and G – grade.

For bucked logs (Figure 5b), the trend was similar to that for full lengths logs, but with Grade 2 logs, the decrease from the optimal to the horns-down position was smaller than that seen in full-length logs. The volume yield of sawn timber using the horns-down position for Grade 2 logs was 11% less than the yield with optimal positioning, but for Grade 1 logs, the decrease was similar to that found for full-length logs. Bucking reduced the magnitude of the crook, for example, the crook varied from 90 mm to 190 mm for Grade 2 full-length logs and from 60 mm to 127 mm on bucked logs (Table 1).

The decrease in volume yield from optimal position to horns-down position in this study was greater than that reported by *e.g.*, Lundahl and Grönlund (2010) who investigated the positioning of Scots pine. In their study, the maximum crook was 28 mm whereas in the present study, it was 52 mm, and the crook was oriented in more than one direction, which is less common in Scots pine logs from Scandinavia. However, the impact of the crook on the volume yield of the species studied here might be reduced because of their larger diameters. Large-diameter logs are easier the fit to the sawing pattern and they are less sensitive to the precision of the positioning procedure.

The results show the potential of bucking the logs. More important in these findings is the ratio between the crook and the log length, *i.e.* reducing the log length reduces the effect of crookedness and hence increases the volume yield.

Figure 5 also shows that the volume yield of the bucked logs was greater than that of full-length logs. For Grade 1 logs, the mean increase in volume yield (mean for both sawing patterns) for both positions was 8%. For Grade 2 logs, the increase at optimal positioning was approximately 14% but in the horns-down position is was approximately 16%.

Figure 5 also show the volume yield standard deviation (SD), indicated by error bars. In the horns-down position the SD was similar to that in the optimal position. This variation shows how the volume yield is sensitive to positioning, and it was reported by Drake *et al.* (1986) that optimal positioning is more sensitive to variation than the horns-down positioning method. However, the present results show that horns-down positioning can be an alternative to optimal positioning for tropical hardwood species because the crook can be reduced by bucking, and the logs sawn using the horns-down position.

To predict how much the volume yield decreases from the optimal to the horns-down position, the relation of volume yields is shown in Figure 6, where the horns-down volume yield (HD) is plotted versus optimal volume yield (OP), together with the linear regression equation and the adjusted coefficient of determination (R^2). The result shows that for Grade 1 logs 78% of the total variation in HD can be explained by the linear relationship between OP and HD while for Grade 2 logs 81% can be explained.

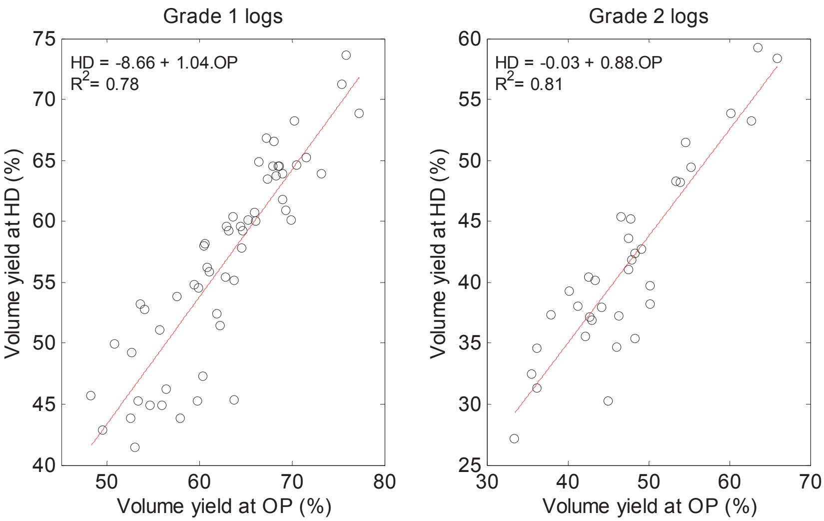

Figure 6. Scatter plots of horns-down position (HD) versus optimal position (OP) of Grade 1 and Grade 2 logs. The coefficient of determination (R^2) was 0.78 for Grade 1 and 0.81 for Grade 2 logs.

CONCLUSIONS

The result shows that the horns-down positioning prior sawing can be used as an alternative to optimal positioning in tropical hardwood species, although the volume yield is less than that in the optimal positioning. Positioning the log at horns-down decreases the mean volume yield by between 10% and 14%.

Sawmills can achieve a volume yield similar to that in the optimal positioning by bucking the logs and then sawing using horns-down positioning, since bucking reduces the crook of the logs. The volume yield can be increased by between 8% and 16% when the logs are bucked.

The result also shows that it is important to grade the logs according to crook. In this study, logs with a crook less than 60 mm gave a considerable higher volume yield and were less affected by the error in positioning in both positions methods.

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