UNIVERSITI PUTRA MALAYSIA

EFFECTS OF NODES AND FINGER-JOINTED BAMBOO STRIPS ON PROPERTIES OF LAMINATED BAMBOO TIMBER FROM FROM GIGANTOCHIOA SCORTECHINII GAMBLE

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Effects of Nodes and Finger-Jointed Bamboo Strips on Properties of Laminated Bamboo Timber from *Gigantochloa scortechinii* Gamble

By

ROGERSON ANOKYE

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillments of the Requirement for the Degree of Doctor of Philosophy

November 2015

DEDICATIONS

This study is dedicated to my Parents, my wife Evelyn and children Ethel and Martin.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

Effects of Nodes and Finger-Jointed Bamboo Strips on Properties of Laminated Bamboo Timber from *Gigantochloa scortechinii* Gamble

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Chairman : Associate Professor Edi Suhaimi Bakar, PhD
Faculty : Forestry

Bamboo has good potential as an alternative to wood-based materials especially in wood based composite industry to mitigate against the over increasing decline of the forest resources in Ghana. The abundance of wild bamboo in the Ghana with its numerous potentials of cultivating and developing bamboo necessitated the study into the development of high grade building and furniture material from bamboo as an alternative material and to verify its physical and mechanical properties. Research has shown that, node of bamboo is the weakest point and requires the removal and or rearrangement of the nodes to improve the strength of laminated bamboo timber (LBT) products.

Gigantochloa scortechinii and Bambusa vulgaris species from Malaysia were adopted for the study due to the species' availability and proximity as well as the environmental conditions' similarities to that of Ghana.

The basic physical and mechanical properties of the two species at three different height levels were assessed to determine their similarities. They were also to serve as a guide in the determination of strength properties of the LBT as well as its working qualities and environmental tolerability. The results revealed that, both species have similar basic characteristics in both physical and mechanical properties to indicating G. scortechinii's appropriateness for the study.

The processing of bamboo into strips using split squaring and V-grooving processing methods were compared. This was done in order to recommend the best processing method whilst, the bondability properties of the strips were also assessed in order to proposed the proper method and procedure of bonding, in the lamination process of the LBT. The results of the former confirmed V-grooving method's superiority in terms of processing recovery. However, split squaring method was selected for the processing of LBT due to its time efficiency of about thrice to that of V-grooving method.

Accordingly, basal section of G. scortechinii was then selected for the development of a non-nodal finger-jointed laminated bamboo timber (LBT). The strength performance with respect to finger-jointed, nodal and non-nodal or clear joint types, phenol formaldehyde and polyvinyl acetate glue types, 200 g/m^2 and 250 g/m^2 glue spread rates and joint intervals of 0, 5, 10 and 15 cm were all examined. The results revealed that, the mechanical properties of non – nodal finger - jointed LBT has higher MOE

and MOR than members formed with nodes but slightly lower in strength than clear samples.

Though there was a similar failure behaviour within the samples in the same group of nodal and non-nodal finger-jointed, non-nodal finger jointed LBT bonded with 200 g/m^2 PF showed a higher performance than PVAc on both MOE and MOR. The flexural performance of the LBT with finger-joints increases with increase in joint intervals.

From the results gathered on bending, compression and shear strength on the non-nodal finger-jointed LBT as well as the dimensional stability of it, can be concluded that, the product is extremely satisfactory for interior furniture production. The overall results of the dimensional stability test on the newly developed LBT was found to have mean thickness swelling (TS), water absorption (WA), and linear expansion (LE) (parallel and perpendicular to grain) values within the normal behaviour of bamboo laminated lumber, although the mean moisture absorption (MA) was slightly higher than those obtained by others. Additionally, the results obtained for the LE parallel and perpendicular to grain matches the radial-tangential swelling ratio of 1.0: 1.2 which is more likely to stabilize the LBT when subjected to 55% and 90% relative humidity environmental conditions.

Generally, the removal and the replacement of nodes with finger joints respectively has shown a considerable improvement in the strength properties of LBT. However, the strength attained together with the bonding qualities make LBT bonded with PF glue at 200 g/m^2 spread rate a strong material with better dimensional stability suitable for interior applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

Kesan Nod Dan Jari Paha Jalur Buluh Terhadap Sifat-Sifat Berlaminasi Buluh Kayu Dari *Gigantochloa scortechinii* Gamble

Oleh

ROGERSON ANOKYE

November 2015

Pengerusi : Profesor Madya Edi Suhaimi Bakar, PhD
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Buluh mempunyai potensi yang baik untuk menggantikan bahan berasaskan kayu terutamanya didalam industri berasaskan komposit kayu bagi menghadapi pengurangan sumber hutan yang semakin meruncing di Ghana. Limpahan buluh liar di negara ini sememangnya mempunyai potensi yang banyak untuk pembangunan justeru, kajian ke atas pembangunan bahan bergred tinggi daripada buluh sebagai bahan gantian dan pengesahan sifat fizikal dan mekanikal perlu dijalankan.

Spesies Buluh semantan dan Buluh minyak dari Malaysia diterima pakai untuk kajian kerana ‘sumber yang sedia ada dan berhampiran selain keadaan persekitaran' yang mempunyai persamaan di Ghana.

Ciri asas fizikal dan mekanikal kedua-dua spesies pada tiga tahap ketinggian yang berbeza telah dinilai untuk menentukan persamaan mereka dari segi pemprosesan. Kaedah pemprosesan “Split squaring” dan “V-grooving” juga disyorkan sebagai kaedah pemprosesan yang terbaik. Sifat fizikal dan mekanikal buluh dikaji untuk menilai kualiti kebolehkerjaannya dan juga kesan kepada persekitaran.

Pemprosesan buluh menjadi jalur menggunakan menyegiempatkan perpecahan dan kaedah pemprosesan V-grooving dibandingkan. Ini dilakukan untuk mengesyorkan kaedah pemprosesan yang terbaik manakala, sifat-sifat bondability jalur juga dinilai untuk mencadangkan kaedah yang betul dan prosedur ikatan, dalam proses laminasi daripada LBT. Keputusan keunggulan bekas V-grooving mengesahkan kaedah ini dari segi pemulihan pemprosesan. Walau bagaimanapun, berpecah kaedah menyegiempatkan dipilih untuk memproses LBT kerana kecekapan masa sebanyak kira-kira tiga kali itu kaedah V-grooving.

Bahagian bawah *G. scortechinii* kemudiannya dipilih untuk pembangunan tanggam sambungan jari buluh berlapis tanpa buku (LBT). Prestasi kekuatan berkenaan tanggam sambungan jari, buku buluh dan tanpa buku buluh atau tanggam dari jenis sambungan jelas, gam dari jenis fenol formaldehid dan polivinil asetat, kadar perebakan gam untuk 200 g/m^2 dan 250 g/m^2 dan sambungan selangan untuk 0, 5, 10 dan 15 mm semuanya diuji. Hasil kajian menunjukkan, sifat-sifat mekanikal tanggam sambungan jari LBT mempunyai MOE dan MOR yang lebih tinggi berbanding sample yang dihasilkan daripada buku buluh.

Walaupun ciri kegagalan yang sama ditunjukkan untuk sampel dalam kumpulan yang sama dalam buku buluh dan sambungan jari, tanggam sambungan jari tanpa buku LBT yang di lekatkan dengan 200 g/m^2 PF menunjukkan prestasi yang lebih tinggi daripada PVAc dalam MOE dan MOR. Prestasi lenturan LBT dengan tanggam sambungan jari meningkat seiring dengan peningkatan dalam sambungan selangan.

Daripada keseluruhan keputusan ujian kekuatan, mampatan dan ricihan tanggam sambungan jari tanpa buku LBT dan juga kestabilan dimensi bahan, dapat disimpulkan bahawa produk ini amat berjaya untuk perabot dalaman rumah. Keputusan keseluruhan ujian kestabilan dimensi pada LBT yang baru dibangunkan didapati mempunyai ketebalan min bengkak (TS), penyerapan air (WA), dan pengembangan linear (LE) (selari dan bersudut tepat dengan bijirin) nilai dalam tingkah laku biasa buluh kayu berlamina, walaupun penyerapan kelembapan min (MA) adalah lebih tinggi sedikit daripada yang diperolehi oleh orang lain. Selain itu, keputusan yang diperolehi untuk selari LE dan serenjang dengan ira perlawanan nisbah jejari tangen bengkak 1.0 : 1.2 yang lebih cenderung untuk menstabilkan LBT apabila tertakluk kepada 55% dan 90% kelembapan keadaan alam sekitar.

Secara umumnya, penyingkiran dan penggantian nod dengan sendi jari masing-masing telah menunjukkan peningkatan yang besar dalam sifat kekuatan LBT. Walau bagaimanapun, kekuatan yang dicapai bersama-sama dengan sifat-sifat ikatan membuat LBT terikat dengan gam PF pada kadar penyebaran 200 g/m^2 bahan yang kuat dengan kestabilan dimensi yang lebih baik sesuai untuk aplikasi dalaman.

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I certify that an Examination Committee has met on 25 November 2015 to conduct the final examination of Rogerson Anokye on his Doctor of Philosophy thesis entitled "Effects of Nodes and Finger-Jointed Bamboo Strips on Properties of Laminated Bamboo Timber from *Gigantochloa scortechinii* Gamble". In accordance with Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia and [P.U. (A) 106] 15 March 1998. The committee recommends that the candidate be awarded the Doctor of Philosophy.

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LIST OF ABBREVIATIONS / NOTATION/ GLOSARY OF TERMS

LBT	Laminated bamboo timber
MOE	Modulus of elasticity
MOR	Modulus of rupture
PVAc	Polyinyl acetate
PF	Phenol formaldehyde
BARADEP	Bamboo and Rattan Development Programme
TIDD	Timber Industries Development Division
FAO	Food and Agricultural Organization
UNECE	United Nations Economic Commission for Europe
KMA	Kumasi Metropolitan Assembly
INBAR	International Network on Bamboo and Rattan
PBPC	Pioneer BambooProcessing Company
OIC	Opportunity Industrialization Centre
EMC	Equilibrium moisture content
SG	Specific gravity
MF	Melamine formaldehyde
MMF	Methylolated melamine formaldehyde
MDI	Methylene diphenyl diisocyanate
RF	Resorcinol formaldehyde
UF	Urea formaldehyde
OSB	Oriented strand board
LVL	Laminated veneer lumber
CSLM	Confocal fluorescent scanning laser microscopy
ASTM	American standard testing of materials
OPT	Oil palm tree

ANOVA	Analysis of Variance
MA	Moisture absorption
TS	Thickness Swelling
WA	Water absorption
LE	Linear Expansion
σk	Shear strength
mm	Millimeter
pH	Acid / Alkaline indicator
NaOH	Sodium Hydroxide
HCl	Hydrogen Chloride
cm	Centimeter
hrs	Hours
mmHg	Millimeter mercury
$Mg(NO_3)_2$	Magnesium nitrate
K_2SO_4	Potassium Sulphate

CHAPTER 1

INTRODUCTION

1.1 Background

Supply of wood from the forest has been on the decline throughout the world within the last decade (UNECE/FAO, 2010). The condition of decreasing wood supply from the forest has led to limited quality wood material supply to the wood industries. This phenomenon, coupled with the growing world population with its corresponding improving living standards, a suitable material that has working and aesthetic properties close to wood as a furniture making material should be searched for and exploited.

Prior studies posit that for any class of wood for furniture production must have aesthetically unrivaled with nice texture and figures, mechanically strong in relation to its weight, easy to be machined with small consumption of energy as well as the ability to be joined with nails, connectors and glue (Green *et al*., 2010; Xiao *et al*., 2013). Any suitable material for wood substitution must be versatile, strong, durable, beautiful, environmental friendly, renewable and widely available. All these qualities could be found in bamboo.

There are about 1500 species of woody bamboos in the world (Turnbull, 2008). Takahashi (2006) also reported of over 1110 species all over the world. However, Hidalgo (2003) identified over 1600 bamboo species globally with diverse properties. Bamboo is a fast growing renewable resource, cheap and locally available. Nahar and Hasan (2013) found bamboo to have higher strength to weight ratio as compared with wood, and can be a good substitute for wood.

There are several different features between bamboo and wood. In bamboo, there are no rays or knots, which give bamboo a far more evenly distributed stresses throughout its length. Bamboo is a hollow tube, sometimes with thin walls, and consequently, it is more difficult to join bamboo in its raw form than pieces of wood. Bamboo does not contain the same chemical extractives as wood, and can therefore be glued very well when the outer silica-rich part is removed (Janssen, 1981).

Bamboo's diameter, thickness, and internodal length have a macroscopically graded structure while the fibre distribution exhibits a microscopically graded architecture. According to Recht & Wetterwald (1994), bamboo does not consist of cellulose fibres but with long fibres up to centimeters containing lignin and silica. Its diverse properties could provide an answer to the quest for suitable furniture making material in bamboo.

Extensive research has been carried out on the anatomical, physical, chemical and mechanical properties of bamboo (Nahar & Hasan, 2013; Nordahlia *et al*., 2011; Razak *et al*., 2013). However, these studies mainly focused on the properties of internode, rather than on the node portion of the bamboo culm (Chaowana, 2012, 2013; Shao *et al*., 2010).

In addition, it is generally known that restrictions in processing and utilization are often related to its unsuitable properties. Therefore, a thorough understanding of the relations between structures, properties, behaviour in processing and product qualities is necessary for promoting the utilization of bamboo (Bahari & Krause, 2015; Liese, 1987, 1992; Mahdavi *et al.*, 2011; Zaidon *et al.*, 2004)

Moreover, while a substantial body of studies have investigated the properties of timber in general with conclusive findings (Kollmann & Cote, 1968; Kumar *et al.*, 2015; Richter, 2011), few attempts have been made to examine the properties of bamboo as a constructional material.

1.2 Problem Statement

The global estimated natural forest of about 3.22 billion hectares has reduced to about 1.56 billion hectares with about 10% being managed. This is even at the credit of 7% (264 million hectares) afforestation in the last two decades. This decline coupled with the increase in global consumption of wood approximating 3.23 billion m^3 annually (Bowyer & Stockman, 2001) has resulted in the demand for timber far exceeding the global supply within the last decade (UNECE/FAO, 2010).

Ghana has not been left out in this problem of deforestation. According to FAO (2010), the country's forest resources reduced from 7.45 million hectares to 4.94 million hectares from 1990 to 2010. The country used to be one of the major timber exporters in the world with timber been the third export earner of the country after cocoa and gold ("Ghana Exports," 2015). Between 1997 and 2014, the export volume of timber and timber products has reduced from 442,078.22 m^3 to 24,035 m^3 (TIDD, 2015). This sharp drop in supply to the local and export market and on the account of the enforcement of natural forest protection laws (Ghana Forestry Commission, 2012), wood is becoming increasingly scarce to feed the industries in the country. The trend, if continued, the country will soon face an acute shortage of wood and other forest products.

Bamboo could offer an alternative or useful supplement to many wood products that are currently being used. The realization that bamboo is the most potentially important non-timber resource and fast-growing woody biomass, has evoked keen interest in the processing and utilization of bamboo for high performances and high valued products (Chaowana, 2013; Gutu, 2013). It is important to exploit the versatility of bamboo in intermediate and top-grade building construction, architecture decorating, and other major applications. Its high valued utilization not only promotes the economic development in bamboo areas where people are in low-income, but also saves forest resources to protect our ecological environment as a wood substitute (Zoysa *et al.*, 1988).

Ghana has large reserve of bamboo, which is highly underutilized for both domestic and industrial purposes. Moreover, bamboo utilization for within the local setting is largely limited to the round bamboo culms for the housing props, handicrafts and other constructional purposes, especially in furniture production which does not go through any complicated processes. The use of bamboo in the industries is still not widespread even though it has proven to have comparable strength if not greater, to that of timber.

Bamboo laminated timber (LBT) has been accepted as one of the most efficient use of non-wood material for furniture production. Currently, bamboo laminated products can be safely used in the interior application of many places. For bamboo to be well accepted as a furniture and or building construction material, its properties must be comprehensively investigated.

Many researchers from Malaysia were identified to have studied into the properties of this emerging material (Anwar *et al.*, 2005; Hamdan, 2004; Hanim *et al.*, 2013; Nordahlia *et al*., 2011; Razak *et al*., 2013; Razak *et al*., 2006). Most of these researchers found variations in the physical and mechanical properties within the bamboo culm. However, their studies mainly focused on individual species at different locations. Considerable comparison on the most common Malaysian species - *Gigantochloa scortechinii* (Semantan) and *Bambusa vulgaris* (Gading) - has not been well established. Though, *G. scortechinii* is not common in Ghana, its availability and stem qualities for board making in Malaysia made it a suitable species to be compared with *B. vulgaris* that are common in Ghana. This is to determine whether boards made from *G. scortechinii* may have similar characteristics that could be implemented in developing *B. vulgaris* in Ghana.

Again, researchers in the field of bamboo have extended their knowledge in the product design by producing high end quality sustainable industrial products such LBT, zephyr strand mats and boards (Lee *et al.*, 2012; Mahdavi *et al*., 2012; Nugroho & Ando, 2001; Yang *et al*., 2014). Laminated bamboo has been found by these researchers to have really no limit to its use. It can be used for chairs and other furniture.

Ganapathy *et al.* (1999), Guisheng (1987) and Zhang (2014), also found laminated bamboo usage as just like laminated wood, with the advantage that bamboo laminates are much lighter in weight and the manufacturing process is much the same as for conventional plywood. Regardless of the numerous advantages of the LBT Anwar *et al*. (2005), Hamdan, (2004b), Nordahlia *et al*. (2011) and Razak *et al.* (2006), found distortions in the vascular bundles of the node section of the culm, leading to the variations in strength along the culm. They however recommended the removal of the node and replaced with an appropriate joint.

Having found the extensive work done by researchers from Malaysia on bamboo and with many reasons gathered, investigation into the development of an LBT devoid of node was conducted.

1.3 Justification

Bamboo is a naturally occurring composite material, which grows abundantly in most of the tropical countries. It is considered as composite material because it consists of cellulose fibres imbedded in a lignin matrix. Cellulose fibres are aligned along the length of the bamboo providing maximum tensile flexural strength and rigidity in that direction (Lakkad & Patel, 1980). Bamboo material has a fine, delicate grain, whether natural or amber-toned, making it a distinctive, elegant, and delicate for fine furniture. It has a very high tensile strength and once properly cured and treated is very durable.

Not only does it make durable and beautiful furniture, but it is a sustainable and renewable resource and we own thousands upon thousands of acres of it in the country.

Bamboo can be processed into modern products (engineered bamboo) that may successfully compete with wood products in term of price and performance. With the growth of demand for environmentally friendly green products, the world bamboo market is expected to double by 2015, from USD 10 billion to USD 20 billion (Xuhe, 2003).

Bamboo can be recycled and permits low waste production and easily to be worked with using simple tools. Tools used for felling bamboo are small axe or relatively short, straight-edged machete. McClure (1981) suggested the use of long, fairly heavy blades for the machete. Today small chainsaw machines can be employed in the harvesting of bamboo.

There is also a growing global interest in developing bamboo as a substitute of structural timber and in furniture production. In addition to the growing interest of the development of bamboo, many studies need to be conducted into the plant at different height levels since different heights of trees have different properties (Paulinyova & Makovicka, 2006).

Some studies have been conducted into the use of bamboo as a construction material and furniture production. However, systematic and thorough research on a common but important bamboo species – *B. vulgaris* and *G. scortechinii* is needed to determine the utilization potential for the products such as furniture manufacturing. To use bamboo more efficiently in the development of products, specific characteristics - physical and mechanical properties must be taken into account. High-grade furniture material from bamboo can be produced whereby the cylindrical-shaped bamboo must be processed into flat sheets before finally glued together into LBT with precision lamination.

According to Bakar (2006), split-squaring[1] and V-grooving[2] methods can be employed with their problems, which need further improvements. The split-squaring method is very low in processing recovery (25-30%) and thus inefficient in processes. The V-grooving method is high in recovery (85-90%) but has a limitation in length. This is because, the V-grooving method is only capable to process culm internodes, and therefore only short length sheet can be produced. Because of that, this method requires finger-jointing process to produce lengthy LBT. Therefore, the effectiveness and the efficiency of the two processing methods needed to be assessed.

The nodal portion of bamboo is seen as having the weakest point due to the distortions of the vascular bundles and this is likely to affect the end product of bamboo (Hamdan, 2004b). Nordahlia *et al*. (2011) recommended the removal of the nodes when the material is to be used for laminated bamboo or for manufacturing long and continuous composite due to the inconsistencies in strength because of variations in most of the properties within the node and the internode. Though, they found it to be technically and economically not feasible, finger jointing techniques was recommended to be a best alternative.

These identified problems necessitated this thorough study into the strength properties of lumber produced from laminated bamboo with various joint conditions (clear, with nodes and with finger-joint). This was to ascertain whether there were significant

[1] Splitting bamboo and shaping it to square before gluing edge to edge as a board.
[2] Making series of grooves on the culm without splitting and spread to form a board.

differences in strength in the LBT produced under various joint conditions. These gaps also demanded a thorough investigation into the production of high-grade LBT for furniture application.

The dimensional stability of the LBT was also needed to predict the functionality of the product in different environmental conditions. Bamboo is a hygroscopic and swells to some extent when in contact with water. It is also anisotropic though not as an extreme as wood, which can cause some dimensional changes in the LBT when in use especially, in a humid condition. Many researchers have investigated the use of numerous chemicals to stabilize the dimension of wood (Rowell & Banks, 1985; Rowell & Ellis, 1978; Rowell, 1975, 1980, 1982, 2005). With the use of phenolic resins in the lamination process (Cho *et al.*, 2013; Furuno *et al.*, 2004), it is expected to improve the dimensional stability of the final product and therefore needed to be examined.

It is therefore necessary to note that, for effective use of LBT as a furniture-producing raw material, it will be helpful to predict its behaviour under typical loading conditions that exist in the structure. This analysis requires information regarding the material's physical and mechanical properties. These properties are not only influenced by the geometry of bamboo elements and their arrangement in the lamination, but also by the alterations, the element's properties will undergo during the manufacturing process of the LBT.
It is noteworthy that physical and mechanical properties of bamboo depend on the species and its condition, site or soil and climatic condition, silvicultural treatment, harvesting technique, age, density, moisture content, position along and across the culm, nodes or internodes, and biodegradation, among others (Lee *et al.*, 1994). Therefore, a thorough examination has to be conducted to ascertain its physical and mechanical properties of the bamboo and the newly LBT product, that will help remove the major constraints of lack of design standards.

1.4 Objectives

The project was designed to produce a high grade LBT for effective furniture application from *G. scortechinii* (Buluh Semantan). The effects of culm position (bottom, middle and top) on physical and mechanical properties of each bamboo species were considered. The study consisted of the following specific objectives:

a. To ascertain the physical properties of bamboo strips of selected species at different height levels;
b. To compare two processing methods (split-squaring and V-grooving methods) in terms of processing time and recovery in the production of LBT;
c. To determine the effect of layer's joint conditions (with nodes, with finger joint, clear) and joint distance on the strength (MOE, MOR, compression and shear) of LBT under different glue types and rate of glue spread;
d. To evaluate the dimensional stability of the LBT.

1.5 Structure of the Thesis

The study is organized into seven chapters as follows:

Chapter One gives a general overview of the study and basically includes the background, problem statement, objectives, justification and general organization of the thesis for the study.

The Second Chapter provides a comprehensive review of existing and relevant literature on bamboo and its properties and the performance of finger jointed laminated bamboo timber. The review also discusses adhesives and adhesion principles suitable for the product and their properties as well as their methods of application.

Chapters Three through Chapter Six are written as stand-alone papers addressing each of the objectives presented in this chapter. Chapter Three reports on determination of physical and mechanical properties of bamboo, including density, moisture content, shrinkage, modulus of elasticity (MOE), modulus of rupture (MOR) and compressive strength parallel to the grain of bamboo strips at different height levels of two selected bamboo species. Based on these results, the best one between the two species studied was selected for the formation of LBT based on the three structural formations and two glue types and their strength properties were determined in Chapter 4.

Chapter Five compares the two processing methods of LBT production in terms of processing time and recovery. Chapter Six employs the results presented in Chapters Three to Five to evaluate the functionality of the new LBT product.

Finally, Chapter Seven summarizes the conclusions of this project based on Chapters Three through Chapter Six. Recommendations are also provided in this chapter for further research and development.

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