

**DECODING THE POTENTIALS OF VERNACULAR  
TIMBER PRESERVATION TECHNOLOGY FOR  
STRUCTURAL APPLICATIONS**

Malsha Shehani Mendis

188029J

Degree of Doctor of Philosophy in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

February 2022

**DECODING THE POTENTIALS OF VERNACULAR  
TIMBER PRESERVATION TECHNOLOGY FOR  
STRUCTURAL APPLICATIONS**

Malsha Shehani Mendis

188029J

Dissertation submitted in partial fulfillment of the requirements for the Degree of  
Doctor of Philosophy in Civil Engineering

Department of Civil Engineering

University of Moratuwa  
Sri Lanka

February 2022

## **DECLARATION OF CANDIDATE AND SUPERVISOR**

“I declare that this is my work and this thesis does not incorporate without acknowledgment any material previously submitted and to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

Also, I hereby grant to the University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic, or another medium. I retain the right to use this content in whole or part in future works (such as articles or books).”

.....

Signature:

.....

Date:

The above candidate has researched the Ph.D. Dissertation under our supervision.

.....

**Prof. R. U. Halwatura**

Department of Civil Engineering  
Faculty of Engineering  
University of Moratuwa  
Sri Lanka

.....

**Prof. Raj Somadewa**

Postgraduate Institute of Archaeology  
University of Kelaniya  
Sri Lanka

.....

**Prof. H. Amarasekara**

Department of Forestry and  
Environmental Science  
Faculty of Applied Sciences  
University of Sri Jayewardenepura  
Sri Lanka

.....

**Dr. Randika Jayasinghe**

Department of Civil and Environment  
Technology  
Faculty of Technology  
University of Sri Jayewardenepura  
Sri Lanka

## ABSTRACT

Along with the celebrated history in the field of construction in the world, wood has been a building material for hundreds of years. The stability of timber structures is influenced by their reliance on external factors as it's a hygroscopic material. Where the moisture content has an impact on almost every structural parameter, including strength, stiffness, and dimensional stability. It is also extremely vulnerable to biological degradation caused by insects, fungi, and bacteria affecting the molecular structure.

These scarcities were undertaken in traditional wooden structures in a significant, yet sensitive manner in a tropical country like Sri Lanka. The durability of traditional wooden constructions exists under a highly appreciable status. In a tropical environment, the prolonged physical sustainability of wood is a challenging task. These show a greater degree of tolerance in the harsh tropical environment. Empirically expressive information sources were investigated, therefore structures for shelters were selected for further analysis.

In this case, *Tampita Vihara* (the shrines on pillars), *Devala* (shrines dedicated to deities), *Ambalam* (resting places for travelers), and *Mandapa* (the assembly spaces for administrative practices) of which physical remains are still available in a relatively preserved state of standing evidence were carefully chosen. Numerous literature findings are documented on their religious beliefs and the significance of their architecture. But the structural engineering aspects relevant to material perspectives have not been studied adequately.

A holistic investigation of timber in construction was carried out using knowledge from traditional vernacular buildings. Traditional vernacular<sup>1</sup> construction relied on a thorough awareness of the surrounding environment, as well as the characteristics of locally available materials and manual labor. Traditional people are essential stakeholders in forest management because they are often economically, socially, and culturally reliant on forests. This resulted in building artisans attaining a profound knowledge of the utilization and manipulation of materials.

This study examines the state of the structures, which entails a thorough understanding of past and present conditions. The goal of collecting extensive data from various typological structures is to establish a knowledge basis for the future. Field survey analysis around Sri Lanka was conducted to accumulate and consolidate the traditional vernacular timber processing and preservation technologies.

Results disclosed wood logs burying under paddy field mud as a well-established technique to treat wood. As well, three dominant plant species were identified as *Mikania micrantha*, *Titonia diversifolia*, *Gliricidia sepium* assorted with paddy field mud to enhance the properties before treatment. Further, the field survey results and the microscopic investigations proved *Mangifera indica* wood was used for roof elements utilized after the above treatment in traditional vernacular structures with in the use life range 40 to 50 years. This showed its potential to be used for structural applications after proper treatment.

Finally, an experimental trial was performed to evaluate the traditional vernacular technology with amendments, reinventing two types of wood preservatives based on the material matrix as plant extracts assorted with paddy field mud and only plant extracts obtained for water.

This combination of traditional vernacular and contemporary aspects could offer an interesting and profitable approach to the further development of the wood industry.

**Keywords:** Timber architectural typologies; timber preservation technology; *Mikania*; *Gliricidia sepium*; *Titonia diversifolia*; Plant extracts; wood preservatives.

---

<sup>1</sup> The term vernacular comes from linguistics, where it refers to language usage specific to a time, region, or group.

## ACKNOWLEDGMENT

*When the broad mind has opened, I stare at the stars that shinning in the thoughtful skies and the glittering nature, as well as Earth's mysteries that I ever think of to feel by my thoughts that spread so deep on trying to work with things that sound 'creative'. Here I started my second journey, leaving 219 km away from home three years ago. This up-start was through Science, Engineering, and Design.*

*In that journey, I found a great pillar, where I today express my heartfelt gratitude to my research supervisor, Prof. R.U Halwatura who always guided me to create a railroad to drive my engine. We together drive our engine and today we have one big train.*

*When we arrived at the next station, we met another three pillars, and today I would like to salute and express my earnest gratitude to Prof. Raj Somadeva, Prof Hiran Amarasekara, and Dr. Randika Jayasinghe as my other supervisors. Together as a team, I was able to drive as far as I could in all the ups and downs. More than research, together I learned and enjoyed life as a researcher.*

*Here in honor, my deepest gratitude goes to Prof. Chandrasekara D.P, (Department of Architecture), Dr. Lessy (Senior Lecturer, Department of Civil Engineering), Dr. Artigalle (Department of Material Science Engineering) for their continuous encouragement, comments, and guidance as my examiners of bi-annual review panels.*

*Within the journey, I would appreciatively thankful to the support given by Prof. Kulathilaka (Head, Department of Civil Engineering) and to all the academic and non-academic staff of the University of Moratuwa.*

*In this journey, I met strong and genius souls. Some got to my train to drive together when some left on the next station. Through this drive, few made me more and more strong namely the support I received from all the technical officers, Lab- Attendants and friends from the Department of Civil Engineering the University of Moratuwa, University of Sri Jayewardenepura, and the State timber cooperation Sri Lanka.*

*The journey will not be this easy without this bunch of colleagues in the Management Division including Ms. Priyantha, Ms.Rukma, Naveen for their gracious associations throughout the last three years. More I wish to acknowledge Prof. Halwatura's research assistants and S.N. Malkanthi (Senior Lecturer, University of Ruhuna).*

*A special thanks to my brother (R.W.Mendis) and my sister (K.D. Mendis) for the warmth behind me and my loving pets spending many nights under me.*

*This thesis is dedicated to my parents, for their love and support, from where I got the powers to be inspired to write and prove. If I met Life as a strange stage of different senses and I only say you to enjoy the aggressive fruits of my invention. Here it is for all of you to read and evaluate.*

## TABLE OF CONTENTS

Declaration of Candidate and Supervisor .....	iii
Abstract .....	v
Acknowledgment .....	vi
List of Figures.....	xiv
List of tables .....	xx
i .....	
Chapter 1 : INTRODUCTION.....	1
1.1 General .....	1
1.2 Research Problem.....	3
1.3 Research Gap.....	3
1.4 Aim and Objectives .....	4
1.5 Methodology .....	5
1.6 Main Findings .....	7
1.7 Organization of the thesis.....	8
Chapter 2 : LITERATURE REVIEW.....	9
2.1 General .....	9
2.2 Urbanization and the construction industry .....	9
2.2.1 The environmental impacts of buildings.....	10
2.2.2 Evaluation of construction materials .....	11
2.2.3 The effects of building material selection.....	12
2.2.4 The use of timber in construction .....	14
2.3 Causes of wood deterioration.....	15
2.3.1 Deterioration caused by insects .....	15
2.3.2 Deterioration caused by fungi and bacteria .....	18
2.3.3 Deterioration caused by fire.....	20
2.4 Wood Preservation Principles .....	22
2.4.1 Natural durability of wood.....	22
2.4.2 Wood.....	22
2.5 Wood preservation .....	27
2.5.1 Wood preservatives.....	27
2.5.2 Impacts of inorganic chemicals used for wood protection .....	29
2.5.3 Natural Compounds for wood protection .....	30
2.6 Plant extracts as wood preservatives .....	33
2.7 Timber modification.....	34

2.7.1	Thermal modification.....	35
2.7.2	Chemical Modification .....	35
2.7.3	Impregnation modification.....	35
2.8	Past applications of wood in construction.....	36
2.8.1	Local application.....	36
2.9	Nature and the cultural symbiosis .....	38
2.10	Summary .....	40
Chapter 3 : ANCIENT TIMBER PRACTICE IN SRI LANKA .....		42
3.1	General .....	42
3.2	Archaeological Evidence.....	42
3.3	<i>Ambalam</i> Structures .....	42
3.3.1	Identifying the potentials of traditional construction techniques.....	46
3.3.2	The structure of ‘ <i>Ambalama</i> ’ .....	46
3.3.3	Materials and Methodology .....	49
3.3.4	Results.....	50
3.3.5	Discussion .....	52
3.4	Timber processing techniques practice in <i>Ambalam</i> .....	54
3.4.1	Growth Rings and Grain Distribution.....	55
3.4.2	Growth Stress.....	55
3.4.3	Materials .....	56
3.4.4	Methodology .....	58
3.4.5	Results.....	61
3.4.6	Discussion .....	63
3.5	Strategies used to overcome the mechanical failure .....	66
3.5.1	Major structural components .....	67
3.5.2	Major structural components – Type C .....	67
3.6	Summary .....	69
Chapter 4 : DECODING THE TIMBER PRESERVATION TECHNIQUES.....		71
4.1	General .....	71
4.2	Documenting the traditional vernacular timber preservations practiced in Sri Lanka .....	71
4.2.1	Materials and methodology.....	72
4.2.2	The selected cases .....	72
4.2.3	Field Survey .....	74
4.2.4	Statistical Analysis.....	74



4.2.5	Sampling Technique - Snow-balling Sampling technique (SB).....	74
4.3	Results and Discussion.....	74
4.3.1	Demographic profile .....	75
4.3.2	Identified characteristics of the structures (Building Description) .....	75
4.3.3	Awareness of the preservation technologies of the identified structures .....	78
4.3.4	Identification of traditional vernacular timber preservation technologies .....	79
4.3.5	Awareness of the Plants species used to develop the paddy field mud ..	83
4.3.6	Identify the potentials to formulate a preservative solution.....	84
4.4	Discussion .....	84
4.5	Identifying and materializing the identified traditional vernacular timber preservation techniques .....	85
4.5.1	Mud was prepared by adding leaves .....	85
4.6	Identifying the wood with the potential to further investigate the preservation techniques.....	86
4.6.1	Materials and methodology.....	88
4.6.2	Results of the Experiment 2.....	90
4.6.3	Discussion .....	92
4.7	Investigating the potentials of mango timber as a sustainable construction material.....	93
4.7.1	Materials and Methodology .....	94
A.	<i>Mechanical properties were evaluated using the following standard and the equations.....</i>	95
4.7.2	Results.....	95
4.7.3	Discussion .....	99
4.8	Identify the plants' species for further development .....	99
4.8.1	<i>Mikania micrantha</i> .....	100
4.8.2	<i>Gliricidia sepium</i> .....	101
4.8.3	<i>Titonia diversifolia</i> .....	101
4.9	Conduct experiments and investigate traditional vernacular technology....	102
4.10	Define the experimental procedure .....	102
4.10.1	Conduct experiments and investigate the traditional vernacular technology .....	102
4.10.2	Materials and methodology.....	102
4.10.3	Results of the experiment.....	103
4.10.4	Discussions obtained from the pilot study .....	105

4.10.5	Conduct experiments and investigate the traditional vernacular technology with amendments. ....	106
4.11	Causes for the mechanical performance.....	107
4.11.1	Materials and methodology.....	109
4.11.2	Results and Discussion .....	114
4.12	Comparison of Mechanical properties of Mango wood treated with commercially available wood preservative. ....	122
4.12.1	Investigation on the Mechanical Property Variation on Timber Caused Due to the Chemical Modification .....	122
4.12.2	Results.....	123
4.13	Comparison of mechanical properties of Mango wood treated with commercially available wood preservative and the decoded treatments. ....	125
4.13.1	Materials and methodology.....	125
4.13.2	Results and discussion .....	127
4.14	Spectroscopic screening on the treated wood .....	129
4.14.1	Materials and methodology.....	130
4.14.2	RESULTS .....	133
4.14.3	Discussion.....	138
4.15	The Field Evaluation of Potential toxicity Against the Invasive Subterranean Termite (Isoptera: Rhinotermitidae) in tropics.....	139
4.15.1	Materials and methodology.....	140
4.15.2	Results.....	142
4.16	Evaluation of the antifungal activity of experimental solutions .....	146
4.16.1	Materials .....	147
4.16.2	Results and discussion .....	150
4.17	Summary .....	153
Chapter 5 :	Development of the solutions .....	155
5.1	General .....	155
5.2	Identifying the optimum extraction procedure.....	155
5.3	Extraction Techniquess .....	156
5.3.1	The parameters that affect the extraction efficiency.....	157
A.	The effect of extraction temperature .....	160
B.	The effect of extraction time .....	160
C.	The effect of Water to leaf powder ratio .....	160
D.	The effect of particle size .....	160
E.	The effect of the extraction cycle.....	160

F.	Selection of solvent for bioactive compound extraction.....	161
5.3.2	Selection of the solvent for this research .....	161
<b>A.</b>	<b>Liquid water</b> .....	162
5.4	Investigating the plant leaf particle size for best extraction.....	162
5.4.1	Effect of Particle Size on the yield extract.....	162
5.4.2	Defining the extraction procedure .....	166
5.5	Development of the extraction procedure .....	166
5.5.1	Identify the best fermentation time .....	167
5.5.2	Identify the best filtration techniques .....	167
5.5.3	Preparation of the paddy field mud.....	169
5.5.4	Development of the procedure.....	171
5.6	Investigating the performance of the extracts obtained from the plant leaves	
5.6.1	Solution development comprising the plant extracts. ....	172
5.6.2	Defining the extraction Duration .....	175
5.6.3	Investigating the most effective fraction of the Extraction yield.....	177
5.7	Evaluating the performance of the solution .....	178
5.7.1	Evaluating the wood treated by the above-extracted layers.....	178
5.7.2	Results.....	180
5.7.3	Discussion .....	180
5.8	Effect of extraction methodologies and solvent selection for Chemical analysis.....	181
5.8.1	Dichloromethane.....	181
5.8.2	Evaluation on the most effective fraction of the plant extraction.....	181
5.9	Evaluation of the performance against fungus ( <i>Schizophyllum commune</i> ) that was grown in; Agar disc diffusion method .....	184
5.9.1	Materials and methodology.....	184
5.9.2	Results and discussion .....	186
5.10	Performance of the Solution Toxicity against termites.....	189
5.10.2	Investigating the performance of the plant extracted solutions .....	194
5.10.3	Results of the accelerated field test.....	195
5.10.4	Discussion .....	195
5.11	Evaluating the most toxic fraction against termites under natural feild conditions .....	196
5.11.2	Evaluating the toxicity against fungus.....	199
5.11.3	Preparation of culture plates .....	199
5.11.4	Results.....	200

5.12	Evaluation of the antifungal activity of experimental organic wood preservative .....	208
5.12.1	Materials and methods .....	208
5.12.2	Results and Discussions .....	210
5.12.3	Antifungal activity against white rots was presented as below, .....	216
5.12.4	Discussion .....	221
5.13	Leaching characteristics of the wood treated with the plant extracts.....	222
5.13.1	Experimental methods .....	223
	$weight\ loss\ \% = (Initial\ weight - present\ weight) * 100(initial\ weight)$ ....	225
5.13.2	Results.....	226
B.	Tannin presence in the leachate.....	227
C.	Mass loss percentage.....	227
5.13.3	Discussion .....	228
5.14	The Composition Development with optimum performance.....	232
5.15	Summary .....	234
CHAPTER 6 : A COMPARISON OF THE PERFORMANCE OF DEVELOPED SOLUTION .....		236
6.1	General .....	236
6.2	Development of the final solution.....	236
6.2.1	Experimental program .....	237
6.2.2	Experiment for the gross solution uptake .....	238
6.2.3	The density of the solution.....	240
6.2.4	Visual observation of the penetration .....	240
6.2.5	EDX analysis .....	244
6.2.6	Experiment on the toxicity performance.....	244
6.2.7	Accelerated Test 1 - <i>Filter paper test</i> .....	245
6.2.8	Antifungal properties of the two solutions.....	245
6.2.9	Performance of the treated wood (wood mass loss assay).....	246
6.2.10	Investigating the leachate of the solution.....	248
6.2.11	Ferric test for tannin detection .....	250
6.2.12	Experiment on the performance of the treated wood after leachate against termites (Accelerated field test) .....	250
6.3	Study of heavy metal leaching in the treated wood .....	251
6.3.1	Materials and methodology.....	251
6.3.2	Results and Discussion .....	252
6.4	Mechanical performance after treatment.....	253

6.4.1	Material and methodology .....	253
6.4.2	Results.....	254
6.4.3	Discussion .....	255
6.5	Rapid Identification of Cu presence on Treated Woods Using chemical stain method.....	256
6.5.1	Materials and Methodology .....	256
6.5.2	Results and discussion .....	257
	FSWM solution presented copper on the treated surface representing a significant color change.....	257
6.6	Comparison on the mechanical performance with industrial available preservative .....	257
6.7	Evaluating the water absorption percentage.....	258
6.7.1	Materials and methodology.....	258
6.7.2	Results of the water absorption.....	259
6.7.3	Discussion .....	259
6.8	Effect of pressure exerted on the chemical retention during wood treatments	260
6.8.1	Materials and methodology.....	260
6.8.2	Results and discussion .....	261
6.9	GC-MS analysis of bioactive compounds of Experimental level wood preservative .....	261
6.9.1	Gas chromatography-mass spectrometry .....	262
6.9.2	Materials .....	262
6.9.3	Results of GC analysis .....	265
6.9.4	Discussion .....	270
6.10	Practical Application .....	271
6.11	Summary .....	274
Chapter 7 : CONCLUSION AND RECOMMENDATIONS.....		276
7.1	Conclusion.....	276
7.2	Future Works.....	281
References		282

## LIST OF FIGURES

Figure 1-1; The above diagram presents the conceptual flow of the overall study program....	6
Figure 2-1: Simple classification of the construction model .....	9
Figure 2-2:Then main four challenges in the concept of sustainable construction .....	11
<i>Figure 2-3:Based on the design standards; for concrete [10], for steel [11], and for timber [12], the graph presents the strength normalized by the density vs modulus normalized by density. Source –[13].....</i>	<i>13</i>
<i>Figure 2-4:The Life-cycle assessment from the regeneration of trees to disposal of wood materials (Source: CORRIM Presentations, www.corrim.org/ppt/2005/fps_june2005/lippke/index.sp[14]). .....</i>	<i>15</i>
Figure 2-5: Flow chart on the causes of wood deterioration.....	16
Figure 2-6 : a – Subterranean termites , b- dry wood termites , c-damp wood termites , d – Mud tunnels behavior of the subterranean termites , e- behavior of the dry wood termites, f- damp wood termite behavior .....	17
Figure 2-7: a- Carpenter Ants , b- damage to structures through their nesting behavior , c- Powder-Post Beetles, d- damage caused to the structures. e- Carpenter bee boring into wood, f- Nest of a carpenter bee.....	18
Figure 2-8 : Types of wood decaying fungi.....	19
Figure 2-9: Other molds , blue stains and the bacterial growth on wood surfaces. ....	20
<i>Figure 2-10:The degradation of wood when exposed to fire on the surface A- Schematic diagram , B- Degradation zone observed in pine wood,</i>	<i>21</i>
Figure 2-11; The flow chart presenting the natural polymer .....	22
Figure 2-12; Detail graphical ;a-The hierarchical structure of wood , b. The composition in cross section , the longitudinal direction, c- Anisotropy of wood on multiple length scales [107].....	26
Figure 2-13; The Techniques for preserving wood.....	27
Figure 2-14: A Flow diagram which presents the characteristics of wood preservative .....	28
Figure 2-15 : the main types of wood preservatives existing in the wood industry.....	29
Figure 2-16; The flow chart on the factors affecting the properties of wood. ....	29
Figure 2-17: Classification of the origins of natural compounds.....	30
Figure 2-18: Classification of the tannin.....	31
Figure 2-19; Classification of wood extractives .....	32
Figure 2-20; Classification of the timber modification.....	34
Figure 2-21; The flow chart on the classification of the wood constructions reference to time. ....	36
Figure 2-22; Classifications of information sources ; refereed to tangible and intangible sources .....	37

<i>Figure 2-23; the photo was taken beforehand restoration –taken on late 1800's or early 1900's</i> .....	39
Figure 2-24: : a- Tampita Vihara-, b-Devala , c-Ambalam d- Mandapa .....	40
Figure 2-25; A- Cell Structure, Cell Lumen, Wood cell wall, Micro Fibrils, Elementary Fibrils; B- Cellulose, Hemicellulose, Lignin; C- Cellulose's many hydroxyl (–OH) groups attract water molecules, making the substance hydrophilic, D - Reaction of hydrogen bonds; E -Bound and free water distribution .....	41
Figure 3-1;The construction details of the Ambalam ;a-, b- ,c-, d.....	43
Figure 3-2: A- Timber joinery in Karagahagedera Ambalama, B- Bearers on stumps, C- Panavitiya Ambalama wood carvings.....	44
Figure 3-3;Rukula Ambalama , Kadugannawa Ambalama .....	45
Figure 3-4;Mangalagama Ambalama illustration model; A - Isometric view. Mangalagama Ambalama illustration model; B – Plan .....	46
<i>Figure 3-5; The six Ambalam structures are shown above ; A-Badulla Ambalama., B- Kadugannawa Ambalama, C- Karagahagedra Ambalama, D- Panavita Ambalama, E- Rukula Ambalama ,F-Managalama Ambalama.</i> .....	49
Figure 3-6; Above figure explores building orientation .....	51
Figure 3-7;Map 1- Demonstrating on analyzing the grain distribution .....	58
Figure 3-8; A-Panavitiya Ambalama (Bearer), B – Badulla Ambalama ,C,D -Giruwawa Ambalama King Rafter, Rafter, Bearers).....	59
Figure 3-9;Padivitiya Ambalama External bearers .....	60
Figure 3-10: Joint detail of the Badulla Ambalama .....	60
Figure 3-11;Rafters of Giruwa Ambalama .....	60
Figure 3-12; Mapping the curves using Auto cad Software .....	61
Figure 3-13;Map 28 – Shrinkage in the Tangential plain .....	65
Figure 3-14;The maps represent the sawn log distribution corresponding to the center, and the characteristics and distortion.....	66
Figure 3-15; Direction of the force application to the structural elements .....	66
Figure 3-16;B-Orientation placements with regards to Applications .....	67
Figure 3-17; Rafter orientation ;type B.....	67
Figure 3-18; Type C Orientation.....	67
Figure 3-19; Utilization percentage of the structural elements .....	67
Figure 3-20; Force applications , Annual Ring orientation and wood movement in application when force applied.....	68
Figure 3-21; Graphical summary of the chapter 2 .....	69
Figure 4-1;Map 1- Locations of the identified cases; Red dots denotes the Ambalam Structures , and the green dots denotes the private residences .....	73

Figure 4-2;Flow chart of the detail's phases of the survey .....	74
Figure 4-3;Building type Vs The material composition .....	77
Figure 4-4; Age category of the interviewer vs building type .....	77
Figure 4-5;The building type Vs The timber species used. ....	77
Figure 4-6;The building type Vs The age of the building.....	77
Figure 4-7; The age of the building and the wood preservation technique used to treat the wood used with in the structure .....	79
Figure 4-8; Building Type and the preservation technic used to treat the wood with in the structure .....	79
Figure 4-9;- Graphical representation of knowledge transferring by generations of the Wood kept under paddy field mud .....	82
Figure 4-10;Plant species used to develop the paddy field mud before utilization.....	83
Figure 4-11;Wood preservation vs current usage of the decoded traditional vernacular technology.....	83
Figure 4-12; Field interviews and the case studies considered for evaluation.....	84
Figure 4-13;Further tabulated technics of timber soaking under mud.....	85
Figure 4-15; Highly decoded plant species with in the survey. ....	86
Figure 4-16;cases selected from Uva Province ,A-Soranathota , a- roof details , B- Mahiyangana b- roof details , C- Silverland Badulla , roof details; sample preparation .....	88
Figure 4-18; <i>Flow chart represent the Dehydration of fresh material for permanent mounting using the stains safranin</i> .....	89
Figure 4-19 -Fig. 4. A-The weight obtained through the digital scale , B- apply pressure C- Timber samples soaked in water.....	90
Figure 4-20 -Mango (end grain 10x).....	91
<i>Figure 4-21- A-Transverse section , B- Tangiantial section , C- Radial Section</i> .....	91
Figure 4-22; Plant selection parameters are classified as above .....	100
Figure 4-23; Mikania micrantha appearance of the leaves and the growth vegetation.....	100
Figure 4-24;Gliricidia Sepium .....	101
Figure 4-25;Titonia diversifolia.....	101
Figure 4-27; the observations when the specimens taken out from the solution . ....	103
<i>Figure 4-28 A clear colour variation was observed compared to the control untreated samples. (After drying)</i> .....	103
Figure 4-29; visual observations after 15, 30 , 45, 60 treatment durations.....	103
Figure 4-30; Section the wood specimens as instructed/ed above.....	104
Figure 4-31; Sliced wooden sections .....	105
Figure 4-32; Experimental Design.....	107
Figure 4-33; Classification of the reactions causes towards polymer degradation. ....	108



Figure 4-34; classification of mechanical properties .....	109
Figure 4-35; The compression strength (Nmm-2) the samples from the solution A- Solution G .....	118
Figure 4-36;-The compression strength (Nmm-2) representing the samples from the solution a- Solution g.....	118
Figure 4-37; The comparison among the optimized sample performance 15 days performance and 30-day performance .....	118
Figure 4-38; Average modulus of Elasticity(test A).....	119
Figure 4-39;Average Modulus of Elasticity (test B).....	119
Figure 4-40; Comparison on the optimum MOE obtained on the 15 days and 30 days respectively on test A and test B.....	119
Figure 4-41;Average modulus of Rupture .....	120
Figure 4-42; Average modulus of Rupture .....	120
Figure 4-43; Comparison on the optimum MOR obtained on the 15 days and 30 days respectively on test A and test B.....	120
Figure 4-44; Schematic diagram of the sample selecting position, gold-palladium plated ...	132
Figure 4-45; SEM analysis ,positioning the points .....	133
Figure 4-46- Comparison on the section to observe the penetration .....	135
Figure 4-47; Conclusion of the highly presented main elements.....	137
Figure 4-48;EDS/EDX Microstructure Interpretation: Energy -Dispersive X-rays Spectroscopy Analysis .....	138
Figure 4-49;Selected sites , and half dipped wood .....	141
Figure 4-50; Mikania micrantha(lowest mass loss percentage - A, B , C, D ; Gliricidia sepium- A, B, C, D ( highest mass loss percentage )- after 12 months.....	142
Figure 4-51; The weight loss percentage vs treatment duration ; submerged for 15, 30 and 45 days ( M. micrantha , T. diversifolia, G.sepium) .....	142
Figure 4-52; The weight loss percentage vs treatment duration; submerged for 15, 30, and 45 days ( combinations of the three plant extracts ) .....	143
Figure 4-53; The fungus grown on the exposed wood.....	145
Figure 4-54;Schizophyllum commune.....	146
Figure 4-55; Flow chart presenting the process of the fungus isolation for further investigations .....	146
Figure 4-56;Sample submitted to the national herbarium , Royal Botanic gardens , Peradeniya .....	147
Figure 4-57; Sampling process, PDA filled petri dish preparation and the treated wood block placement .....	149
Figure 4-58;lowest weight loss percentages were presented as above .....	150

Figure 4-59; Summary of the experiments presenting the rot resistance.....	151
Figure 4-60; The treated wood specimens after 16 weeks exposed to the fungus; Comparison of the weight loss percentage of the treated wood exposed to fungus .....	152
Figure 4-61; graphical abstract of the chapter summary.....	153
Figure 5-1; Flow chart representing the extraction techniques.....	156
Figure 5-2; Flow chart representing the solvent extraction .....	157
Figure 5-3; Flow chart representing the parameters of extraction .....	157
Figure 5-4; Flow chart representing the Solvent extraction techniques.....	158
Figure 5-5; The structure of the water , Encyclopædia Britannica, Inc. ....	162
Figure 5-6; Flow chart representing the Solutions.....	166
Figure 5-7; Flow chart representing of types of filtrations .....	168
Figure 5-8; Flow chart representing the leaf digestion speed .....	168
Figure 5-9;Collection of mud from the organic paddy field.....	169
Figure 5-10 Removing the larger unwanted particles using sieves and the washed access of water .....	169
Figure 5-11; Mud solubility in plant extract dissolved in water as the solvent .....	170
Figure 5-12;Visual observation of the surface application ;A, B, C- Darker colors observed when the impurities are applied .....	174
Figure 5-13;The flow chart presenting the extraction duration .....	175
Figure 5-14; visual appearance of the solution .....	175
Figure 5-22;the leaves extracted to water fermented to days.....	177
Figure 5-23; Solution with the layers.....	178
Figure 5-24; The flow chart of two major ways to evaluate the performance of the solutions .....	178
Figure 5-25; Treated mango wood from the above-identified fractions .....	179
Figure 5-26; Field exposure of the samples.....	180
Figure 5-27; Flow diagram representing the dichloromethane extraction procedure .....	182
Figure 5-28;Dicloromethane extraction procedure .....	182
Figure 5-29; The extracted solution fermented for 24 hours .....	183
Figure 5-30 The aqueous layer separated after the dichloromethane extraction.....	183
Figure 5-31 The fraction extracted to the dichloromethane solution.....	183
Figure 5-32; Flow chart representing the steps of the process.....	183
Figure 5-33:Schematic diagram of the practice .....	184
Figure 5-34;A- material matrix ( <i>Titonia Diversifolia</i> , <i>Gliricidia Sepium</i> , <i>Mikania micrantha</i> , Mud , B- The solution developed under the protocol 1 , C- The solutions were mixed with Dichloromethane , D- The fractions were extracted using the separating funnel, E – the extracted fraction; a- original solution , b – DCM extracted fraction , c- others , F- Syringe	

filters , G- punched filter papers submerged with the Solution in E And the filter air papers .....	185
Figure 5-35; Solutions were syringe filtered before introducing to the filter papers .....	186
Figure 5-36; The submerged filter papers exposed to the fungus .....	188
Figure 5-37 ; A- The prepared solutions ,B- 5 ml of the solution, C- the filter papers are saturated , D – the positioning of the filter papers , E- Field exposed treated filter .....	190
Figure 5-38;A-the control (-), B- The control (+) , C- Gs_Td_Mm_m (original solution), D- Gs_Td_Mm (Original solution) .....	191
Figure 5-39 ; E- C- Gs_Td_Mm_m (original solution), F- Gs_Td_Mm_m (DCM fraction ),G- Gs_Td_Mm_m (D- Aqueous fraction ) .....	192
Figure 5-40; Woos specimens submerged in the solutions.....	195
Figure 5-41; The fraction extracted to the DCM layer and the layer removed after the DCM fraction was removed (aqueous layer) .....	196
Figure 5-42 ; treated wood specimens out of the developed solutions .....	197
Figure 5-43; The PDA solutions and the poisoned solutions.....	200
Figure 5-44;Antifungal activity against <i>Talaromyces purpureogenus</i> (F1), <i>Aspergillus</i> <i>japonicus</i> (F2), <i>Pleurotus ostreatus</i> (F3), <i>Schizophyllum commune</i> (F4) .....	207
Figure 5-45; Material matrix composition.....	210
Figure 5-47 - timber blocks immersed in distil water ;6 hours later .....	225
Figure 5-49;Visual observation of the color variation presented on 6 hours later, 1 day later, 3 days later, 6 days later , 8 days later .....	229
Figure 5-50; Visual observation of the color variation presented on 6 hours later, 1 day later, 3 days later, 6 days later, 8 days later after the color indicator was added to the solution .....	230
Figure 6-1; Developed solutions from the leaf extracts.....	236
Figure 6-2;Figure 6 2; Cleaned Matured fresh green leaves, B- The leaves were crushed using blenders, C – the sieved paddy fields mud to remove the large particles and washed using normal tap water, and then the extra water is removed after the mud is sedimented, D- proper mix of the material matrix , E- Filtered solution .....	239
Figure 6-3 ; A- Treated with FSWM and B- treated with FSWOM .....	240
Figure 6-4; A-Physical appearance after treatment of <i>M. indica</i> , B- visualizing the treated surfaces compared to the non-treated Surfaces.....	241
Figure 6-5;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section A-A') .....	242
Figure 6-6;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section A-A') - FSWOM .....	242
Figure 6-7;Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section B-B')-FSWOM.....	242

Figure 6-8; Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section B-B')- FSWM.....	243
Figure 6-9; Visual observation evident the penetration the treated 100 mm x 152 mm wood block were sliced to 5 mm slices. (Section A-A') - FSWM .....	243
Figure 6-10; classification of the grave yard test based on the exposure time.....	244
Figure 6-11; Leachate observed on the treated wood .....	249
Figure 6-12; A – control wood specimen , B- FSWOM treated specimen, C- FSWM wood specimen .....	254
Figure 6-13; The name of the preservative Vs Mechanical Parameters .....	255
Figure 6-14; The structure of the C <sub>23</sub> H <sub>13</sub> Cl <sub>2</sub> Na <sub>3</sub> O <sub>9</sub> S .....	256
Figure 6-15; Chrome Azurol S solution was sprayed on the wooden surfaces.....	256
Figure 6-16; Visual observation when the colour indicator sprayed on the surface .....	257
Figure 6-17; Mechanical property difference compared to the control Sample .....	258
Figure 6-18; Treatment process using I l volume measuring cylinders . .....	260
Figure 6-19; the sample preparation process for GC analysis . .....	264
Figure 6-20; Identified solution under protocol 2 .....	271
Figure 6-21; The Initial visual observations performed to identify whether the solution is ready for the treatment .....	272
Figure 6-22; 50 mm x 100 mm x 2438 mm timber submerged in the solution ( Similar industry available dipping technique).....	272
Figure 6-23; The treated timber taken out after 4 days , b – treated wood was then washed from the normal tap water to remove the impurities.....	273
Figure 6-24; The appearance were further enhanced using the clear vanish application .....	273

## LIST OF TABLES

<i>Table 2-1 The predictable sources</i> .....	37
<i>Table 3-1:List of the case studies</i> .....	50
<i>Table 3-2:Dominantly visible timber species and their grading</i> .....	50
Table 3-3:Sustainable construction strategies.....	52
Table 3-4:CO <sub>2</sub> storage and CO <sub>2</sub> release of for major construction materials; .....	53
<i>Table 3-5:Brief information of the selected case studies</i> .....	57
Table 3-6; The sectional distribution along with the tree log is presents as in Map 3 to map 14.	
Table 3-7; The below table represents the mainly utilized structural components. ....	63
Table 3-8; the deteriorating pattern of the identified structural components. ....	63
Table 3-9:Four types of Structural components.....	67
Table 4-1- The demographic profile of the survey ( n = 270 ) .....	75
Table 4-2; Building Description .....	75
Table 4-3; Awareness of the preservation technique .....	78
Table 4-4;Chi-Square test ( $\alpha =0.05$ ) .....	78
Table 4-5; Characteristics of the known vernacular timber preservation technologies .....	79
Table 4-6;Identify the opinions of the effectiveness of the known wood preservative technique	
Table 4-7; Summary of the rank question- Reasons for avoiding using wood preservatives..	81
Table 4-8;Common names, scientific names, and the Sinhalese names of the highly decoded plant species. ....	85
Table 4-9; Below table comprise of the utilized equations.....	95
Table 4-10; Scientific name and the classification of the wood Species reference to STC .....	95
Table 4-11; More information about the mango wood .....	96
Table 4-12; Types of wood species exiting and their definition.....	97
Table 4-13; wood type and the wood grain pattern .....	98
Table 4-14; mechanical properties the above woody trees .....	98
Table 4-15; wood type and the price.....	99
Table 4-16:Test Series A: Solution composition; Solution (A) to Solution (G) (only water and leaf extracts).....	110
Table 4-17:test Series B: Solution composition; Solution (a) to Solution (g) (water mud mix solution leaf extracts).....	110
Table 4-18:Visual Appearance of the treated wood.....	114
Table 4-19; Conclusion of the mechanical performance obtained as highest and lowest Solution.....	117
Table 4-20; Summary on the relationship among the properties .....	121
Table 4-21; Timber species(mango) .....	125

<b>Table 4-22; The surface applicant and the naturally synthesized applicants</b> .....	125
Table 4-23; The physical appearance.....	126
Table 4-24; The preservative solution and the treatment techniques.....	126
Table 4-25; Performance of the chemical elements against wood deteriorating agents. ....	130
Table 4-26; Test Type A (Indicates the composition of the solution composed of. ....	131
Table 4-27; test Type B (Indicates the composition of the solution composed of). ....	131
Table 4-28 presents the data are means $\pm$ standard deviation of existing in five sample points, determination on the atomic percentage .....	137
<i>Table 4-29 presents the data are means <math>\pm</math> standard deviation of existing in five sample points, determination on the atomic percentage.....</i>	<i>137</i>
Table 4-30;Description about the white rot Fungi. ....	147
Table 4-31; Abbreviations of the samples used . ....	148
Table 4-32; level class resistance to test fungus .....	150
Table 5-1; The solvents used for extractions .....	161
Table 5-2; The plant matrix with different particle size .....	163
Table 5-3; fermented duration and the particle size.....	164
Table 5-4; Particle size and the fermentation time .....	164
Table 5-5; The optimum fermentation time and the particle size. ....	165
Table 5-6; The solution obtained from the leaf extracts with in 3 extraction durations .....	167
Table 5-7; The identified optimum extraction duration.....	167
Table 5-8; Ratio development Solute to solvent.....	170
Table 5-9; Solute to solvent ratio on the solution developed with only plant extracts .....	172
Table 5-10; Solute to solvent ratio on the solution (plant extracts) assorted with mud.....	172
Table 5-11; Visual observation of the 96 hours fermented extracted solutions.....	173
Table 5-12; Visual observation of the 96 hours fermented extracted solutions.....	174
Table 5-13; Presents the observations to further determine the extraction duration to be kept before the initial filtration. ....	176
Table 5-14; Density values of the solutions including the standard deviations.....	177
Table 5-15; Description of the Solutions .....	189
Table 5-16; FRIM visual rating scale to evaluate the termite attack .....	190
Table 5-17;material matrix used to develop the solutions .....	194
Table 5-18; A- The color of the treated wood specimens , the field exposure of the treated wood specimen .....	197
Table 5-19; Combination by weight composition of leaves: water mud .....	199
Table 5-20;Control Petri dishes with no exposed fungus. ....	200
Table 5-21; Effectiveness' of the solutions against Talaromyces purpureogenus .....	201
Table 5-22; Effectiveness' of the solutions against Aspergillus japonicus.....	202

Table 5-23; Effectiveness of the solutions against <i>Pleurotus ostreatus</i> .....	203
Table 5-24; Effectiveness of the solutions against <i>Schizophyllum commune</i> .....	204
Table 5-25; combination by weight composition of leaves: water mud .....	209
Table 5-26; Solution name and its composition.....	210
Table 5-27; Control Specimens , .....	211
Table 5-28;Description of the material matrix and the composition of the solutions .....	224
Table 5-29; Solution Composition.....	227
Table 5-30; The composition of the material matrix .....	232
Table 5-31; The material matrix assorted with mud. ....	232
Table 5-32 the composition was developed as follows,.....	233
Table 6-1; Source [301]; Durability classification of the timber referred to the EN BS 350 . .....	246
Table 6-2; Results conclude based on the standard , the durability classification .....	247
Table 6-3; The FSWM solutions treated wood specimens against the four fungus types ....	247
Table 6-4,; The Boron treated wood specimens against the four fungus types .....	247
Table 6-5; The CCB treated wood specimens against the four fungus types .....	247
Table 6-6; The visual observation against the fungus after 6 days .....	248
Table 6-7; FSWM treated mango wood, CCB treated mango wood, Boron treated mango wood.....	248
Table 6-8; the color variation after ferric chloride color indicators were used.....	250
Table 6-9; the material matrix of the color indicator .....	256
Table 6-10-Water absorption after 10 days.....	259
Table 6-11; the material matrix used for the extraction was as follows, .....	271
Table 7-1; The summery of the experiments planed with in the study .....	277