DESIGN AND MODELING OF HARDWOOD BEAM LAMINATE USING CSC ORION AND SOLID WORKS

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CERTIFICATION

This is to certify that this project topic titled “Design and Modeling of Hardwood Laminate Using CSC Orion, and Solid works” was undertaken by Oliver Kingsley Obiajulu with registration number (NAU/2016224004) in the Department of Civil Engineering, Nnamdi Azikiwe University, Awka, Anambra State.

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APPROVAL PAGE

This research work "Design and Modeling of Hardwood Laminate Using CSC Orion and Solid works" has been assessed and approved by department of civil engineering Nnamdi Azikiwe University.

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DEDICATION

This work is dedicated to Almighty God for the gift of life and also for guiding me through school.

ACKNOWLEDGEMENT

Special thanks go to Almighty God for giving me the strength to complete this work and also for His guidance and protection throughout my stay in Nnamdi Azikiwe University.

Also I will like to express my profound gratitude to my parents Mr. and Mrs. Onyekwe Oliver for their moral support, constant prayers throughout my stay in school, special thanks goes also to my siblings, for their encouragement during trying times of my academic pursuit.

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ABSTRACT

The study was undertaken to design and model hardwood beam laminate using CSC Orion, and Soild works. Three species of hardwood namely: Iroko (Miicia excels), Obeche (Triplochinia scleroxylen) and Mahogany (Swietenia macrophylla) was used for the study. The design and modeling code used was Euro code 5.Apart from the computer aided design and modeling of the hardwood beam laminate, the failure mode of the selected species of hardwood was evaluated through three point bending strength test. Results obtained from the computer aided design and modeling of the hardwood beam laminate using CSC Orion and Solid works revealed that the bending moment of Iroko, Obeche and Mahogany ranged from 7.3kNm – 7.34kNm, bending strength ranged from 5.92N/mm^2 – 6.23N/mm^2, bending stress ranged from 10.18N/mm^2- 10.34N/mm^2, bending strength ranged from 1.48N/mm^2 – 1.54N/mm^2, bearing strength ranged from 0.88N/mm^2-0.92N/mm^2, shear stress ranged from 0.62N/mm^2-0.65N/mm^2, shear strength ranged from 1.56N/mm^2 – 1.62N/mm^2. Serviceability limit state check for bending, bearing and shear using the three different design and modeling software were satisfied. Evaluation of the failure mode of the three hardwood beam laminate revealed that the hardwood beam laminate showed similar failure characteristics. Failure was flat-wise and was initiated at the bottom fiber which was propagated upward. It was concluded that the timber extract from Mahogany showed better structural properties than Iroko and Obeche.

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LIST OF SYMBOL & ABBREVIATION

GLULAM- Glue laminated Timber

MOE – Modulus of Elasticity

MOE – Modulus of Rupture

SW –Softwood

HW- Hardwood

BM – Bending Moment

BS – Bending Stress

SF- Shear force

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Timber is one of the natural and most attractive construction material due to it's renewability and as a result, constitute an essential part of the built environment (Nwokoye, 2015). Multiple studies (De wolf et al., 2017: Anderson et al., 2021: Ryberg et al., 2021) suggested that when timber or it's engineered products (e.g Glue laminated timber, Cross laminated timber and laminated veneer lumber) is compared to concrete or steel as a building material, timber present a favourable environmental balance.

Timber as a material is vastly recyclable, can be prefabricated and have good thermal insulation properties among many other desired properties which makes timber stand out as a good material which can be easily adopted for building construction (Ede and Okundaye, 2016). With the rapid depletion of ozone layer and daily increase in global warming, it is pertinent that we devise a means to reduce the use of construction materials which are harmful to the environment (Ede, and Oshiga, 2014). The extraction and production of non-renewable materials for construction have been one of the major causes of global warming climate (Ede and Oshiga, 2014). Timber is an environmentally friendly material and will be more appropriate for building construction were economy and reduction in effect of global warming is given due cognizance.

There is a growing concern by professional in the construction industry on deficiency of timber or it's engineered products (Glue laminated timber or Cross laminated timber) as a structural member, this is partly due to knowledge gap in its design and modeling and also discrepancy in design output obtained using varieties of design and modeling software’s.

This study will raise awareness on the structural capacity of hardwood beam laminate as a construction material and also unravel the discrepancy in design outputs obtained from design and modeling of hardwood laminate using varieties of design software’s.

1.2 Statement of Problem

Timber is one of the natural and most attractive construction material due to its renewability and as a result constitute an essential part of the built environment (Foliente, 2000). Timber can be engineered to form products like glue laminated timber (GLT) commonly known as glulam, cross laminated timber (CLT) and laminated veneer timber (LVT). However, there is a growing concern by professional in the building industries on deficiency of timbrer as a structural member which is partly due to knowledge gap in the structural properties of laminate and deficiency in design and modeling output obtained using varieties of design software.

This study will therefore promote the use of laminate as a structural member in building and other construction works and also unravel the discrepancy in design output by making comparison and contrast of the design outputs obtained using varieties of design software and thereafter making relevant recommendation.

1.3 Aim and Objectives of Study

The aim of the study is to design and model hardwood laminate using Orion, and Solid works while the objectives of the work are:

i. Manually produce hardwood laminate using adhesives

ii. Design and model hardwood laminate using varieties of design softwares.

iii. Generate design outputs from varieties of hardwood used.

iv. Compare the structural properties of different hardwood laminate.

v. Analyze the failure mode of the different hardwood beam laminate.

vi. Unravel discrepancies in design output obtained from different softwares.

1.4 Scope of Study

The study is basically focused on design and modeling of hardwood beam laminate using Orion and Solid works. The study is mainly analytical and partly experimental. The experimentation involves the investigation of the failure modes of the hardwood beam laminate. Three hardwood laminate namely Mahogany (Swietenia macrophylla), Iroko (Milicia excels) and Obeche (Triplochiton scleroxylen) will be used for the study. Failure modes of the three hardwood beam laminate will be investigate as part of the experimentation phase of the study. The structural properties of the different laminate will be assessed, discrepancies in design outputs obtained from the different hardwood laminate will be evaluated.

1.5 Significance of Study

The design and modeling of hardwood laminate will be significant in the following ways:

i. Promote the use of laminate as a structural member by bridging knowledge gap on the structural properties of the material.

ii. Create awareness on the relevance of computer aided design and modeling of laminates.

iii. Promote knowledge on structural properties of different hardwood laminates and recommend effective and efficient software for design and modeling of timber laminate.

1.6 Justification of Study

Timber is a natural and renewable material used for building construction. Most of the structures being designed particularly in Nigeria are composed of concrete and steel. This is due to knowledge gap on the properties of timber to withstand high intensity of loads. Steel and concrete even though possess high strength properties, is marked by high cost, especially in Nigeria where steel is imported. The excessive harvest of raw materials for the production of cement leads to a rapid depletion of the countries raw materials. Wood on the other hand is a renewable raw material that grows back naturally.

There are different Wood species in Nigeria with varying strengths. If properly sawn and treated these timbers species can be used as a more economical alternative to steel and concrete in the construction of building, bridges and other infrastructures. Procuring the timber with the most desirable strength properties requires that design and modeling must be done using relevant code of practice and varieties of timber design software. This software includes: Orion and Solid works.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Review of Past Work

Structural glued laminated timber (glulam) is an engineered stress rated product that consists of two or more layers of lumber i.e. (lamination) glued together with the grains running lengthwise (Ekundayo and Alake, 2018) Laminated timber is usually planed all round and is available in various finishes and pressure impregnated. Laminated timber is used for load-bearing structure in both the horizontal and vertical directions, which are either left visible, or clad. In addition to buildings, laminated timber is also used in load bearing bridge construction. These laminated timbers were developed to improve the use of natural timber beyond its natural limitations. According to (APA, 2013), glulam has remained the most resource efficient approach to wood building products. When it comes to optimizing products from a carefully managed timber resource, glue laminated wood can be built of defective wood without losing its strength properties as repeated by Tunkut, et al., (2014).

According to (GLTA, 2014), Glulam is probably the fastest growing structural material in Britain. Germany and Italy cumulatively accounted for around 60% of the Europe market revenue owing to glulam high acceptance. There has been a tremendous surge of demand for glulam as it is the evolution of wood as a low cost and sustainable alternative to steel and concrete. As documented in an article by Wilson et al, (2021), glulam offers the additional advantage of virtually unlimited flexibility in shape and size. Straight beams can be designed and manufactured with horizontal laminations (load applied perpendicular to the wide face of laminations) or vertical laminations (load applied parallel to the wide face of the laminations).

Ede and Okundaye, (2014), conducted a research on design and modeling of timber as a structural member for residential building using Orion and also a manual timber design. Result obtained revealed that the application of timber as a structural member will help to drive the cost of residential building and make them affordable for habitation.

2.2 Review of Structural Properties of Hardwood Glulam.

2.2.1 Flexural Strength

Flexural strength as discussed by (Ekundayo and Alake, 2018), is commonly known as modulus of rupture and it is ‘’defined as the bending stress in a flexural member at the failure load and is computed assuming an elastic stress distribution. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress. Flexural rigidity is the stiffness of a material when subject to bending also defined as the force couple required to bend a rigid structure to a unit curvature. In other words, Flexural strength of a material can be defined as the maximum stress at the outermost fiber on either the compression or tension side of the specimen in bending.

Thuc, (2018), investigated the flexural behaviour of hardwood and softwood beams with glue laminated connectors, the experiment include strengthening and testing of a total of 91 beam (51 hardwood and 41 softwood). Each beam was loaded above it service load until complete failure. The findings obtained indicate that the flexural strength of the hardwood laminate was relatively higher than that of the softwood with the value for hardwood ranging from 60.03N/mm^2 to 76.64N/mm^2 while the softwood ranges from 38.89N/mm^2 to 51.29N/mm^2.

Aguwa, J. I., (2015), assessed the structural reliability of the Nigerian grown Abura timber bridge beam subjected to bending and deflection forces. The study was conducted to ascertain the structural performance of Abura as a timber bridge beams. Samples of the Nigerian grown

Abura timber were bought from timber market, seasoned naturally and their structural/strength properties were determined at a moisture content of 18%. The determined strength properties were subjected to statistical analysis to determine some statistical parameters used in the design. Structural analysis and deterministic design of a timber bridge beam using the Nigerian grown Abura timber in accordance with BS 5268 were carried out under the Ultimate Limit State of loading. A computer programme in FORTRAN language was developed and used for reliability analysis of the Nigerian grown Abura timber bridge beam so designed, to ascertain its level of safety using First-Order Reliability Method (FORM). Sensitivity analysis was carried out by varying the depth of beam, imposed live load, breadth of the beam, unit weight of the Abura timber, span of the beam as well as the end bearing length. The result revealed that the Nigerian grown Abura timber is a satisfactory structural material for timber bridge beams at depth of 400mm, breadth of 150mm and span of 5000mm under the ultimate limit state of loading. The probabilities of failure of the Nigerian grown Abura timber bridge beam in bending and deflection are 0.23×10^{-3} and 0.27×10^{-15} respectively, under the design conditions.

Okafor and Ezeagu, (2020) conducted a study on analysis of Bending Stiffness and Strength of Glue Laminated Nigerian Timber. Five hardwoods and five softwoods were investigated, namely: Mansonia, Mahogany, Orji, Ukpi, Ufi mmanu, White Afara, Owen, Melina, Akpu and Ubia. The dimensions of the wood specimens are 100mm×50mm×20mm. The wood samples were tested for flexural strength using a Universal Testing Tensile Machine. The results obtained shows that Owen has the highest ultimate wood strength of 46.806N/mm² for the softwood glulam. Ukpi has the highest wood strength of 73.375N/mm² for the hardwood glulam, and highest MOE at 2412.93N/mm². Akpu recorded the weakest sample with bending strength values for glulam at 11.929 N/mm².

Yusof and Rahman, (2017) conducted a study on flexural strengthening of timber beams using carbon fibre reinforced polymer. Five timber beams of Yellow Meranti species were tested. One of the beams was used as a control beam (un-strengthened) while the remaining four beams were strengthened before tested to failure under four point loading. The results showed that the strengthened beams performed better than the control beam. The ultimate and service load of the strengthened beams were increased between 31.8 – 44.5% and 27.1 – 80%, respectively when the CFRP area was between 0.15 – 0.42%. The strengthening of timber beams with CFRP has enhanced their stiffness. The stiffness of the beams was increased between 32.6 – 87.6%. The tensile crack and crushing occurred simultaneously (balanced reinforced) when the CFRP was about 0.16%. Modification factors for bending strength and stiffness for timber beam strengthened using CFRP plates were proposed from this research

Jimoh and Chabi, (2017) determined the strength class of Daniellia Ogea Harms green timber species and the results conform to BS 5268. Classification of four seasoned Timber species grown in Nigeria including Isoberlinia doka was carried out by Wilson, et al. (2021) and the results revealed that Isoberlinia doka is a hardwood and assigned class N3 in line with NCP 2, (1973). Characterization of two commonly used timber species in Nigeria; Isoberlinia doka and Anogeissus leiocarpus for structural use was carried out by Jimoh, et al., (2018) in accordance with BS 5268:2002 and NCP2:1973. The study assigned class N7 to Isoberlinia doka.

Ekundayo and Alake, (2018) conducted a study on the bending strength of solid and glue laminated timber from three selected Nigerian Timber species. Three species of timber namely: Funtumia africana, Alstonia congensis and Antiaris toxicora were investigated and used for the production of glue laminated timber elements using polyvinyl acetate glue. The glue-ability, physical and mechanical properties of solid and glue-laminated species were assessed and compared. Bending strength and characteristic values of bending strength were determined. Results showed that the timber species were glueable and bending strength across the species was 65.22N/mm^2 vs 36.44N/mm^2; 26.15N/mm^2 vs 25N/mm^2; 14N/mm^2 vs 20N/mm^2 in solid vs glued laminated Funtumia Africana, Alstonia congensis and Antiaris toxicaria beams respectively in edge wise bending. The glued laminated elements across the species developed 55%, 95% and 143% of the solid wood strength. It was shown that the timber species were structurally glueable using polyvinyl acetate glue. The study has shown that the bending strengths of glue-laminated Nigerian timber species were of structural significance given the bending strength of 36.44N/mm^2, 25N/mm^2 and 20N/mm^2 in Funtumia africana (Ire), Alstonia congensis(Awun) and Antiaris toxicaria (Oriro).

Aguwa and Sadiku, (2014). Conducted a reliability study on the Nigerian Ekki timber as bridge beam in bending under the ultimate limit state of loading. The study was carried out to ascertain the structural performance of the timber bridge beam. Samples of the Nigerian Ekki timber were collected, seasoned naturally and their structural/strength properties were determined at a moisture content of 18%, in accordance with the British Standard BS 373, methods of testing small clear specimens of timber. Statistical analysis was carried out using the structural/strength properties determined. Structural analysis and design of a timber bridge beam using the Nigerian Ekki timber in accordance with BS 5268 were carried out under the ultimate limit state of loading. Reliability analysis of the Ekki timber bridge beam so designed to ascertain its level of safety was carried out using first-order reliability method (FORM). Sensitivity analysis was carried out by varying the depth of beam, imposed live load, breadth of the beam, unit weight of the timber, span of the beam as well as the end bearing length. The result revealed that the Nigerian Ekki timber is a satisfactory structural material for timber bridge beams at depth of 400 mm, breadth of 150 mm and span of 5000 to 7000 mm under the ultimate limit state of loading. Its probability of failure in bending under the specified operating conditions is 1.1 x 10-7, that is, one in ten million.

Tunkut, et al., (2014), investigated the physical and mechanical properties of laminated wood panels manufactured with Nanoparticles Filled Poly (vinyl acetate) Adhesive. PVAc adhesive was prepared with adding of SiO2, TiO2 and nano clays for 0.5%, 1%, and 2% loadings.

Spruce (Picea orientalis L) and Oak (Quercus robur) wood species were used to produce the panels. The prepared adhesive was applied to wood layers, and then all layers were combined to obtain laminated wood panels which have 5 layers. The panels having 12% moisture content (MC) were tested to determine the physical properties such as water absorption, thickness swelling; and the mechanical properties such as flexural strength and modulus of elasticity in flexure and compression strength. The results showed that the density and moisture content between wood species was found to be slightly different to each one, but water absorption and thickness swelling were determined to increase with increasing of loading rates. The mechanical properties were found to increase with nanoparticles and the maximum increasing of mechanical properties were determined to panels with nanoclays at 2%. Nanoclays at 2% can be advised to the production of laminated wood panels due to improving the mechanical properties more than 50%.

Abubakar, et al., (2020) carried out structural reliability based assessment of Nigerian Anogeissussch imperi timber bridge beam in shear and bearing forces. Specimens for laboratory tests were prepared using the timber specie in accordance with BS 373 (1957). Tests were carried out to determine the physical and mechanical properties at 12% moisture content in line with BS 5268 (2002). Statistical analysis was carried out using strength properties obtained and the specie was classified to strength class D60, confirmed to be Hardwood. Anogeissus schimperi timber bridge beam was designed in accordance to BS5268 (2002), using deterministic approach. While, reliability analysis to confirm the safety level of the timber bridge beam designed was carried out using constant failure rate model in accordance with Jimoh, (2018). Sensitivity analysis to ascertain the safety margin of a simply supported timber bridge beam subjected to shear and bearing by varying the span, depth, width and live load was carried out. Results of reliability analysis showed that Anogeissus schimperi met the minimum reliability index of 0.5 under ultimate state of loading in Shear and bearing. Safety index was found to be directly proportional to the depth and width but inversely proportional to the span and live load of the timber bridge beam during Sensitivity Analysis. The result confirmed that Anogeissus schimperi specie from north western Nigeria at 400mm depth, 150mm breadth and 5000mm span under ultimate limit state loading in Shear and bearing can be used as a reliable timber bridge beam material.

2.2.2 Shear Strength

Lam et al. (1995) investigated the shear strength of Canadian softwood structural lumber using five-point bending tests. Comparisons with results of finite element models that used values obtained of ASTM D143 (1994) shear block tests as input parameters and considered Weibull weakest link theory showed good agreement. However, longitudinal shear failure was achieved in only 40 % of the tests. Yeh and Williamson (2001) evaluated the shear strength of GLT made of Northern American softwoods based on full-size four-point bending tests with a small distance between the two central load application points. A shear failure was achieved in 70 % of the tests. Based on the investigations by Yeh and Williamson (2015), the full-size shear test method was adapted in ASTM D3737-99 (2000).

Aicher and Ohnesorg (2014) investigated the shear strength of Glue Laminated Timber (glulam) made from European beech timber. A four-point loading configuration with a beam length of 3530 mm and an I-shaped cross-section with a height of 608 mm were used. The mean value of shear strength found was 6.1N/mm^2. Van de Kuilen et al. (2017) conducted shear tests on small beech wood specimens using the configuration described in EN 408 (2012) reporting a mean shear strength of 13.4N/mm^2.

Usually, shear stresses are accompanied by stresses perpendicular to grain that influence the determined shear strength. Steiger and Gehri (2016) investigated the inter-action of shear stresses and stresses perpendicular to grain in full-size glue laminated timber beams using a three-point bending test configuration. A positive influence of compression stresses perpendicular to grain, and good agreement of experimental test results and data from literature (Mistler, 2013; Eberhardsteiner, 2017) with the design approach given in the standard SIA 265 (2012) was reported.

Pure shear stress states hardly occur in structural timber elements and it is thus neither simple nor necessary to aim for a pure shear stress state when determining the shear strength of full-size GLT beams. Material properties should be determined for volumes and types of stresses that are representative of situations that the material will be subjected to in real structures (Gehri and Steiger, 2016).

Borjan and Thomas, (2014), evaluated the shear strength of glue laminated timber (glulam) using a full size four point test method, the findings obtained from the study indicate that the characteristic shear strength values based on full size shear test are approximately 70% of the values determined from small block shear tests. However, the allowable horizontal shear stress could be increased by a factor of at least 1.25 including a 10% reduction to allow for occasional.

2.2.3 Charpy Energy Impact.

Unlike most engineering materials, Timber is an organic material that is anisotropic, hydroscopic and exhibits high variability of mechanical properties Nwokoye, (2015). These mechanical / structural properties include the elastic, plastic and elasto-plastic (viscoelastic) properties this timber species possess, which forms the basis of the timber design. The combined elastic and plastic energy of a material gives the toughness energy of that material Toughness of a material is defined as the ability of the material to absorb energy and plastically deform before failure occurs. It is the ability of a material to absorb sudden shock without breaking or shattering. Toughness of a material is also a measure of the plasticity and plasticity of a material in terms of energy absorbed. Toughness of timber material is inversely proportional to the temperature of the timber material; this can be attributed to the decrease in moisture content of the material when exposed to high temperature. The toughness of a material can be determined using two main methods**;** by finding the area under a stress-strain curve of the material and from an impact energy test of the material

Charpy impact test is used to obtain the impact strength of timber materials. These impacts strength obtained in the form of toughness energy gives the amount of energy the timber can absorb before undergoing plastic deformation.

Nwokoye, (2015) wrote that the behaviours of timber material on the application of load can be explained as follows; Timber does not behave in a truly elastic mode, rather its behaviour is time dependent, the magnitude of the strain is influenced by a wide range of factors. Some of these are property dependent, such as density of the timber, angle of the grain relative to direction of load application and angle of the micro fibrils within the cell wall. Others are environmentally dependent, such as temperature and relative humidity.

On the application of load timber deforms, these deformations can be divided into the elastic, delayed elastic and viscous-deformation. The elastic deformation appears directly after loading, after which the deformation increase slowly under a constant load. This increase in deformation is made up of delayed elastic and viscous deformation. The difference between these two is that the delayed elastic deformation is recoverable after unloading, but the viscous-deformation is permanent (Marie, 2015). The delayed elastic deformation together with the viscous deformation is called creep. The viscous deformation which is a permanent deformation is also termed a plastic deformation since its effect is irreversible. In materials such as timber where such behaviours are observed, they are treated as viscoelastic (elastic-plastic) material.

Ezeagu and Onwunduba, (2019), investigated the Charpy Energy Impact on Variable Nigerian Timber species short beams. Charpy impact test method was used to determine the impact energy/toughness of twenty locally available timber species, comprising of ten hardwoods and ten softwoods. Three sets of specimen (having dimension 125 mm by 12.5 mm by 12.5 mm) were obtained from each of the timber species. The findings indicate that the toughness energy obtained for the different softwood species was 1.49Kgfm/cm^2 for Obia, 2.89Kgfm/cm^2 for Okwe, 1.08Kgfm/cm^2 for Avu, 2.2Kgfm/cm^2 for Akpu, 2.4Kgfm/cm^2 for Anyasualo, 2.26Kgfm/cm^2 for Egba, 1.6Kgfm/cm^2 for Owen, 1.23Kgfm/cm^2 for Ojoo, 1.08Kgfm/cm^2 for Yellow man, 1.4Kgfm/cm^2 for Marima. While for the hardwood specimen, the following range of result was obtained; 2.22Kgfm/cm^2 for Ughi Mmanu, 2.4Kgfm/cm^2 for Ukpi, 2.62Kgfm/cm^2 for UburuMmiri, 1.85Kgfm/cm^2 for Iroko, 1.08Kgfm/cm^2 for Oha,1.6Kgfm/cm2 for Mango nkiti, 1.42Kgfm/cm^2 for Egbu, 1.46Kgfm/cm^2 for Meligna, 2.0Kgfm/cm^2 for Obala and 1.6Kgfm/cm^2 for Mahogany. A comparison of the toughness energy of the twenty timber specimen was made, which showed that Cordiamillenii (Okwe) possessed the highest impact energy/toughness which occurred when the grain orientation was parallel to the longitudinal axis of the specimen.

2.2.4 Bending Stiffness

Bending stiffness (K) is the resistance of a member against bending deformation. It is a function of elastic modulus (E), the area of moment of inertia (I) of the beam cross section about the axis of interest, length of the beam and beam boundary condition. The load bearing capacity of glulam under bending is highly related to the material properties and the tensile capacity of the timber boards used. The glulam timber has more uniform mechanical properties mainly due to the intent of minimizing the influence or defects in timber (e.g. nodes, cracks, misalignment of fibbers) with the production process Helder et al, (2013).

Ioakar, et al., (2022) worked on the Analysis of Stiffness and Bending Strength of Green Isoberlinia Doka Timber Specie Grown in North Central Nigeria. The specimens for the experiment were obtained from log of Isoberlinia Doka specie at green condition. Test specimens were prepared and tested in accordance with ASTM D198, (2018), ASTM D143, (2014) and BS 373 (1957). The mean values of moisture content and density obtained were 62.62% and 687kg/m3 respectively. Three-point bending test was conducted at Civil Engineering Laboratory of the Ahmadu Bello University, Zaria using Universal testing machine of 250KN capacity. The mean values of bending strength and MOE recorded at green condition were 34.07N/mm2 and 6035.19N/mm^2 respectively. The green grade bending stress and MOE computed were 6N/mm2 and 345N/mm^2 respectively. While the corresponding dry grade stress were 19.31N/mm2 and 8369.32N/mm2 respectively. The green grade bending stress and MOE did not conform with that in Table 9 of NCP 2, (1973). The 18% moisture content grade bending and modular of elasticity conform to that of Wilson et al., (2021). The green strength obtained in this study could be used in designing and constructing timber structures that intends to use green Isoberlinia doka in construction.

Rahmon, et al., (2017) investigated the strength characterization and grading of Eku (brachystegia eurycoma) timber grown in Kwara State, Nigeria in accordance to BS 5268. Specimens used in the experiment were obtained from sawmills in Kwara State, Nigeria. The samples were seasoned naturally for seven months and prepared according to British Standard BS 373 (1957) Methods of Testing Small Clear Specimen of Timber. Test carried out on the prepared specimens were bending, tension, compression and shear parallel to grain, compression perpendicular to grain, moisture content and density. The timber properties determined were adjusted to the values at 12% and 18% moisture content in conformity with BS 5268 (2002) and NCP 2 (1973) for application in the Northern part of Nigeria. All the results were analyzed statistically. Eku has an average moisture content of 11.78% and mean air-dried density of 1148.25kg/m3. The Basic and grade stresses were computed using experimental failure stresses. The material properties showed that, Eku (Brachystegia eurycoma) can be graded and assigned to strength class D40. Therefore Eku timber has been successfully characterized and graded in accordance to British Standard and thereby recommended for load bearing structure like bridge beams.

Alake and Ekundayo, (2018), evaluated the suitability of Funtumia africana, Alstonia congensis and Antiaris toxicaria Nigerian timber species in the production of glue-laminated timber elements using adhesive (polyvinyl acetate glue) otherwise known locally as top bond. “The glue ability, physical and mechanical properties of solid and glue-laminated species were assessed and compared. Bending strength and characteristic values of bending strength were determined. The findings showed that the timber species were glue able and the bending strength across the species were: Funtumia Africana solid and glue laminated beams at 65.22N/mm^2 and 36.44 N/mm^2; Alstonia congensis solid and glulam beams at 26.15N/mm^2 and 25N/mm^2; and Antiaris toxicaria beams at 14N/mm^2 and 20N/mm^2 in edge wise bending. The glued laminated elements across the species developed 55%, 95% and 143% of the solid wood strength. It was shown that the timber species were structurally glue able using polyvinyl acetate glue. The study has shown that the bending strengths of glue-laminated

Nigerian timber species were of structural importance given the bending strength of 36.44 N/mm^2, 25 N/mm^2 and 20 N/mm^2 in Funtumia africana (Ire), Alstonia congensis (Awun) and Antiaris toxicaria (Oriro)". It also goes to show that the kind of adhesive used for experiments should be taken into cognizance as regards when the load is applied to the members. The stronger the adhesives in grade the better the glulam in resisting load, thus making it a better structural member.

Jimoh and Ibitolu, (2018) conducted a study on characterization and grading of three selected timber species grown in Kwara state Nigeria according to en 338 (2009) for structural use. The timbers namely Vitex doniana, Ceiba pentandra and Pseudocedrela kotschyi were obtained in Ilorin, Kwara State of Nigeria. Physical and Mechanical properties of the selected timber species were determined in accordance with EN 13183-1 (2002) and EN 408 (2003) for structural timbers. Four point bending tests based on EN 408 (2003) with specimen 50x50x1000 mm were carried out using a Universal Testing Machine (UTM) to determine the bending strength and Modulus of Elasticity of the each timber specie. Characterisitc values of Bending strength, Modulus of Rupture and Density were determined using EN 384(2004). The timber species; Vitex doniana, Ceiba pentandra and Pseudocedrela kotschyi had equilibrium moisture content (EMC) of 15.70%, 13.71 % and 24.28 % respectively. Strength grading of timber species was then conducted by adjusting the material properties values of species to 12 % moisture content using the required adjustment factors. The timber were then graded according to EN338 (2009). Pseudocedrela kotschyi had the highest density of 813 kg/m3 followed by Vitex doniana (706 kg/m3) while Ceiba pentandra had the lowest density of 402 kg/m3. Vitex doniana, ceiba pentandra and Pseudocedrela kotschyi were assigned to strength class D30, C16 and D35 respectively in accordance with EN338(2004).

Anshari et al. (2016) proposed a new approach to strengthen glulam beams which was tested under bending. Teles et al. (2013) performed a nondestructive test to assess the deflection of glulam beams made from hardwood. Rohanova and Lagana (2015) made a description on quality parameters and the according requirements of structural timber. Fink et al. (2105) proposed and illustrated a probabilistic method for simulating the capacity of glued-laminated timber.

An important feature of glued-laminated timber is that the bonding of lamina can result in sections of higher strength than the strength of the single lamina from which they are constructed (1995).

Osuji and Inerhunwa, (2017) investigated the Characterization and Strength Classification of Timber Species in Akwa Ibom State, Nigeria for Structural Engineering Applications. In the study, determination of the physical and mechanical properties of timber species in Akwa Ibom state in southern Nigeria was carried out using methods defined in BS EN 1193:1998, BS EN 384:2016, BS EN 408:2010 and BS 373:1957, while strength classification of the timber species was in accordance with BS EN 338:2016. Twenty-five (25) samples each of five common timber species in Akwa Ibom namely: IyipOkoyo (Stauditiastipitata), Owen (Mitragyna spp.), Mkpenek (Uapacaguineensis), Atarabang (Xylopia spp.) and Ata (XanthoxylonSenegalensis) were selected for the study. Results of physical properties indicated that the timber species have low susceptibility to fungal degradation and high durability but prone to dimensional change. Of the five timber species, Atarabang (Xylopia spp.) was the only softwood specie, suggesting that Akwa Ibom is dominated by hardwood species. Mechanical properties obtained were consistent with properties of strength class assigned to each timber specie and are useful parameters for structural engineering design process. The study further showed that the timber species have moderate to high densities and find application in general construction such as for flooring, formwork systems, cladding, joinery and paneling.

Shan et al. (2019) investigated the Mechanical Properties of Glued-Laminated Timber with Different Assembly Patterns. The bending stiffness and reliability of the beams were assessed according to the experimental results. The influence of the assembly pattern on the bending behavior of glued-laminated timber was investigated by finite element models. The results show that the assembly pattern of the section has little influence on the failure mode of glued-laminated timber.

Aguwa, (2015), assessed the structural reliability of the Nigerian grown Abura timber bridge beam subjected to bending and deflection forces. The study was conducted to ascertain the structural performance of Abura as a timber bridge beams. Samples of the Nigerian grown Abura timber were bought from timber market, seasoned naturally and their structural/strength properties were determined at a moisture content of 18%. The determined strength properties were subjected to statistical analysis to determine some statistical parameters used in the design. Structural analysis and deterministic design of a timber bridge beam using the Nigerian grown Abura timber in accordance with BS 5268 were carried out under the Ultimate Limit State of loading. A computer programme in FORTRAN language was developed and used for reliability analysis of the Nigerian grown Abura timber bridge beam so designed, to ascertain its level of safety using First-Order Reliability Method

(FORM). Sensitivity analysis was carried out by varying the depth of beam, imposed live load, breadth of the beam, unit weight of the Abura timber, span of the beam as well as the end bearing length. The result revealed that the Nigerian grown Abura timber is a satisfactory structural material for timber bridge beams at depth of 400mm, breadth of 150mm and span of 5000mm under the ultimate limit state of loading. The probabilities of failure of the Nigerian grown Abura timber bridge beam in bending and deflection are 0.23 x 10^{-3} and 0.27 x 10^{-15} respectively, under the design conditions.

Carlos et al. (2020) conducted a study on the Assessment of Bending Properties of Sawn and Glulam Blackwood in Portugal. The valuation of Blackwood for structural applications has been considered through the non-destructive and destructive assessment of their mechanical properties as sawn wood. Their potential was also assessed for a more technologically engineered wood product, the glulam. The dynamic modulus of elasticity (MOE) was estimated through the Longitudinal Vibration Method (LVM) and the Transformed Section Method (TSM); the static MOE and bending strength were assessed through a four-point bending test. Agreement was obtained between both approaches. Sawn Portuguese Blackwood showed a density of 647 kg/m^3, 13,900N/mm^2 of MOE and a bending strength of 65N/mm^2 (mean values). The glulam beams fabricated with this raw material had improved properties relative to sawn wood, most obviously concerning the bending strength, with an improvement of 29%.

Wdowiak and Brol (2020) tested beams manufactured from glued pine timber type c (combined), of which each was composed of four lamellas. Bending reinforcement CFRP tapes were glued to the bottom face of the beam or between the two bottom lamellas. This provided a 23% increase in load-bearing capacity and a 36.29% increase in rigidity. Moreover, reinforcement had a positive effect on the structural durability of the beams. Additionally, an analytical model was proposed as a useful tool in calculations for such beams, showing high consistency with empirical testing results.

Idris and Muhammad, (2014) carried out a study on Bending Strength Classification of Some Common Nigerian Timber Species Strombosia pustulata, Macrocarpa bequaertti, Nauclea diderrichii and Entandrophragma cyclindricum. Twelve (12) timber planks from the selected species were supplied from Ekiti state in the southern part of Nigeria. The specimens for experimental measurements were prepared from the obtained timber planks. Laboratory experiments were conducted to determine the physical and mechanical properties of the selected timber species in accordance with EN408 (2003). The mechanical properties were determined using four point bending test. The generated properties were used to obtain the characteristic values of the material properties in accordance with EN384 (2004). The selected timber species were then graded in accordance with EN 338 (2009). Strombosia pustulata, Macrocarpa bequaertii, Nauclea diderrichii and Entandrophragma cyclindricum were assigned to strength classes D35, C14, D30 and D18, respectively. Other properties such as tensile and compressive strengths parallel and perpendicular to grains, shear strength as well as shear modulus were computed from the empirical relationships given in EN 338.

Jimoh and Chabi, (2017) evaluated the Physical and Mechanical Properties of Daniellia Ogea Harms Green Timber Species. The study presents some physical and mechanical properties of Daniellia ogea (Iya) green timber specie freshly felled from matured trees in forests around Ilorin Local Government, Kwara-State, Nigeria and cut into structural sizes within the Wood workshop of University of Ilorin premises according to BS EN 408: 2003. The moisture content and the density were the physical properties tested while the mechanical properties were the modulus of rupture and the local modulus of elasticity in bending strength, the apparent modulus of elasticity, the compressive strength perpendicular to grain then the compressive strength and tensile strength parallel to grain using the Universal Testing Machine of 300kN capacity of the food laboratory of the department of Agriculture of the University. Then the basic and grade stresses were determined and found to conform to the BS 5268 codes of practice. The results obtained post-tests for the moisture content and the density had respectively average values of 140.45% and 854.67 kg/m^3.

Wilson, et al., (2017) conducted a review of mechanical strength properties of some selected timbers in Nigeria. Species of timber adopted for the study are: Iroko (Chlorophora excelsa), Mahogany (Khaya ivorensis), Fanpalm (Borassus aethoiopum), Ekki (Lophira alata), Opepe (Nauclea diderrichii), Apa (Afzelia, bipindensis), Ayin (Anogeissus leiocarpus), Afara (Terminalia superba). The Annual Book of ASTM Standard Section 4, (D143), method of testing small clear specimens of timber was adopted to evaluate the variation of strength properties of the species from standard speed and dimension specifications. The strength properties reviewed were, compression parallel to grain, compression perpendicular to grain, static bending (flexure) and tensile strength parallel to grain. From the review, it was found that strength of timbers along the grain is far greater than across or perpendicular to grain showing the anisotropic nature of timber. Prior soaking of the specimen before test accounts for reduction in strength. Also deviations from the specified dimensions and speed of testing of specimen will in one way or the other affect the accuracy of strength obtained in the test. It is therefore recommended that strict adherence to the test procedure and specifications should be followed so as to achieve the exact strength values of timbers and that further research work be done on other timbers in order to maximize their usefulness as a construction material.

Rahmon and Jimoh, (2020) investigated the strength characterization and grading of less-used nigerian grown timber species for structural applications. Ayunre (Albizia zygia), Eku (Brachystegia eurycoma) and Ire (Funtunia elastica) timber species were obtained from different sawmills in Ilorin, Nigeria and preparation of various test specimens are in accordance with British Standards BS 373: 1957. A total of 300 specimens were used in determining the strength characteristics of the timber species a 300kN capacity Testometric Universal Testing Machine (UTM) at Agricultural and Biosystems Engineering Laboratory, University of Ilorin. Twenty (20) specimens for each timber species were tested for structural/strength properties according to the British Standard. Results show that the timber species had average moisture contents of 12.47, 11.78 and 12.71% for Ayunre, Eku and Ire, respectively. For density classification, Ayunre and Eku were classified as heavy wood and Ire as light wood. The results obtained provided quantitative details of the strength properties of selected timber species which can be used in determining the application of these timber species for structural applications. The timber species were, therefore graded according to NCP 2 (1973), EN 338 (2009) and BS 5268 (2002).

Ekundayo, (2015) conducted a study on comparative assessment of the strengths of solid and glued laminated timber. The research therefore conducted laboratory experiments on selected timber species namely; Ire (Funtumia africana), Awun (Alstonia congensis) and Oriro (Antiaristoxicaria) being readily available and widely used species with no information on Oriro and Ire in NCP 2 of 1973. The aim was to assess their strength properties as glulam elements with the view to improving their structural capacity.It also set out to determine their glueability, the effects of temperature variation on compressive strength parallel to grain for glulam short columns by subjecting specimens ofequal dimension for the three species to different temperatures of 0 0C, 40 0C, 50 0C, 70 0C, 100 0C and room temperature for 4 hours in an electric oven prior to testing; to compare the mechanical properties of solid and glulam elements. In furtherance, specimens were prepared and tested for; static bending strength, compression parallel and perpendicular to grain, density and moisture content in line with ASTM D193, EN 408(2003) and EN13183-1(2002). The research established that the species are; structurally glueable, that due to temperature increase compressive strength is lost in glulam columns from control temperature (30^0C and 27.9^0C) to 100 was 41% 14.4% and 21.6% in Ire, Awun and Oriro. Results showed that glulam elements developed 55%, 95% and 143% of clear solid wood bending strength and that bending strength of

65.22N/mm^2; 36.44N/mm^2, 26.15N/mm^2; 25N/mm^2 and 14N/mm^2; 20N/mm^2 in solid and glulam in the species are structurally significant. The study has therefore demonstrated that the timber species studied can be engineered to load bearing glued laminated structural elements using polyvinyl acetate glue without severe loss of strength below and above room temperature.

2.2.5 Compressive and Tensile Strength

The compressive and tensile strength property of timber qualifying it as a structural material comes from the macro and microscopic structure of the wood cell. Timber is made of fibre materials, which are oriented so that their length is parallel to the axis of the tree trunk, the strength of wood parallel with the grain is different from the strength across the grain (Nwokoye 2015). The grain orientation makes wood an orthotropic material possessing different strength in different directions.

Timber as a material has many characteristics that make it a good material for construction of buildings. The material has a very high strength, especially when compared with its low weight. The material is, however, very anisotropic with different properties in different directions due to its make-up of oriented fibers kathem et al. (2014). The compressive strength perpendicular to grain is one property of wood which is important for structural design kathem et al. (2014). The strength parallel to the fiber direction is very good while the strength when loaded perpendicular to the fiber direction is very low kathem et al. (2014). This low strength perpendicular to the fiber direction needs to be addressed when designing timber structures.

Adre, et al., (2019) conducted a study on estimation of tensile strength parallel to the grain of wood species. Using an alternative approach, we aimed to determine the approximate fracture surface of wood specimens subjected to tensile test. For this purpose, we used the least square method to estimate tensile strength of four hardwood species, which were equally divided into strength classes. Then, we determined the relationship between the cross-sectional areas of intact and fractured specimens. The results showed that the approximate area of a fractured surface was 2.14 higher than that of an intact sample. As a result, tensile strength estimates were 47% lower than those currently estimated, which is unfavorable for the safety of construction structures.

Jimoh, and Rahmon, (2019) worked on investigation of compressive strength characteristics of

structural-sized arere (triplochiton scleroxylon) and emi (vitellaria paradoxa) timber columns grown in Nigeria. The strength and physical properties of these timber species were determined to predict the suitability of the species as structural material. Twenty lengths of timber species of 50 x 50 mm cross-section were purchased from timber market in Ilorin, Nigeria. The prevailing environmental conditions during the test were 31oC and 64% relative humidity. The properties tested included; air dry density, moisture content and compressive strength parallel to grain of twenty (20) test specimens each of lengths, 200, 400, 600 and 800 mm done in accordance with the British Standard BS 373 (1997). Mean air-dried moisture content for Arere and Emi were 14.48 and 15.89 % respectively. Mean density of Arere and Emi were 514.32 and 1147.75 kg/m3 respectively. The reliability index of Arere and Emi timber species are 0.64 and 0.65 respectively for a service life of 50 years, assuming all other design conditions are met.

Kayode. (2016) conducted a study on investigation of engineering properties of some common Nigerian timber species for building construction. Twenty-two species of Nigerian grown hardwood were sourced from different sawmills, cut and planed in accordance with the specification of Reunion of International Laboratories and Material (RILEM). Appropriate compression and bending strength tests were conducted on a total of 132 tests specimen of the indicated stress conditions. The result of the tests revealed areas of best application of the timber species. It was observed that the green basic tensile strength of Ayo timber parallel to the grain was the highest of all twenty-two tested specimens (39.5N/mm^2) while Ayunre has the highest dry basic tensile strength parallel to the grain (25.8N/mm2). Similarly, Ata has the highest green basic bending strength parallel to the grain at 44.3N/mm^2 while Ekki exhibited the strongest dry basic bending strength at 30.1N/mm2. Oro indicated the highest green basic compression strength at 30.5N/mm^2 while Apa was the strongest by dry basic compression strength at 27.8N/mm^2. A single factor analysis of variance (ANOVA) carried out on the strength results revealed that at 0.05 pre-set of significance, the variance in the values of tension, compression and bending strength for all the timber species considered were significant. The results suggest that there is a need to revisit the present strength grouping of Nigerian timber as well as their stress for groups of species.

Augustin et al. (2016) carried out an investigation on the behavior of Glulam in compression perpendicular to grain in different strength grades and load configurations. The findings suggest that for all glulam strength classes, the specification of a constant characteristic strength value perpendicular to the grain fc, 90, g,k of about 2.1N/mm^2 to 2.3N/mm^2 can be recommended. This is also the fact for the characteristic modulus of elasticity perpendicular to the grain where a constant mean value of 300 N/mm^2 valid for all glulam strength classes should be taken into consideration.

Silveira, et al., (2017) investigated the toughness and impact strength in dynamic bending of wood as a function of the modulus of elasticity and the strength in compression to the grain. Ten tropical species, from different strength classes, grown in Brazil were tested according to the Brazilian Standard Code ABNT NBR 7190:1997. The studied species were: Cedro (Cedrella sp.), Cambará Rosa (Erisma uncinatum Warm), Cedrorana (Cedrelinga cateniformis), Catanudo (Calophyllum sp.), Cupiúba (Goupia glabra), Angelim Saia (Parkia spp.), Tatajuba (Bagassa guianensis Aubl.), Guaiçara (Luetzelburgia sp.), Cumaru (Dipteryx odorata) and Angelim Vermelho (Dinizia excelsa Ducke). It was developed a relation between the studied properties through regression models, evaluated according to the variance analysis (ANOVA). The results of the statistical analysis revealed led to the conclusion that there is no correlation between the proposed properties for the analyzed species.

Kociszewski and Gozdecki (2017) presented research results for new beams manufactured from glulam reinforced with glass fiber GFRP, which was glued between lamellas in the compression and tensile zones. This effective, relatively simple, and inexpensive reinforcement method produced an increase in rigidity by 7.2%, at the theoretic increase of 8.1%.

Studies on three-span beams reinforced with steel rods bonded in the tensile zones were conducted by Lukin (2021), who determined the optimal degree of reinforcement to eliminate the risk of failure as a result of brittle cracking.

Radoslaw et al. (2021) carried out an investigation on the Strength Properties of Structural Glulam Elements from Pine (Pinus sylvestris L.) Timber Reinforced in the Tensile Zone with Steel and Basalt Rods. Reinforcement elements included smooth and ribbed steel rods as well as basalt rods. These rods were placed only in the tensile zone, assuming that they will not only impart increased rigidity but first of all will reduce the scatter of bending strength values. The findings suggested that the manufactured beams reinforced with steel and basalt rods were characterized by mean bending strength amounting to 54N/mm^2 and 47N/mm^2, respectively. However, no significant improvement was found in the scatter of the observed variable. Beams reinforced with steel exhibit a 20% higher strength than unreinforced beams.

Kathem et al. (2014) compared the Compression perpendicular to grain in timber to bearing strength for a steel plate. In this study the compressive strength for a fully supported beam loaded with a point load was studied. Two different loading lengths were studied as well as loading in a point in the middle of the beam, at the edge of the beam and at a distance of 10 mm between the edge and the loading point. The loading was made with a steel stud.

Calculations were also performed according to the following standards; Euro code 5 (EN1995-1-1:2004) before and after amendment, the German Code (DIN 1052:2004), the Italian Code (CNR-DT 206:2006) and two versions of the Swedish Code (BKR). The results showed that the results from the new version of Euro code 5 agreed best with the experimental results. The tested results, however, were lower than the values calculated using Euro code (and all the other codes); this might be explained by the hard loading conditions using a steel stud instead of a wood stud.

Aguwa, et al., (2015) conducted a study on characterization and grading of South Eastern Nigeria grown Irvingia gabonensis timber in accordance with BS 5268. Specimens used in the experiment were collected from a matured gabonensis in Akpugo forest, which were sliced into planks in green condition. The samples were seasoned naturally for six months and prepared according to British Standard BS 373 (2000) Methods of Testing Small Clear Specimen of Timber. The following laboratory test were carried out bending parallel to the grain, tension parallel to the grain, tension perpendicular to the grain, compression parallel to the grain, compression perpendicular to the grain, shear parallel to the grain, moisture content and density. The physical and mechanical properties of the timber specie, which were determined in the laboratory were adjusted to the values at moisture content of 12% in conformity with BS5268 (2002). The results were analysed statistically. Basic and grade stresses were computed using experimental failure stresses. The result of grade bending stress, density and mean modulus of elasticity showed that, Irvingia gabonensis can be graded and assigned to strength class D70. The timber is a strong, heavy hardwood and it is suitable for load bearing structures like railway sleepers and bridge beams.

2.3 Review of Effect of Adhesives on Lamination of Timber

Adhesives contribute significantly in determining and enhancing some of the properties of laminated wood. Lamination should be viewed as a technique that substantially improves the value of wood material (Gaff and Gaborik, 2014). Laminated wood is especially utilized in manufacturing chairs and beds. Laminated wood’s properties are affected primarily by the type of wood and its subsequent physical and mechanical properties (Gaff and Gáborík, 2014). The material is also affected by the type of adhesive and technology used (Sviták et al. 2014). Almost all types of adhesives are used to produce laminated wood. Gluing mixtures (adhesives) used to produce laminated wood must form strong and elastic bonds between the individual layers

Alake and Ekundayo (2018) assessed the suitability of Funtumia africana, Alstonia congensis and Antiaris toxicaria Nigerian timber species in the production of glue-laminated timber elements using adhesive (polyvinyl acetate glue) otherwise known locally as top bond. “The glue ability, physical and mechanical properties of solid and glue-laminated species were assessed and compared. Bending strength and characteristic values of bending strength were determined. His results showed that the timber species were glue able and the bending strength across the species were: Funtumia Africana solid and glue laminated beams at 65.22N/mm^2 and 36.44 N/mm2; Alstonia congensis solid and glulam beams at 26.15N/mm^2 and 25N/mm^2; and Antiaris toxicaria beams at 14N/mm^2 and 20N/mm^2 in edge wise bending. The glued laminated elements across the species developed 55%, 95% and 143% of the solid wood strength. It was shown that the timber species were structurally glue able using polyvinyl acetate glue. The study has shown that the bending strengths of glue-laminated Nigerian timber species were of structural significance given the bending strength of 36.44N/mm^2, 25N/mm^2 and 20N/mm^2 in Funtumia africana (Ire), Alstonia congensis (Awun) and Antiaris toxicaria (Oriro)”. It also goes to show that the kind of adhesive used for experiments should be put into consideration as regards when the load is applied to the members. The stronger the adhesives in grade the better the glulam in resisting load, thus making it a better structural member.

Jozef et al, (2019), focused on the adhesive’s effect on selected properties of laminated wood while comparing laminated wood’s bending properties with those of solid wood. The strength, flexibility, and durability (service life) of laminated wood, glued with four types of adhesives, were examined. The results were compared with solid beech wood, conditioned to 9% moisture content. Depending on the adhesive used, the results indicate that laminated (layered) wood improved the strength and bending characteristics in comparison to the intact wood.

2.4 Review of Hardwood Species

Swietenia macrophylla are the botanical name with which Mahogany is identified with. It is a tropical evergreen or deciduous tree that can attain heights of 150 feet. Mahogany is a member of the Meliaceae, which includes other trees with notable wood for cabinet making. Swietenia macrophylla is world renowned for its beautifully grained, hard, red-brown wood. It has been harvested since 1500 A.D. for its wood, with large branches being in higher demand than the trunk. This is due to the closeness of the grain in the branch's wood. Mahogany is used for furniture, fixtures, musical instruments, millwork, cars, ships, boats, caskets, airplanes, foundry patterns, veneer, and plywood (Hill, 2002).

The history of the term Mahogany raises a taxonomic controversy. When the Yoruba tribe was brought from Nigeria to Jamaica as slaves, they recognized a tree in Jamaica just like one back home. The American mahogany, S. mahogani, looked identical to the African Mahogany, Khaya sengalensis. For this reason the Yorubas referred to American Mahogany as they did African Mahogany, M'Oganwo. Over time the term was changed to M'Ogani by the Yorubas. Americans spelled it how they heard it, and thus M'Ogami became Mahogany. The controversy is that the Yorubas believed African and American Mahogany to be the same tree, but French botanist Adrien de Jussieu (2010) insisted that they were from two different genera. He based this on his African Mahogany specimens having four parted flowers instead of the five parts displayed by American Mahogany.

Milicea excels commonly known as Iroko is an important timber tree species in Africa. It belongs to the family Moraceae and distributed the entire breadth of Africa (Keay, 2019). Milicea excels is the most valuable timber species from the entire west, central and east Africa. The wood is extensively used due to its high durability and good working properties. There is high demand of Milicea excels timber from Milicea wood such as sliced veneer, rotary veneer and profile boards for decorative and structural uses. Cultivation of Milicea species is being constrained widely across west Africa by Iroko gall bugs, phytolyma lata (Cobbinah and Wagner, 2002: Cobbinah and Appiah-Kwarteng, 2006). The psyllid (Iroko gall bug) attacks the buds and young leaves of Milicea excels plant especially the seedlings which later leads to formation of galls on the site of the attack. The gall afterward burst to release adults when the psyllid completes their life cycle inside the gall. The bug lay egg on young stems, leaves and shoots of the host tree in high numbers (Nichols et al, 2008). When the first instar nymph hatches, it puncture plant surface and induce gall formation which later develop to enclose the nymph inside the gall.

Obeche, Triplochiton scleroxylon (Family: Sterculiaceae) also known as Arere (Yoruba, Nigeria) is an environmentally and economically important African tropical tree and it was a successful plantation tree species in Nigeria. Obeche has moderately adequate broad leaf structure and specialty stem characters such as self-pruned cylindrical bole of 30 m (Hall and Bada, 2019), good anchorage buttress of 6 m and trunk diameter of 1.5 m (Bosu and Krampah, 2005). The timber is naturally widely distributed in its range with recognized three sections: from Sierra Leone to Togo, from the Benin Republic to Nigeria and from Cameroun to Zaire (Hall and Bada, 2009).

Triplochiton scleroxylon is a tropical tree of Africa. This timber is also known as Abachi, under the Nigerian name Obeche, the Ghana name Wawa, the Cameroon name Ayous and Ivory Coast name Samba. The tree grows to over 50m high and 1.5m in diameter at the base of the trunk. Obeche is a light weight wood with a pleasant appearance of pale yellow colour, with a natural lustre that gives a silky finish. Obeche can be dried quickly undergoing little degradation and once dry, is very stable. Brittleheart is present in large logs. The grain is usually interlocked, giving a faint stripe on quarter surfaces but otherwise featureless.

The bending, crushing strengths, stiffness and resistance to shock loads are very low. Steam bending classification is moderate to poor. This is due to slight wrinkling at the edges of bends, even with a supporting strap. Very easy to work with hand or machine tools, with only a slight blunting effect on cutters. The density is in the region of 390 kg per cubic metre. Extensively used where durability and strength are unimportant, such as interior rails, draw sides and linings, cabinet framing, interior joinery. A specialized use of Obeche is the construction of sauna interior parts that touch skin, where the wood is prized for its lack of splinters or resin, and most importantly its low heat retention.

2.5 Review of Design Fundamentals

The successful completion of any structural design project is dependent on many variables, however, there are a number of fundamental objectives which must be incorporated in any design philosophy to provide a structure which throughout its intended lifespan:

1. Must possess an acceptable margin of safety against collapse while in use.

2. Must be serviceable and perform its intended purpose while in use.

3. Must be sufficiently robust such that damage to an extent disproportionate to the original cause will not occur.

4. Must be economic to construct and maintain.

Historically, timber design was carried out on the basis of intuition, trial and error, and experience which enabled empirical design rules, generally relating to structure/member proportions, to be established. These rules were used to minimize structural failures and consequently introduced a margin-of-safety against collapse. In the latter half of the 19th century, the introduction of modern materials and the development of mathematical modeling techniques led to the introduction of a design philosophy which incorporated the concept of factor-of-safety based on known material strength, e.g. ultimate tensile stress; this is known as permissible stress design. During the 20th century two further design philosophies were developed and are referred to as load-factor design and limit state design; each of the three fundamental is discussed separately in Sections below.

2.5.1 Permissible Stress Design

When using permissible stress design, the margin of safety is introduced by considering structural behaviour under working/service load conditions and comparing the stresses under these conditions with permissible values. The permissible values are obtained by dividing the failure stresses by an appropriate factor of safety. The applied stresses are determined using elastic analysis techniques, i.e.

$$\text{Stress induced by working load} \leq \frac{\text{Failure Stress}}{\text{Factor of Safety}} \qquad (2.0)$$

2.5.2 Load Factor Design

When using load factor design, the margin of safety is introduced by considering structural behaviour at collapse load conditions. The ultimate capacities of sections based on yield strength (e.g. axial, bending moment and shear force capacities) are compared with the design effects induced by the ultimate loads. The ultimate loads are determined by multiplying the working/service loads by a factor of safety. Plastic methods of analysis are used to determine section capacities and design load effects. Despite being acceptable, this method has never been widely used.

$$\text{Ultimate design load effects due to } \leq$$
$$\text{ultimate capacity based on the failure stress of the material.}$$
$$(\text{Working load } \times \text{ factor of safety}) \qquad .$$

(2.1)

2.5.3 Limit State Design

The Eurocode are limit state design codes, meaning that the requirements concerning structural reliability are linked to clearly defined states beyond which the structure no longer satisfies specified performance criteria. In the Eurocode system only two types of limit states are considered: ultimate limit states and serviceability limit states. The design models for the different limit states shall, as appropriate, take into account the following:

1 Different material properties (e.g. strength and stiffness);

2 Different time-dependent behaviour of the materials (duration of load, creep);
3 Different climatic conditions (temperature, moisture variations).
4 Different design situations (stages of construction, change of support conditions).

2.5.3.1 Ultimate Limit State

Ultimate limit states are those associated with collapse or with other forms of structural failure. Ultimate limit states include: loss of equilibrium; failure through excessive deformations; transformation of the structure into a mechanism; rupture; loss of stability. The analysis of structures shall be carried out using the following values for stiffness properties:

1. For a first order linear elastic analysis of a structure, whose distribution of internal forces is not affected by the stiffness distribution within the structure (e.g. all members have the same time-dependent properties), mean values shall be used.
2. For a first order linear elastic analysis of a structure, whose distribution of internal forces is affected by the stiffness distribution within the structure (e.g. composite members containing materials having different time-dependent properties), final mean values adjusted to the load component causing the largest stress in relation to strength shall be used.
3. For a second order linear elastic analysis of a structure, design values, not adjusted for duration of load, shall be used.

2.5.3.2 Serviceability Limit State

Serviceability limit states include: deformations which affect the appearance or the effective use of the structure; vibrations which cause discomfort to people or damage to the structure; damage (including cracking) which is likely to have an adverse effect on the durability of the structure. The deformation of a structure which results from the effects of actions (such as axial and shear forces, bending moments and joint slip) and from moisture shall remain within appropriate limits, having regard to the possibility of damage to surfacing materials, ceilings, floors, partitions and finishes, and to the functional needs as well as any appearance requirements.

2.6 Review of Design Code

2.6.1 Euro code 5

The basis of the approach is statistical and lies in assessing the probability of reaching a given limit state and deciding upon an acceptable level of that probability for design purposes. The method in most codes is based on the use of characteristic values and partial safety factors. In the Euro code series of European standards (EN) related to construction, Eurocode 5, (2015). Design of timber structures (abbreviated EN 1995 or, informally, EC5) specifies technical rules for the design of timber using the limit state design philosophy. It was approved by the European Committee for Standardization (CEN) on 16 April 2004 to enable designers across Europe to practice in any country that adopts the code.

2.7 Review of Design Software

2.7.1 Solid works

The Solidworks certification catalog currently offers 17 unique certifications. Users wishing to start their Solidworks certification journey may begin with the Solidworks Certified Associate (CSWA) level certification as it is the beginner or entry-level certification. Within the CSWA category, users can become certified in additive manufacturing, electrical, sustainability, and simulation. Solidworks also offers an academic version of the CSWA targeted specifically at students. The intermediate or mid-level certification is the Solid works Certified Professional (CSWP). Within the CSWP category users can become certified in model-based definition, simulation, sheet metal, weldments, surfacing, mold making, and drawing tools. Solid works also offers an academic version of the CSWP targeted specifically at students. For users seeking a certification in product data management (PDM), Solid works offers the Certified PDM Professional Administrator exam. The advanced or top-level certification is the Certified Solid works Expert (CSWE). For a user to attempt the CSWE they must have 1) successfully passed the CSWP and 2) successfully passed at least four of the CSWP advanced topic exams. Users can gain access to an exam voucher by purchasing it online, having it supplied by a certified testing center, retrieving it through the Solid works Customer Portal, attending Solid works World, or being given one from a Solid works employee or another representative of Solid works provide an overview of Solid works certification pricing and further details. According to the Solid works Certification Center there are, at the time of this writing, 232,168 CSWA, 100,997 CSWP, and 3,693 CSWE users world-wide.

2.7.3 Orion

Orion is a structural analysis, design, and drafting program developed for the design of concrete building systems (CSC Orion Reference Manual, 2017). The program consists of several modules for performing the following tasks; 3-D Analysis of the structural model of the building, Column, Shear wall, Slab, and Beam reinforcement design, Column, Shear wall, and Beam detailing, Foundation design and detailing, Analysis and Design of Stairs and Concrete and Steel Quantity extractions. Orion is also used for design of timber structure. Orion combines the data sources and integrates the information so as to allow the linked data to be searched in a unified platform. Orion is one of the most widely used software in the world. Even though it use is limited to reinforced concrete design, it has unique feature that it integrate design with detailing in one suits unlike some analysis and design software. Orion provides basic concepts for concrete structure calculations and procedures. The graphic interface is expected to help users understand the design process.

CHAPTER THREE

MATERIALS AND METHODS

This section presents the materials and methods the material and methods employed for actualizing the research goal. The study was predominantly analytical and partly experimental. The analytical phase of the study involves the modeling of the three hardwood beam laminate to euro code using design and modeling software while the experimentation phase involves the determination of failure modes of the three hardwood beam laminate. Failure mode determination was done at faculty of engineering laboratory Nnamdi Azikiwe University Awka Anambra State.

3.1 Collection and Preparation of Materials

A total of three (3) glulam specimens namely Mahogany (Swietenia macrophylla), Iroko (Milicia excels) and Obeche (Triplochiton scleroxylen) were dimensioned, this samples were cut into a dimension of 1000mm x 150mm x 200mm (length x breadth x height) for the determination of their respective failure mode as part of the experimentation phase of the study. The analytical phase of the study involves analyzing and modeling of the three hardwood beam laminate using design and modeling software (Orion and Solid works). The three hardwood beam laminate was analyzed and modeled using euro code design for timber structures. These materials were procured from a timber shed at Head Bridge in Onitsha Anambra State Nigeria. The process employed in obtaining the material is enumerated below:

The process used to obtain the specimen is as follows:

1 The trees are felled and loaded into transport trucks which transports the logs to the sawmill facility (Timber shed at head bridge in Onitsha Anambra State).

2 Logs are properly scaled before entering the saw mill, this involves measuring, inspection for defects.

3 The logs are then sorted in terms of species.

4 The logs were then taken to a saw mill where they are debarked and then cut into planks using the circular sawmill machine.

5 The air drying process removes naturally occurring moisture from the planks.

6 Using a pencil, ruler, square, and equipment for angle measurement two diagrams are drawn on the surface of the timber,

7 Using a vertical band saw machine the specimens were cut out of the plank using the drawings on the plank as a guide.

Iroko (Milicia Excels) Mahogany (Swietenia macrophylla) Obeche (Triplochiton Scleroxylen) Glulam Beam Samples

Plate 3.0: Selected Species of Hardwood Beam Laminate used in the Study

The samples of hardwood beam laminates and their dimension are summarized in Table 3.1 below:

Table 3.1: List of Hardwood Beam Laminate their dimension and Classification.

Botanical Names	**Classification**	**Other Names**	**Dimension**
Swietenia macrophylla	Hardwood	Mahogany	1000mm x 150mm x 200mm
Milicia excels	Hardwood	Iroko	1000mm x 150mm x 200mm
Triplochiton scleroxylen	Hardwood	Obeche	1000mm x 150mm x 200mm

3.2 Procedure for Fabrication of Hardwood Glulam Beam Samples

The mechanisms involved in the fabrication process are done in compliance with the fabrication methods adopted by many researchers in producing glulam. Brief summary of the processes are as follows:

1. **Drying:** Feed stocks are dried to within a range of moisture contents specified by adhesive suppliers. These can be air-dried or artificially dried to reduce the moisture content to between 8% and 15% as suggested by the adhesive producer
2. **Strength grading:** Air-dried timbers are sent for strength grading. Only the structural grade timbers will be considered for fabrication of structural Glulam. Grading can be done by means of non-destructive tools such as machine stress grader, natural frequency tools, or visual grading.
3. **Plaining:** Timbers are sent for plaining to improve surface smoothness and uniformity of dimension. This is to facilitate lamination and improve wood-adhesive bonding. It also helps to minimize raised grain, warping or cupping occurrence.
4. **Glue spreading:** Appropriate adhesive mixed are prepared and applied on the surface of the timbers by either one or both of the following adhesive applicators. Tools used in my work were a glue spreader. Both sides of the lamella surface can be concurrently spread with adhesive using the glue spreader at a recommended spread ratio. Freshly planed wood surface would make better and stronger glue joints and the timber should be exposed for a limited amount of time between the plaining, glue spreading and lamination process so as to minimize surface contamination, occurrence of raised grain, warping or cupping. It is best that gluing is done right after plaining process. Thus, it is recommended to ensure that the glue spreader be placed near the planer to facilitate working both machines in tandem.
5. **Clamping:** After glue spreading, the glue spread laminations are transferred to the clamping station. Clamping is the process where the lamellae of the glulam member are clenched using clamping jigs, screws and bolts.
6. **Post curing:** This is also known as conditioning period. The bonded members are left for curing for several days depending on the requirement of the type of adhesive being used. In the case of PUR, it is a very strong and fast moisture curing adhesives hence samples were left for just 24 hours before removing from clamp.
7. **Finishing:** Trimming off the excessive adhesives and planning the edges to a smooth surface finish.

3.3 Methods of Study

3.3.1 Experimental Phase (Failure Mode Determination)

Bending stiffness test is performed to determine the resistance of a member against bending deformation and is used for analysis of failure mode of the timber beam. It is a function of elastic modulus E, the area of moment of inertia I of the beam cross section about the axis of interest, length of the beam and beam boundary condition. The load bearing capacity of glulam beam under bending is highly related to the material properties and the tensile capacity of the timber boards used. The glulam timber beam have more uniform mechanical properties mainly due to the intent of minimizing the influence or defects in timber (e.g. nodes, cracks misalignment of fibbers) with the production process Helder et al, (2013).

Apparatus Employed

I. M500 – 25CT universal testrometric testing machine
II. Dial gauge deflector
III. Calibrated steel roller beam supports
IV. Metal plate
V. Steel roller loading device

Plate 3.1: Testometric Universal Testing Machine

Test Procedure

1. The specimen was measured and weighed.
2. The centre loading point and supports were marked, such that the orientation of the test species ensured perpendicularity to the direction of loading.
3. The test piece was then stabilized with an initial load, after which the dial gauge is mounted and adjusted to zero to monitor deflection.
4. The test piece was supported at the ends while unrestrained to allow bending action throughout the member and ensure failure due to flexure.
5. The speed of the machine was set to load the test piece and allow adequate monitoring of the dial gauge.
6. Reading on the dial gauge was then taken at intervals within the elastic limit before failure.
7. The test piece was allowed unrestrained till failure occurred.

3.4 Analytical Phase

Design of flexural members (timber beams) involves consideration of the effect of actions such as bending, deflection, shear, lateral buckling, bearing and vibration and specification of appropriate geometrical properties to take care of this actions (Euro code 5, 1995). The process of analyzing and designing of timber beam laminate according to Euro code 5 for design of timber structures is outlined below:

3.4.1 Ultimate Limit State Design

1 Determine the beam type (continuous beam, cantilever beams, simply supported beams).
2 Calculate all the characteristic loads (dead, snow, wind and live loads).
3 Calculate all the load combinations
4 Determine the geometric properties of the beam (depth, width and clear span of beam).
5 Determine the section modulus of the beams.
6 Determine the beam laminate properties (strength class, characteristic bending strength, percentile modulus of elasticity, mean modulus of elasticity, mean shear modulus and mean density of the timber beams).
7 Compute the beam design actions (design action from self-weight of the beam, design action from characteristic self-weight of the beam, characteristic permanent action due to point load and characteristic permanent action due to uniformly distributed loads).
8 Apply the modification factor
9 Compute the design bending moment
10 Compute the design bearing stress.
11 Compute the design shear stress.

3.4.2 Serviceability Limit State Design

1 Verify the timber beam for bending stress and if not satisfied, increase the cross section (depth and width) of the beam and redesign.
2 Verify the timber beam for shear stress and if not satisfied, increase the cross section (depth and width) of the beam and redesign.

3. Verify the timber beam for instantaneous deflection criteria and if not satisfied, increase the cross section (depth and width) of the beam and redesign.
4. Verify the timber beam for final deflection criteria and if not satisfied, increase the cross section (depth and width) of the beam and redesign
5. If all the serviceability limit checks are satisfied according to the specification provided by Euro code 5 designs for timber beams, the selected geometric properties of the timber beams becomes the properties to be adopted for practical construction.

3.5 Methods for Computer Aided Modeling of Hardwood Beam Laminate

3.5.1 CSC Orion

To model the timber beams using Orion, it is expected that the beam type, geometrical properties (depth, clear spacing and width), characteristic loads and other properties (strength class, characteristic bending strength, percentile modulus of elasticity, mean modulus of elasticity, mean shear modulus and density of the timber beam) have been determined. To model the timber beam using Orion apply the following steps:

1. Click on new project and insert the project code of your choice.
2. Enter the setting centre and specify the design code (Euro code 5 design of timber structure) thereafter, click on import.
3. Create axis on the graphic user interface (GUI) and specify the necessary axis spacing (use for determination of clear spacing of the timber beam).
4. Go to design parameter settings and adjust the necessary parameters accordingly.
5. To model the timber beams, click on beam icon, specify the beam cross section (depth and width) and apply the beam cursor thereafter, go to 3d model to view the beam model created.
6. Apply all the necessary characteristic loadings and load combination to the beam modeled.
7. To design the timber beam, go to beam design and select beam section design to determine the value of the internal stresses (bearing stress, bending moment, and shear force).
8. Run the analysis to verify if the beam cross section specified is satisfied.

3.5.2 Solid Works

To model the timber beams using Solid works, it is expected that the beam type, geometrical properties (depth, clear spacing and width), characteristic loads and other properties (strength class, characteristic bending strength, percentile modulus of elasticity, mean modulus of elasticity, mean shear modulus and density of the timber beam) have been determined. To model the timber beam using Solid works apply the following steps:

1 Click on new project and insert the project code of your choice.
2 Enter the setting centre and specify the design code (Euro code 5 design of timber structure) thereafter, click on import.
3 Create axis on the graphic user interface (GUI) and specify the necessary axis spacing (use for determination of clear spacing of the timber beam).
4 Go to design parameter settings and adjust the necessary parameters accordingly.
5 To model the timber beams, click on beam icon, specify the beam cross section (depth and width) and apply the beam cursor thereafter, go to 3d model to view the beam model created.
6 Apply all the necessary characteristic loadings and load combination to the beam modeled.
7 To design the timber beam, go to beam design and select beam section design to determine the value of the internal stresses (bearing stress, bending moment, and shear force).
8 Run the analysis to verify if the beam cross section specified is satisfied.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter presents the results obtained from the analysis and modeling of the three different hardwood beam laminate using CSC Orion and Solid Works. Failure mode evaluation of the three different hardwood beam laminates was also presented. Below is table 4.1 present of the findings obtained from the experimental and analytical study.

Table 4.1: Analysis and Modeling of Iroko (Milicia excels) Using Euro Code 5

Structural Properties	**CSC Orion**	**Solid Works**
Design Bending Moment (kNm)	7.34	7.25
Design Bending Strength (N/mm^2)	6.23	5.92
Design Bending Stress (N/mm^2)	10.34	10.18
Bending Check	Satisfied	Satisfied
Design Bearing Strength (N/mm^2)	1.54	1.45
Design Bearing Stress (N/mm^2)	0.92	0.88
Bearing Check	Satisfied	Satisfied
Design Shear Stress (N/mm^2)	0.652	0.62
Design Shear Strength (N/mm^2)	1.62	1.56
Shear Check	Satisfied	Satisfied

Table 4.2: Output Obtained from Analysis and Modeling of Obeche (Triplochiton scleroxylen) Using Euro Code 5

Structural Properties	**CSC Orion**	**Solid Works**
Design Bending Moment (kNm)	7.42	7.33
Design Bending Strength (N/mm^2)	6.28	6.08
Design Bending Stress (N/mm^2)	10.45	10.38
Bending Check	Satisfied	Satisfied
Design Bearing Strength (N/mm^2)	1.52	1.48
Design Bearing Stress (N/mm^2)	0.94	0.9
Bearing Check	Satisfied	Satisfied
Design Shear Stress (N/mm^2)	1.04	0.97
Design Shear Strength (N/mm^2)	1.62	1.54
Shear Check	Satisfied	Satisfied

Table 4.3: Output Obtained from Analysis and Modeling of Mahogany (Swietenia macrophylla) Using Euro Code 5

Structural Properties	**CSC Orion**	**Solid Works**
Design Bending Moment (kNm)	7.45	7.36
Design Bending Strength (N/mm^2)	6.34	6.15
Design Bending Stress (N/mm^2)	10.48	10.42
Bending Check	Satisfied	Satisfied
Design Bearing Strength (N/mm^2)	1.64	1.55
Design Bearing Stress (N/mm^2)	0.92	0.84
Bearing Check	Satisfied	Satisfied
Design Shear Stress (N/mm^2)	1.12	1.04
Design Shear Strength (N/mm^2)	1.68	1.58
Shear Check	Satisfied	Satisfied

Table 4.4: Three Point Bending Strength Test Results for Iroko (Milicia excels)

Test Piece	Failure Load (kN)	Bending Strength (N/mm^2)
1	13.3	66.5
2	6.9	34.5
3	10.2	51
4	10.9	54.5
5	7.4	37.0
6	11.3	56.5
7	8.3	41.5
8	9.7	48.5
9	9.2	46
10	7.8	39

Table 4.5: Three Point Bending Strength Test Results for Obeche (Triplochiton scleroxylen)

Test Piece	Failure Load (kN)	Bending Strength (N/mm^2)
1	14.5	72.5
2	8.6	43.0
3	11.2	56.0
4	12.4	62.0
5	8.3	41.5
6	9.2	46.0
7	7.4	37.0
8	9.8	49.0
9	11.2	56.0
10	8.8	44.0

Table 4.6: Three Point Bending Strength Test Results for Mahogany (Swietenia macrophylla)

Test Piece	Failure Load (kN)	Bending Strength (N/mm^2)
1	15.8	79.0
2	14.2	71.0
3	12.8	64.0
4	10.4	52.0
5	11.6	58.0
6	10.2	51.0
7	9.6	48.0
8	9.2	46.0
9	8.7	43.5
10	8.3	41.5

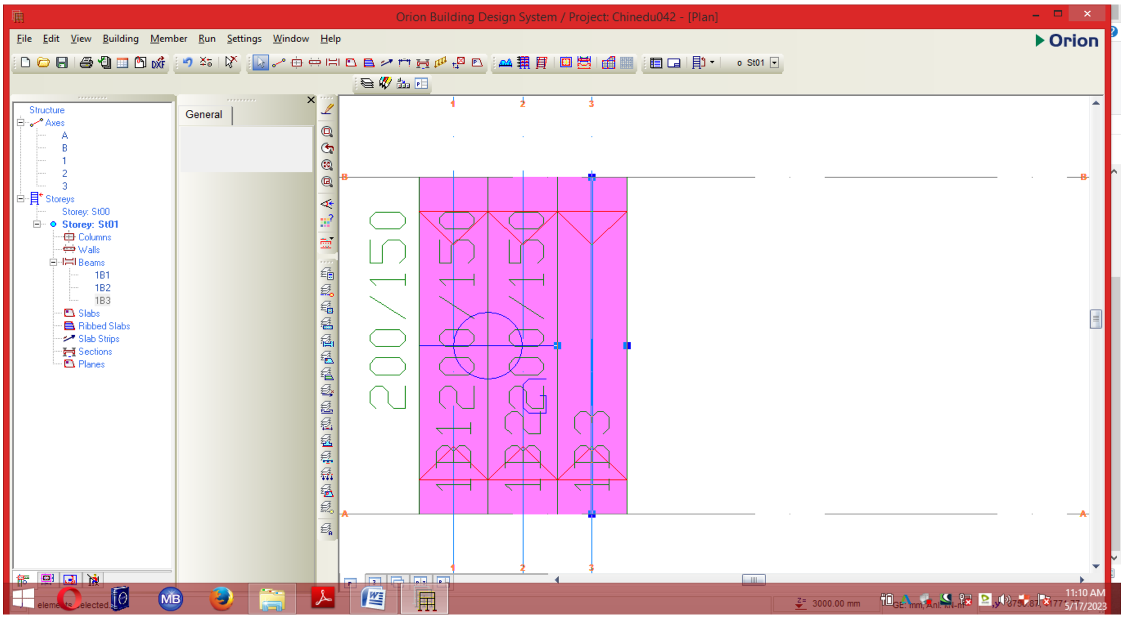


Figure 4.0: Plan Modeling View of Hardwood Beam Laminate Using CSC Orion

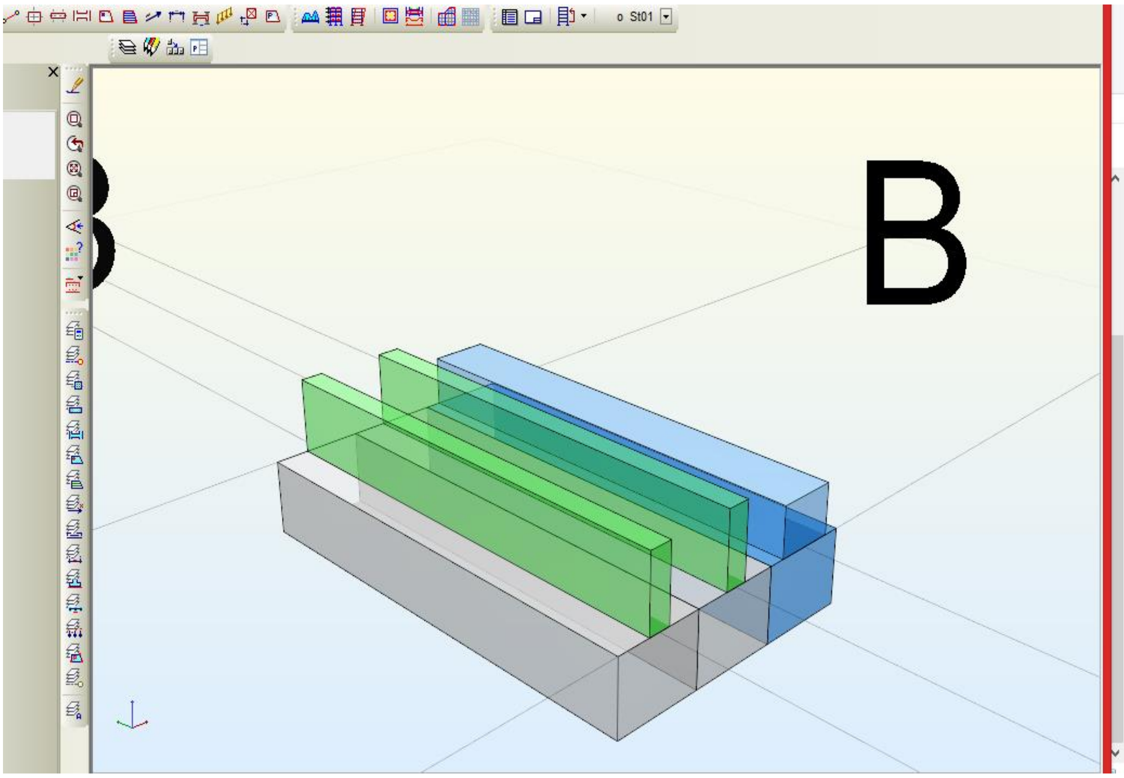
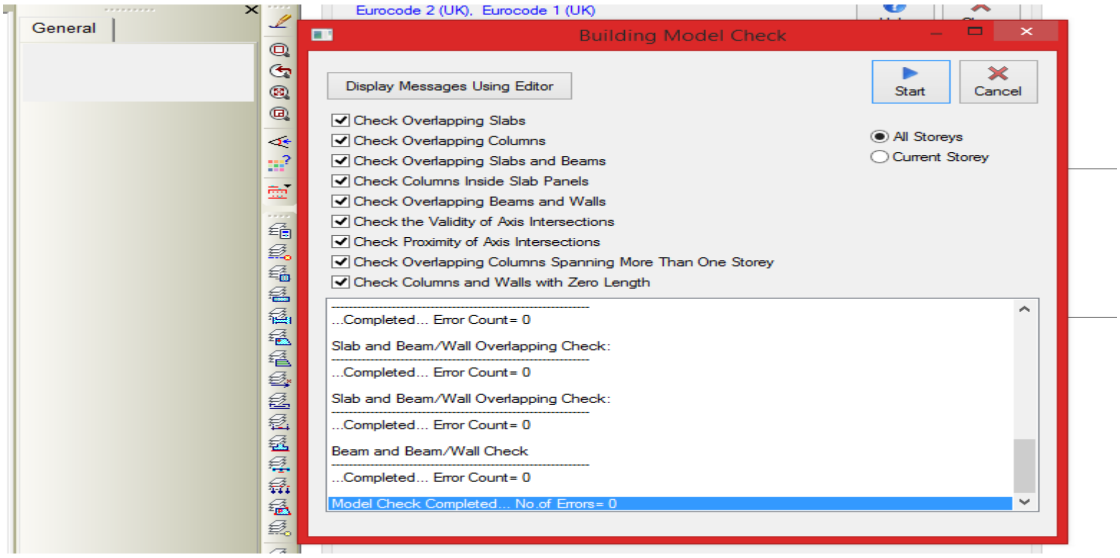


Figure 4.1: 3D Modeling View of Hardwood Beam Laminate Using CSC Orion



☑ Check Overlapping Slabs
☑ Check Overlapping Columns
☑ Check Overlapping Slabs and Beams
☑ Check Columns Inside Slab Panels
☑ Check Overlapping Beams and Walls
☑ Check the Validity of Axis Intersections
☑ Check Proximity of Axis Intersections
☑ Check Overlapping Columns Spanning More Than One Storey
☑ Check Columns and Walls with Zero Length

● All Storeys
○ Current Storey

```
--------------------------------------------------------
...Completed... Error Count= 0
Slab and Beam/Wall Overlapping Check:
--------------------------------------------------------
...Completed... Error Count= 0
Slab and Beam/Wall Overlapping Check:
--------------------------------------------------------
...Completed... Error Count= 0
Beam and Beam/Wall Check
--------------------------------------------------------
...Completed... Error Count= 0
Model Check Completed... No.of Errors= 0
```

Figure 4.4: Output from Analysis of Hardwood Beam Laminate Using CSC Orion

4.2 Discussion on Findings Obtained from Computer Aided Analysis and Modeling

Table 4.1-4.3 shows the outputs obtained from analysis and modeling of the three hardwood beam laminate using euro code 5. It was observed that the section provided (1000x150x200) for the three different beam laminate satisfied the serviceability requirements for shear, bearing and bending stress and as a result the section provided was deemed structurally workable. Comparative deduction of the structural properties of the three different hardwood beam laminate suggest that mahogany produced the highest bending, bearing and shear strength while iroko produced the least bending, shear and bearing strength.

Comparative deduction of the outputs obtained using the different modeling software (CSC Orion, and Solid Works) showed the discrepancies were minimal and the results obtained using the three different modeling software’s were the same.

4.3 Evaluation of Failure Mode of Hardwood Beam Laminate

Table 4.4-4.6 depicts the failure load and bending strength results obtained for the three hardwood beam laminate. Assessment of the failure load of the three hardwood beam laminate showed that mahogany produced the highest failure load (15.8kN) while iroko produced the least failure load (13.3kN). These results suggest that mahogany which produced the highest failure load will invariably yield the highest bending strength while iroko which produced the lowest failure load will invariably yield the lowest bending strength. Evaluation of failure modes of the three hardwood beam laminate employed in the study revealed that the three hardwood beam laminate showed similar failure characteristics. Failure was flat-wise and was initiated at the bottom fiber which was propagated upward with iroko showing relatively larger failed section than mahogany and obeche.

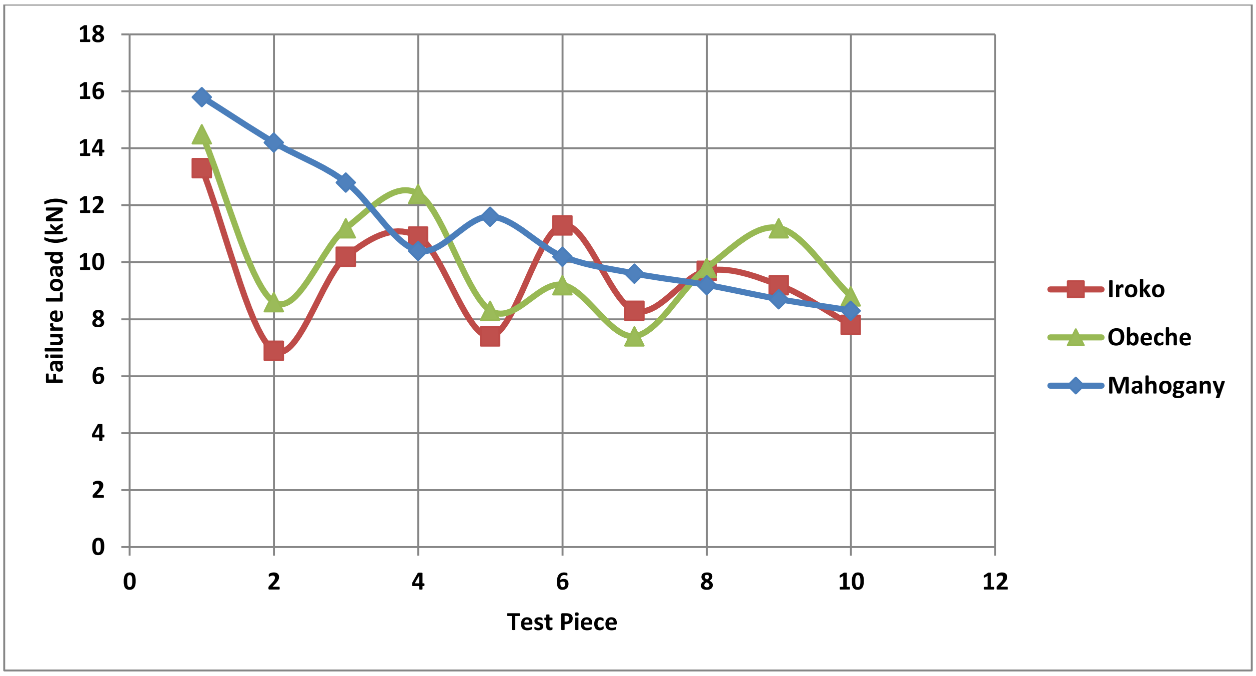


Figure 4.5: Graph Showing the Failure Load of the Different Hardwood Beam Laminate

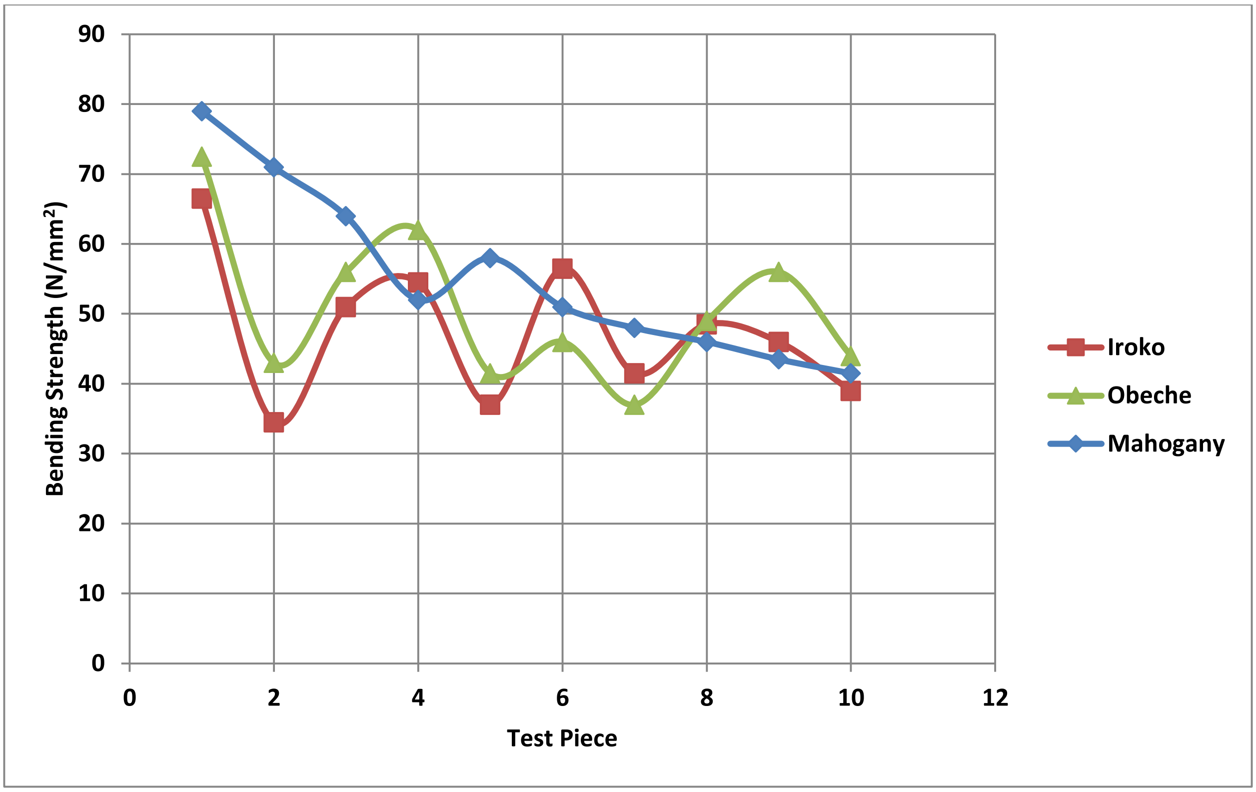


Figure 4.6: Graph Showing the Bending Strength of the Different Hardwood Beam Laminate

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the findings obtained from analysis and modeling of hardwood beam laminate using CSC and Solid works, the following conclusion can be drawn:

1 Analysis and modeling of the three hardwood beam laminate using CSC Orion and Solid works revealed that mahogany produced the highest value in bending strength, bearing strength and shear strength.

2 The three different hardwood beam laminate satisfied the serviceability requirements for bearing, bending and shear.

3 Comparison of the outputs obtained from the analysis and design of the three different hardwood beam laminate using CSC Orion and Solid Works suggest that the outputs obtained from the three different modeling softwares were the same.

4 Evaluation of the failure mode of the three different hardwood beam laminate revealed that mahogany produced the highest bending strength before failure while iroko produced the least bending strength before failure. The three different hardwood beam laminate showed similar failure characteristics.

5.2 Recommendation

From the findings obtained from the analysis and modeling of the three different hardwood beam laminate, the following recommendation can be made:

1 The study recommend the use of extracts from mahogany for structural application particularly as beams in building and other civil engineering structures owing to the fact that has better structural properties than other hardwood glulam species.

2 The study also recommend the use of CSC Orion for analysis, design and modeling of timber structures, this is due to the fact that CSC Orion gives more detailed information on the internal stresses of a given structural member than other design and modeling soft wares.

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