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RESEARCH ARTICLE

Cross-Laminated Timber (CLT) and the potential for adoption in construction projects

Dele Roger Simeon [1], Olatunji Joseph Oladiran [1], Oluwole Otufowora [2], David Gabriel [1]

[1] University of Lagos, Department of Building, Akoka, Yaba, Lagos-state, Nigeria
[2] Olabisi Onabanjo University, Department of Building, Ago-iwoye, Ogun-state, Nigeria

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Abstract

Cross-laminated timber (CLT) is a versatile and eco-friendly building material that may be utilized in a variety of applications. It is however rarely utilized on construction projects in Nigeria. Thus, the study sought to establish the level of adoption of CLT and identify key drivers to its adoption in the Nigerian construction industry in an attempt to keep up with the global trend of adopting more sustainable construction practices and materials. A survey research approach was employed to gather data from 137 construction professionals who were selected using the snowball sampling technique in Lagos and Ogun States, Nigeria. A structured questionnaire instrument was designed to gather data from the respondents. A combination of Microsoft Excel and the Statistical Packages for Social Sciences was the software used to aid data analysis. The statistical tools deployed for the analysis were frequency, percentages, percentage mean adoption, relative importance index, and ranking. The findings revealed that the top four highly important drivers for the adoption of CLT are aesthetics, prefabrication, lightweight, and cost competitiveness. Besides, the findings also revealed that CLT was mostly applied as partition walls, door leaves, shelving units, and countertops. The study concludes that CLT is not engaged in as many as 20 building areas and components. This indicates that the construction industry is yet to embrace the eco-friendly features of CLT in building projects. The study therefore recommends that practitioners should endeavor to employ CLT in the building areas and components where they are not engaged to fully optimize CLT's eco-friendliness in building projects. This may be accomplished by conducting workshops, and trainings as well as domesticating the necessary technologies to fully harness its potential.

1. Introduction

The construction industry contributes to global greenhouse gas emissions and consumes a significant amount of energy [1]. According to [2], the industry accounts for about 40% of total CO_2 emissions into the atmosphere. In a bid to exacerbate environmental impacts on construction, more recently, attention and resources have been directed towards the development of alternative building materials (ABMs). According to [3],

Correspondence Dele Roger Simeon dsimeon@unilag.edu.ng

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ABMs include the avoidance of dangerous elements in construction that may impair the environment, and human health, and recycling possibilities as a crucial element of good building materials. These features make ABMs desirable not just for housing in developed countries, but also for use in humanitarian engineering projects in developing countries. It is useful to note that not all ABMs are sustainable. [4] corroborates that sustainable construction materials must meet the following criteria energy efficiency and cost, indoor air quality and efficiency, a high recycled content, and fast renewable resources with minimal emission potential. Some examples of sustainable ABMs include bamboo, straw bales, compressed earth blocks, and Ferrock cement among others [5].

One of the most promising sustainable ABMs receiving a lot of research and commercial attention in recent years is cross laminated timber (CLT) otherwise known as X-LAM. CLT is a subcategory of engineered wood products (EWPs) collectively regarded as mass timber. According to [6], Mass Timber Construction is an umbrella word that incorporates particular materials such as Glued Laminated Timber (GLULAM), Laminated Veneer Lumber (LVL), and CLT. CLT is an EWP produced via stacking multiple layers of timber at right angles and joining them by applying structural adhesives. [7, 8] opine that CLT is an excellent substitute for traditional concrete and masonry construction for being an environmentally friendly prefabricated solution and has been gaining popularity in construction industries across the globe. [9] opines that CLT has evolved into a well-known and adaptable construction material across the world. Over the past decade, a lot of studies have been carried out on CLT. [10] note that countries that have adopted CLT technology include Australia and New Zealand, Brazil, Canada, China, the European Union, Japan, South Africa, the United Kingdom, and the United States. In this regard, [11] carried out a study on the suitability of CLT for high-rise building construction in Australia. In their review of CLT in China, [12] highlighted the development of China's CLT-bamboo hybrid. Also, studies conducted by various researchers such as [6, 13, 14, 15], posit CLT as a sustainable material for the future that does not have limitations associated with concrete and steel and is relatively easily integrated into current construction practices. [16] proposed that CLT will be the future of timber construction in Nigeria. There are several factors driving the adoption of CLT on construction projects. Some of the drivers for the adoption of CLT have been discussed by [8, 11, 13]. For instance, [8] opined that CLT panels are extensively utilized in mass-timber multistorey structures due to their prefabrication, flexibility, environmental credentials, and superior weight-to-strength ratio compared to other building materials. Yet, as a result of the hygroscopic behaviour of Timber, it is susceptible to biodegradation. Meanwhile, [11] reckoned that CLT incorporates coherence, moisture content, variation, and cellular structure to offer benefits over timber. The authors further note that CLT offers excellent thermal insulative properties than reinforced concrete; reduces on-site noise pollution, erection time, waste; lightweight; moderate fire resistance; releases oxygen and time savings as a result of its pre-fabricated design but however constrained in averting last-minute design modifications; unfavorable user impression of environment, fire safety, and stability; and access to the cost implications of CLT is limited. Meanwhile, [13] believed CLT may be used to construct mid- and high-rise structures because of its carbon-negative qualities; and less primary energy consumed from non-renewable sources than GLULAM and LVL. However, the authors believe that the primary obstacles to a broader adoption of CLT remain uncertainties surrounding the material.

These studies and more like this have spurred the development and adoption of CLT for building construction globally. Despite previous studies establishing CLT as a suitable and structurally sound ABM in building construction and the suitability of locally sourced wood species for its production, the Nigerian construction industry has been slow to implement sustainable building construction practices [17]. This is so because the usage of concrete and steel as construction materials dominates the Nigerian construction industry, with little consideration given to sustainable materials. Thus, the study aims to appraise the level of adoption of cross-laminated timber in the Nigerian building industry with the intention of promoting the use of sustainable alternative building materials among built environment professionals on construction projects. The study's objectives are to identify drivers for the adoption of CLT and determine the level of adoption of CLT in construction projects. The study is significant because it provides data that can be used to support policies and strategies aimed at increasing the use of CLT, as well as to highlight areas for improvement.

2. Literature Review

2.1. Drivers for the adoption of CLT

Given its advantages over other ABMs in terms of prefabrication, construction flexibility, environmental credentials, and weight-to-strength ratio, CLTs are frequently utilized in mass-timber multi-story buildings [8]. [18] note that CLT may function well as the material of the future by virtue of its low-carbon characteristics and advantages of affordable prices and efficient structural features to be taken into consideration in tall buildings, especially due to effects against fire, wind, and earthquakes. In this regard, [19] investigated the environmental advantages of using wood for construction, and there is a consensus that when forests are managed sustainably, wood is carbon-neutral and serves as a repository for carbon, either as growing stock or as a product with added value. While [13] is of the view that the peculiar qualities of mass timber allow it to char rather than burn. Another driver of CLT is that walls and floors are delivered directly from the mills to construction sites. As a result, CLT material reduces total construction time, rendering CLT work less harmful to the environment and the nearby residents [20]. Besides, CLT has superior thermal characteristics to steel, concrete, and even existing kinds of insulation such as mineral wool [11, 13, 21, 22, 23, 24, 25, 26]. [27] averred that CLT and other timber-based products outperform conventional construction materials in terms of energy conservation and carbon reduction. Meanwhile, [13] adds that CLT is a lightweight panel and its lack of mass means that vibrations pass more easily through it and can also travel from floors into walls, known as flanking transmission. These drivers are further summarized in Table 1.

2.2. Application of CLT on building construction projects

Due to the rising demand for ecologically friendly building materials and the expansion of global development, EWPs have become more widely adopted on a global scale [51, 52]. In this regard, construction is being revolutionized by the adoption of CLT thereby providing a robust, durable, and adaptable replacement for conventional materials. More recently, CLT has been used by Architects and Builders to produce cutting-edge, green buildings and has become a feasible construction material for structural purposes [53]. [20] opine CLT is a versatile and lightweight building material that may be used for both small and large-scale construction projects, including detached homes, wooden multi-story buildings, and public building projects. [54] corroborates that CLT can be utilized effectively in prefabricated and modular systems to create single- and multi-family housing, multi-story residential housing (condominiums), schools, office buildings, medical facilities, industrial buildings, agricultural buildings, the addition of newly built stories, urban aggregation and infrastructures, and infrastructure for tourism and leisure. Meanwhile, [55, 56] posit that CLT has considerable potential for multi-storey structures and high-rise buildings as a building material for structural purposes. In a similar vein, [57] asserts that prefabricated buildings, bridge structures, and multi-story buildings can all benefit from the use of CLT.

In this regard, [9] note that a CLT product may be used as a full-size wall and floor element as well as a linear timber member that can support loads both in-plane and out-of-plane owing to its orthogonal, laminar structure.

Table 1. Summary of findings for studies on drivers of CLT

Drivers	Description	Library source
Cost-effectiveness	- The cost-effectiveness and load-bearing strength of CLT make it ideal for tall structures with wide spans.	[28]
	- CLT's lighter weight lowers foundation and transportation expenses.	[29]
	- Costs are expected to decrease as design familiarity and local CLT supply grow.	[11, 22]
	- CLT allows for up to a 30% decrease in construction time, which greatly cuts on-site labor costs.	[21]
Design flexibility	- Increasing the thickness of CLT panels allows for larger spans with lesser internal supports.	[21]
	- CLT may be modified using basic tools when necessary.	[11]
	- Similar to concrete slabs, 9-inch CLT panels may span up to 25 feet.	[23, 30]
	- Greater architectural flexibility in the arrangement of areas in the design and layout of openings.	[31]
Fast installation	- Faster occupancy and cheaper capital expenses are the outcomes of the shorter assembly time.	[21, 22]
	- Savings in time due to prefabricated design.	[11]
	- Maximize off-site work, reducing noise, waste, and congestion for efficiency.	[32, 33]
	- Mechanical fastening technologies are employed in the assembly of CLT panels.	[22]
	- CLT changes the design from "Frame" to "Plates".	[34]
	- CLT floor construction might take up to four days, compared to 21 days for concrete.	[35]
Fire resistance/performance	- The tightness between panels keeps smoke and fire from spreading and causing damage in certain locations.	[36]
	- Because CLT panels burn slowly, their thick cross section offers considerable fire protection.	[21, 22]
	- CLT provides superior fire resistance.	[37]
	- Using a 7-inch-thick CLT wall specimen, the ASTM E119 fire resistance test took three hours, five minutes, and 57 seconds.	[38]
Thermal performance/energy efficiency	- CLT is very energy-efficient and capable of storing both heat energy and moisture.	[27]
	- The panel's thermal performance improves with increasing thickness.	[21]
	- CLT panels provide better insulation and lower U values, lowering heating and cooling costs.	[22]
	- CLT outperforms steel and concrete in terms of thermal characteristics.	[24]
	- HVAC and lighting expenditures are reduced by 10% with a CLT construction.	[39]
	- CLT provides a tighter structure with fewer air leaks, enhancing the thermal performance of the building.	[40]
	- The R-value of a 7-inch thick CLT panel would be roughly $8ft^{2o}fhr/Btu$	[41]

Table 1. Cont'd

Environmental advantages/Eco-friendliness	- Decrease in the construction's overall environmental effect, including recycling and disposal.	[27]
	- In terms of embodied energy, water pollution, and air pollution, CLT performs better than steel and concrete.	[21, 39, 42]
	- CLT has a lower carbon impact since wood absorbs carbon from growing trees.	[43]
	- Wood production emits less greenhouse gases.	[22]
	- Users associate greener buildings with healthier lives.	[11]
	- CLT buildings use less energy to operate.	[39]
	- CLT is an environmentally friendly, recyclable, and sustainable building material with extended durability.	[27]
Less waste	- CLTs are designed for specific uses, resulting in minimal or no worksite waste.	[21]
	- Manufacturers can use manufacturing leftovers into staircases and other architectural features.	[32]
Wind loads/seismic performance	- Given its high strength-to-weight ratio, CLT structures can resist earthquakes with high seismic intensity.	[44]
	- A CLT-based structure resists lateral stresses.	[11]
	- Seismic energy is dissipated via fastening systems.	[45]
	- After being tested in an earthquake simulator, CLT constructions revealed no lasting deformation.	[46]
	- CLT operates exceedingly well in multi-story applications, with negligible residual deformation.	[21].
Acoustic performance	- CLT is considered a strong alternative to heavy-weight structures.	[27]
	- Airborne and impact sound transmission is well controlled by CLT structures.	[21]
	- The higher the mass of a CCLT panel, the better its acoustic performance.	[13]
Reduced weight	- CLT panels have a greater load-bearing capability relative to their own weight than the majority of conventional building materials.	[27]
	- CLT weighs approximately four times less than concrete.	[21, 29]
	- CLT weighs up to 30% less than concrete and steel equivalents.	[11, 47]
Structural performance	- The most essential feature of CLT is its high strength-to-weight ratio.	[6, 31]
	- Buildings as tall as 150mm might be designed using a combination of CLT and concrete.	[48]
	- The stiffness of CLT panels is determined by the homogeneity of the individual layers.	[49]
	- CLT panels perform effectively as load-bearing plates and shear panels due to their cross-laminated structure.	[50]

As a result of its strength and stiffness in two directions provided by the resultant alternating grain directions, [58] asserts that CLT is a suitable panel for two-way spanning slabs, walls, and diaphragms. Studies done in the past on the usage of CLT goods have shown that this invention is still not being widely used since its capabilities, qualities, and prices are not well understood [24, 51, 59]. In their study, [60] established that CLT floors can match the load-bearing capacities of reinforced concrete (RC) floors with only a little difference in overall thickness. It is in this regard that [12, 56] note that the mechanical and physical characteristics of CLT are better than those of other types of manufactured wood products, such as glued laminated timber, oriented strand board, and laminated veneer lumber.

Furthermore, [61] conducted a life cycle analysis for CLT and discovered that CLT can store carbon while avoiding greenhouse gas emissions, resulting in 34-84% lesser climate change impacts than reinforced concrete structures. Thus, CLT is adjudged environmentally sustainable [62]. To this end, this literature review of CLT has highlighted numerous driving factors and benefits, such as structural performance, aesthetic appeal, lightweight attribute, sustainability, amid other factors. Notwithstanding its positive attributes, obstacles including cost implications, regulatory difficulties, and low market awareness still exist. However, an optimistic trajectory for CLT's widespread use in building construction is suggested by the growing acknowledgment of its benefits. CLT has the potential to completely transform the built environment and provide solutions to built environment problems, provided practitioners and regulators are willing to imbibe sustainability culture.

3. Methodology

A cross-sectional research design was employed in the study. [63] defines survey research as an established quantitative technique that investigates the views, attitudes, or experiences of one or more groups of individuals. Lagos and Ogun states were chosen as research areas because they have a significant number of built professionals/organizations and a substantial number of active construction operations. Specifically, Lagos state is evolving into a megacity and Nigeria's commercial centre. Other bordering southwest states, such as Ogun, translate the developmental activities of Lagos. A structured self-administered questionnaire was used to obtain data from construction professionals who were familiar with CLT and had been involved in the usage of the material for building work.

The snowball sampling approach was used to sample 137 construction professionals, including architects, builders, engineers, estate surveyors, and quantity surveyors who are acquainted with CLT and have used it. Given that CLT is not a commonly utilized construction material, the snowball sampling approach was used to draw its sample. Furthermore, the lack of a list of CLT contractors or organizations from which a scientifically determined sample frame could be adopted enabled investigators to rely on respondent referrals to recruit additional participants. Initially, just a few participants who fit the selection criteria and had used CLT were discovered. Until the final participant is met, the recognized responses provide referrals to those who have utilized the material. According to [64], the snowball sampling approach is a non-probability sampling strategy that may be used when a researcher is attempting to discover samples of a population that are not easy to identify.

The questionnaire instrument comprised closed-ended questions. Using a scale of 1 to 5, seventeen important drivers to the adoption of CLT were assessed. Where 1 denotes unimportant, 2 denotes slightly important, 3 denotes moderately important, 4 denotes more important, and 5 denotes very important. Moreover, the study established the level of adoption of CLT in 36 common areas of application. Each of the projects was scored on a rating scale of 1-10, with participants asked to identify areas on the project where CLT has been applied in the last five years. The data were checked for errors and completeness at the end of the survey period before coding and analysis began. To aid the data, the Microsoft Excel Package and Statistical Packages for Social Science (SPSS Version, 23.0) were used. Statistical tools of analysis such as frequency tables, percentages, relative importance index (RII), percentage mean adoption (PMA) and ranking were the tools of analysis for the descriptive results.

The survey instrument was divided into 3 sections. Section A focused on the demographics of the respondents. The study’s demographics were analyzed using frequency and percentages. Section B seeks to encompass drivers for the adoption of CLT on building projects. This was analyzed using the RII.

The RII was calculated using the formula in Equation 1:

$$\mathrm{RII} = \frac{\sum \mathrm{W}}{\mathrm{A} \times \mathrm{N}} \tag{1}$$

Where:

W = weight given to each factor by the respondents and ranges from 1-5

A = the highest weight = 5

N = the total number of respondents

The RII score varies between 0 and 1. Each factor's resulting value provides an indication of its level of implementation [65].

Section C seeks to establish the professionals' level of adoption of CLT on building projects. This was analyzed using the PMA equation. The PMA was calculated using the formula in Equation 2:

PMA of each area

$$= \frac{\begin{matrix} Number\ of\ times \\ CLT\ was\ applied \end{matrix}}{\begin{matrix} Total\ number\ of\ times \\ CLT\ was\ applied\ on\ a\ project \end{matrix}} \times 100\% \quad (2)$$

4. Results

4.1. Demographic profile of respondents

Table 2 shows the demographic information of the respondents and has been divided into eight: profession; educational qualification; professional affiliation; years of experience; organization practice; organization size; ownership type; and nature of business. It can be seen that majority (29.9%) of the participants were architects, while the estate surveyors and valuers constituted the least percentage (12.4%) of professions surveyed. This result on Architects constituting a larger proportion of respondents validates the significant role Architects play during building procurement. Moreover, Architects are usually the first point of contact between potential construction industry clients and other professionals. In terms of educational qualification, the highest number of the respondents are qualified with a Bachelor's degree (30.7%), while the lowest number of respondents have a Doctorate Degree (3.6%). The results indicate that the respondents have received extensive formal education and specialized knowledge in their respective fields, making them more capable of understanding complex issues and providing thoughtful responses to the research questionnaire. In terms of professional affiliation, the highest (29.9%) of respondents were affiliated with the Nigerian Institute of Architects (NIA), while the least numbers of professionals (12.4%) were affiliated to the Nigerian Institution of Estate Surveyors and Valuers (NIESV). This result shows that all respondents were members of their respective professional organizations, indicating a commitment to professional standards and accountability. In terms of years of experience, a vast majority (70.8%) of the respondents had over 5 years of experience in the construction industry, while the least (29.2%) of the respondents had 1-5 years of experience. The results indicate that the professionals possess adequate experience in the industry and can provide accurate responses to the study. In terms of organizational practice, 31.4% of the respondents work in consulting organizations, while 68.6% work in contracting organizations. The significant engagement of contracting businesses is a desirable trend since they are more actively involved in the building construction process and have more interactions with a range of building materials. As a result, their views are more crucial to the issue under investigation. Besides, majority of the participants (94.8%) work in construction micro-small-medium enterprises (CMSMEs), the least (5.1%) of the respondents work in large-scale construction enterprises. The CMSEMs constitute the greatest number of responses since they are often more accessible and receptive to research surveys; this might be due to reduced bureaucracy in their organizational system. In terms of the respondents' organizational type, 89.1% are fully indigenous, while 10.9% are partly indigenous and partly expatriate. The large participation of fully indigenous respondents is crucial to the study's focus on CLT adoption in Nigeria as it demands an indigenous perspective. In terms of the nature of business in the respondents' organizations, a larger number of the organizations surveyed (46%) execute residential buildings, while the least (0.7%) execute public/cultural buildings). The findings revealed that a greater emphasis should be placed on the usage of CLT in residential and commercial construction projects since it has greater acceptance among respondents.

Table 2. Demographic information of the respondents

Description	Frequency (N)	Percentage (%)
Profession		
Architect	41	29.9
Builder	26	19.0
Civil/structural Engineer	33	24.1
Quantity Surveyor	20	14.6
Estate Surveyor and Valuer	17	12.4
Total	*137*	*100.0*
Educational Qualification		
ND	26	19.0
HND	35	25.6
B.Sc.	42	30.7
M.Sc.	29	21.1
Ph.D.	5	3.6
Total	*137*	*100*
Professional Affiliation		
NIA	41	29.9
NIOB	26	19.0
NSE	33	24.1
NIQS	20	14.6
NIESV	17	12.4
Total	*137*	*100.0*
Years of experience		
1-5 years	40	29.2
6-10 years	49	35.8
11-15 years	29	21.2
16-20 years	11	8.0
21 years and above	8	5.8
Total	*137*	*100.0*
Organization practice		
Consulting	43	31.4
Contracting	94	68.6
Total	*137*	*100.0*
Organization size		
Micro-sized (< 10 employees)	27	19.7
Small-sized (10-49) employees)	45	32.8
Medium-sized (50-249 employees)	58	42.3
Large-sized (>249 employees)	7	5.1
Total	*137*	*100.0*
Ownership type		
Fully indigenous	122	89.1
Partly indigenous and partly expatriate	15	10.9
Total	*137*	*100.0*
Nature of business		
Residential building	63	46.0
Commercial building	54	39.4
Institutional building	5	3.6
Industrial building	14	10.2
Public/cultural building	1	0.7
Total	*137*	*100.0*

4.2. Important drivers for the adoption of CLT in construction projects

Table 3 sheds light on the viewpoints of experts in Lagos and Ogun states on the drivers influencing the adoption of CLT products in construction projects. The experts were asked to rate the importance of 17 factors driving the adoption of CLT in construction projects. For easy assessment, a decision rule was calibrated to interpret the results. The decision rule for interpreting the RII was adapted and modified from [66] using the scale: 0.76 and above implies highly important (HI), 0.67 - 0.75 implies important (I), 0.45 - 0.66 implies slightly important (SI), 0.44 and below implies not important (NI). Findings from Table 3 reveals 17 drivers in varying degree of importance. Aesthetics (RII = 0.84), allows for prefabrication and lightweight tied with (RII = 0.82), and cost competitiveness (RII = 0.80) are "highly important" to the experts. Besides, structural performance (RII =0.75), durability (RII = 0.74), recyclable (RII = 0.71), waste reduction (RII = 0.71), waste reduction (RII = 0.69), and improved site safety (RII = 0.68) are "important" to the experts. While, resource efficiency, quick and easy installation (RII = 0.64), design flexibility, and improved indoor air quality (RII = 0.62), excellent thermal insulation (RII = 0.61), superior fire resistance (RII = 0.58) and optimum acoustic property (RII = 0.55) are "slightly important" to the experts. According to the experts, none of the drivers were "unimportant".

4.3. Adoption of CLT in construction projects

Table 4 displays CLT products' adoption in different areas of a building. Thirty-one areas of possible application of CLT products were presented to the experts. With a scale of 1-10 for each project, the experts were asked to identify and rate the areas in a building where CLT products had been applied on 10 projects that had been executed in the last 5 years. The results from Table 4 indicate that CLT was applied in varying degrees in 16 out of the possible 36 areas of application. The sixteen (16) areas and components of the buildings where CLT is applied include: partition walls, door leaves; shelving and storage units; table and counter tops; claddings; ceilings; kitchen cabinets; window frames; floors; staircases; sunshade and shading devices; external walls; elevator shafts and cores; beams; canopies and awnings; and balconies and railings.

Table 3. Important factors driving the adoption of CLT in construction projects

Important Drivers	1	2	3	4	5	N	SD	RII	R	Remark
Aesthetics	0	0	28	51	58	137	0.764	0.84	1	HI
Allows for prefabrication	0	0	36	49	52	137	0.796	0.82	2	HI
Lightweight	0	4	25	64	44	137	0.786	0.82	2	HI
Cost competitiveness	0	0	37	60	40	137	0.752	0.80	4	HI
Structural performance	0	2	56	39	40	137	0.862	0.75	5	I
Sustainability	0	0	64	37	36	137	0.833	0.74	6	I
Durability	0	0	58	68	11	137	0.624	0.73	7	I
Recyclable	0	0	77	45	15	137	0.686	0.71	8	I
Waste reduction	0	3	77	43	14	137	0.708	0.69	9	I
Improved site safety	0	11	58	64	4	137	0.685	0.68	10	I
Resource efficiency	0	11	70	44	12	137	0.764	0.64	11	SI
Quick and easy installation	0	10	90	28	9	137	0.689	0.64	11	SI
Design flexibility	0	32	69	25	11	137	0.855	0.62	13	SI
Improved indoor air quality	0	44	56	26	11	137	0.915	0.62	13	SI
Excellent thermal insulation	0	28	79	29	1	137	0.669	0.61	15	SI
Superior fire resistance	0	40	78	12	7	137	0.760	0.58	16	SI
Optimum acoustic property	0	57	61	18	1	137	0.712	0.55	17	SI

Note: 1 denotes "not important", 2 denotes "slightly important", 3 denotes "moderately important", 4 denotes "more important" and 5 denotes "most important", N denotes "Frequency", S.D denotes "Standard Deviation", and R denotes "Ranking".

Table 4. CLT adoption in construction projects

Areas of Application	F	PMA	Rank
Partition walls	484	21.97	1
Door leaves	357	16.21	2
Shelving and storage units	282	12.8	3
Table and countertops	178	8.08	4
Claddings	174	7.9	5
Ceilings	170	7.72	6
Kitchen cabinets	150	6.81	7
Window frames	134	6.08	8
Floors	66	3	9
Staircases	47	2.13	10
Sunshade and shading devices	44	2	11
Exterior walls	33	1.5	12
Elevator shafts and cores	31	1.41	13
Beams	21	0.95	14
Canopies and awnings	20	0.91	15
Balconies and Railings	12	0.54	16
Mezzanine flooring	0	0	17
Roof panels	0	0	17
Bathroom and vanity tops	0	0	17
Institutional building construction	0	0	17
Fencing	0	0	17
Columns	0	0	17
Roof trusses	0	0	17
Structural insulated panels	0	0	17
Theatre stages	0	0	17
Prefabricated construction	0	0	17
Auditorium seats	0	0	17
Laboratory workbenches	0	0	17
Museum construction	0	0	17
Exhibition booths	0	0	17
Acoustic panels	0	0	17
Multi-story building construction	0	0	17
Guardrails	0	0	17
Bracing elements	0	0	17
Pavilions	0	0	17
Warehouse construction	0	0	17
Total application of CLT	2203	100	

Note: F denotes “Frequency of application on the project”, PMA denotes “Percentage Mean Adoption”

The results also show that CLT is mostly used as partition walls in Nigeria. Besides, CLT is not applied in as much as twenty (20) building areas and components. The 20 areas of the building and components where CLT is not engaged includes mezzanine flooring, roof panels, bathroom and vanity tops, institutional building construction, fencing, columns, roof trusses, structural insulated panels, theatre stages, prefabricated construction, auditorium seats, laboratory workbenches, museum construction, exhibition booths, acoustic panels, multi-story building construction, guardrails, bracing elements, pavilions, and warehouse construction.

4.4. Discussion of results

This section discusses the study's results. The topmost factor driving the adoption of CLT on construction projects is aesthetics. Practitioners in the construction industry admire CLT's natural and warm look. The aesthetic characteristic of CLT accentuates the position of [59] that designers attach priority to issues such as aesthetics rather than financial and risk management. Besides, CLT's grain patterns and texture enhance the aesthetic attractiveness of the surface it is applied. [67] added that aesthetics is a key consideration when selecting sustainable construction materials. The prefabrication attribute of CLT is an important driving factor to the practitioners because CLT panels are often manufactured off-site in a controlled industrial environment. This considerably accelerates the construction process since the panels can be put together rapidly on-site. This effectiveness is particularly useful in urban settings with constrained sites and short project timelines. These statements affirmed the position of [54] that CLT is efficiently utilized because it enables prefabrication and modular systems to produce multiple building typologies. [59] substantiated that the utilization of CLT can accelerate construction completion, leading to increased income and ROI for owners. In addition, [12] attributed the factors driving CLT to include high prefabrication rate, easy shipping, quick installation, and less environmental harm. [68] Gasparri et al. (2015) believed that CLT building projects require around 75% less labor due to its prefabricated nature. Meanwhile, practitioners appreciate the lightweight characteristics of CLT due to the significant reduction in the cost of foundation and cost savings in transporting prefabricated panels to construction sites. The result of the lightweight driver of CLT is in line with the discoveries of [11, 27, 29, 69] that CLT's lightweight attribute lowers foundation and transportation costs. Thus, ultimately leading to significant savings in the cost of construction. The cost-effectiveness feature of CLT arises from reduced labour and material waste. The findings on cost competitiveness corroborate the results of [28] that the cost-effectiveness and load-bearing strength of CLT make it ideal for tall structures with wide spans. Moreover, [11, 22] substantiate that costs are expected to decrease as design familiarity and local CLT supply grow. Besides, the reduction in construction time implies lower financing costs. Hence, making it a cost-effective option for construction projects. Studies indicate that CLT panels with a thickness of up to 20 inches, can maintain structural integrity during fires, outperforming concrete and steel components [70]. Furthermore, [71] compared a seven-story concrete structure to a renovated seven-story CLT building in China and found that the CLT building reduced CO_2 emissions by almost 40%. CLT's natural insulative features lead to reduced operational energy costs after construction providing an additional environmental benefit [72]. Architects and engineers viewed CLT as a cost-effective and efficient alternative to existing materials and procedures [69]. According to [73], adopting CLT reduces on-site deliveries by 80%, leading to increased efficiency and cost savings. According to [74], mass wood buildings are 85% faster to construct than standard concrete and masonry buildings. This is due to the lack of waiting time for poured concrete. [75] found that employing CLT for hotel building resulted in a 37% quicker build time compared to standard methods and materials. [76] found that employing alternative project delivery approaches, such as design-build or design-bid-build, can improve CLT project performance and boost developer value. According to [77], CLT may be used with standard building methods to form a hybrid system. [78] demonstrated that CLT is compatible with older construction materials and may be utilized to restore heritage dwellings.

The study further presented results on the level of utilization of CLT in the Nigerian building industry. The result showed that there is a low adoption rate of CLT in Nigerian construction projects. This is evident from the result presented as CLT is not being effectively utilized in as many as 20 areas and components. The 20 areas of the building and components where CLT is not engaged includes mezzanine flooring, roof panels, bathroom and vanity tops, institutional building construction, fencing, columns, roof trusses, structural insulated panels, theatre stages, prefabricated construction, auditorium seats, laboratory workbenches, museum construction, exhibition booths, acoustic panels, multi-story building construction, guardrails, bracing elements, pavilions, and warehouse construction. This low level of application of innovative CLT on building projects according to [24, 51, 59] are attributed to the less awareness and understanding of the material's capabilities, qualities, and prices by construction practitioners. The non-adoption rate of CLT in key building areas and component significantly differ from findings from other parts of the world. For instance, Europe continues to produce over fifty percent of the global CLT output annually [79], indicating a high adoption rate. In the United States, Architects utilized CLT for framing, flooring, and walls. Whereas, Structural engineers utilized CLT for floors, walls, and framing. In Canada, CLT is used for Fabrication of roof, floor, and wall components [80]. [81] regarded CLT as the greatest alternative to conventional construction materials. Other key applications of CLT on construction projects have been discussed. [82] affirmed that CLT is applied in wall, roof, and floor panels, as well as bridge decks. In 2009, The Stadthaus, a 9-story CLT timber mixed-use apartment in Hackney, London, was completed [83]. [12] reported that CLT was utilized throughout the superstructure of a 9-story Stadthaus, including walls, core tubes, and floor slabs, to provide vertical and lateral support. Similarly, Forte, a 10-story condominium in Melbourne's Port of Asia Victoria, was the world's first CLT wood structure in 2012 which included a shear wall. In 2014, the 14-story Treet building in Bergen, Norway, was built with a beam-column frame-support construction. [84] reported that CLT panels were utilized for prefabricated room units, walls, hallways, elevator shafts, and balconies in the building. Furthermore, the professionals from other nations of the world expressed interest in using CLT for beams and columns, roofing, exposed structural applications, and exposed ceiling roof structures [69]. Modern mid-rise and high-rise residential and commercial structures are constructed using CLT either alone or in conjunction with other structural materials [85]. CLT panels can be utilized for walls, flooring, roofs, and exposed areas in mass timber building projects [86]. The panels fulfill or surpass construction criteria for bending, stiffness, thermal characteristics, and air tightness in buildings [24]. Furthermore, the adoption of sustainable materials for the construction of residential and commercial structures, such as CLT systems, is an important method of supporting global attempts to create more sustainable construction materials [25]. To this end, sustainable building materials (SBMs) are those whose life cycle, from manufacturing to disposal, has the least negative influence on the environment. They frequently originate from renewable sources and are made to be resource- and energy-efficient. Despite the vast application of CLT as a SBM in key building areas and components, there are barriers that limit its application in nations of the world. SBMs address current needs without limiting future prospects [81]. [87] opine that adoption of SBMs can be challenging due to the construction industry's complexity and fragmentation, as well as the various parties involved. [88] identified many performance parameters that impact SBM selection. This includes occupant requirements and health, recyclability, renewable resources, low maintenance costs, decreased environmental effect through pollution, and reduction of harmful emissions. Thus, when selecting materials, it is important to consider technical abilities for implementing SBM into building processes. [89] reckoned that SBM can reduce the environmental effect of construction, reduce resource depletion, balance ecosystems, and mitigate the impact of climate change and global warming. Nigeria is a developing nation where the market for SBM like CLT is still mostly under-tapped and unsaturated, and there is a discrepancy between the degree of consciousness and adoption of SBMs [89]. Significant barriers to sustainable development in

Sub-Saharan Africa are mostly caused by a lack of knowledge and education, a lack of a standard sustainable building instrument, a lack of government financial incentives, and an overemphasis on capital costs relative to operational costs [90]. Meanwhile, obstacles to the adoption of SBM in Singapore and Australia include inadequate communication by green building teams, a lack of green practitioners, high initial costs, a lack of government support, a lack of interest in and marketplace understanding of sustainable building, uncertainty about the performance and benefits of SBMs, a lack of building codes and regulations, and strained relationships among stakeholders [91]. In the United States construction industry, the barriers to adopting green building technologies according to [92] include resistance to change from conventional technologies, insufficient knowledge and awareness of their benefits, high cost, shortage of skilled labor, and lack of government incentives/supports. In this regard, [93] opined that in the Australian construction sector, the low adoption of SBMs is due to higher costs, potential cost overruns, lack of incentives, lack of government policies, and industry resistance to change. Stakeholders must overcome impediments to include SBMs into future construction projects and make current structures more sustainable. Meanwhile, [94] note that the main challenges to SBMs for sustainable building in Kuwait include lack of knowledge, qualified people, lack of rules, lack of government support/incentives, and unwillingness to adapt. The impediments to adoption of green building in India according to [95] include a lack of knowledge in life-cycle cost, information on advantages, labeling, infrastructure, and small and medium-sized businesses in the construction sector. Meanwhile in Iraq, top challenges to the adoption of SBMs according to [96] include a lack of awareness, coordination, expertise, trusted suppliers, skills, and adequate support for project implementation. Also, fire is frequently regarded as the most significant barrier to CLT adoption [37].

5. Conclusions and Recommendations

The following conclusions are drawn based on the study’s findings:

The study concludes that CLT is not engaged in as many as twenty (20) building areas and components. The implication is that the construction industry is still lagging behind in eco-friendly structures. Moreover, the study concludes that the current level of CLT adoption on construction projects falls well short of the material's potential. This indicates that CLT products are not being utilized as effectively as expected on construction projects in Nigeria. Moreover, the study concludes that, while the relevance of the drivers for CLT adoption varies for a variety of reasons, professionals consider aesthetics to be the most important driver for CLT adoption. This implies that professionals place a high importance on aesthetics for material selection and specification. Multiple obstacles stand in the way of adopting CLT in construction projects. Practitioners perceived that cost is a significant barrier, with CLT sometimes costing more than conventional building materials. The widespread adoption is further hampered by the lack of recognition of CLT and Mass Timber in the country’s national building Code and regulations. Besides, despite advancements in material testing and technology, there are concerns regarding the structural integrity and fire resistance of the product when adopted on building projects. Moreover, another perceived barrier limiting the adoption of CLT in Nigeria is the difficulties builders and engineers encounter due to the requirement for certain expertise and abilities when working with large quantities of wood. Despite its benefits in terms of strength, sustainability, and design flexibility, CLT is not widely used in Nigeria owing to the lack of established standards. Consequently, stakeholders are hesitant owing to concerns over fire resistance, structural integrity, and quality control across the supply chain. Based on the conclusions drawn, the study recommends that practitioners should endeavor to employ CLT in the 20 building areas and components (mezzanine flooring, roof panels, bathroom and vanity tops, institutional building construction, fencing, columns, roof trusses, structural insulated panels, theatre stages, prefabricated construction, auditorium seats, laboratory workbenches, museum construction, exhibition booths, acoustic panels, multi-story building construction, guardrails, bracing elements, pavilions, and warehouse construction) where they are not engaged to fully optimize CLT's eco-friendliness in building projects. This may be accomplished by sensitizing the professionals on the non-engagement of CLT in some building areas and components such as roof panels, multi-story buildings, prefabrication, among other areas and components to fully optimize the materials' potentials. Moreover, the study recommends advocacy and material awareness of EWPs and by extension CLT in order to keep up with the global trend of adopting more sustainable construction practices and materials. This may be accomplished by conducting training and domesticating the necessary technologies to fully harness its potential. Besides, materials specifiers and stakeholders should make intentional efforts when considering and specifying CLT for construction projects. This may be achieved by examining the project's unique needs while providing education on the benefits and features of CLT. Also, establishing appropriate laws and standards is critical for realizing CLT's potential in the Nigerian building industry. Moreover, to promote wider adoption, myths and preconceptions about sustainability and environmental effects must be addressed. Research, instruction, and policy development must work together to overcome these obstacles of low adoption of CLT. A consensus-based product standard is necessary for the designers and regulatory agencies to approve innovative building materials.

6. Limitations and Areas for Future Research

The study is limited to Nigeria. Therefore, there should be comparative study on CLT between Nigeria and other Nations. Additionally, barriers that limit the wider adoption of CLT in the Nigerian construction industry should be investigated.

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Author Contributions

D. R. Simeon: Conceptualization, Methodology, Software, Data curation, Writing- Original draft, Visualization, Investigation, Supervision, Validation, Writing- Reviewing and Editing; O. J. Oladiran: Methodology, Software, Data curation, Writing- Original draft, Visualization, Investigation, Supervision, Validation, Writing- Reviewing and Editing; D. Gabriel: Methodology, Software, Data curation, Writing- Original draft, Visualization, Investigation, Validation, Writing- Reviewing and Editing; O. Otufowora: Data curation, Writing- Original draft, Visualization, Investigation, Writing- Reviewing and Editing.

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Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Ethics Committee Permission

The authors declared that all participants were fully informed consent for inclusion before they participated in the study, and the study meets national and international guidelines.

Conflict of Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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