RAHUMA AHMEDRAHUMACROSS LAMINATED TIMBER AS GREEN BUILDING MATERIAL: NEU ELTAGGAZA STUDY IN NORTH NICOSIA 2019

CROSS LAMINATED TIMBER (CLT) AS GREEN BUILDING MATERIAL: A CASE STUDY IN NORTH NICOSIA

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIEDSCIENCES OF NEAR EAST UNIVERSITY

By

RAHUMA AHMED RAHUMA ELTAGGAZ

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Architecture

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that I have fully cited and referenced all material and results that are not original to this work, as required by these rules and conduct.

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To my brothers and sisters...

ABSTRACT

Green building materials belong to the vast variety of building materials that are environmentally safe throughout their lifecycle and still meeting up with present-day building construction.Mass timber is a green building material and used for sustainability as it reduces greenhouse gas emission over its counterparts in the construction of buildings. In this thesis, the potentiality of Cross Laminated Timber (CLT) building product in relation to its different properties was examined in detail aiming to explain the significance of CLT mass timber as a sustainable green building material and to use it for sustainable building construction in North Cyprus. As a case study an existing building built almost entirely with reinforced concrete was remodified into a mass timber construction. A structural plan was put in place to replace the building materials used with majorly CLT and the 3D model of the building focused on both the interior and exterior aspects of the building. A qualitative approach with a systematic comparative evaluation of the significant impact of CLT as a sustainable building material was carried out by comparison method it with other building materials such as steel and cement. Conclusively, the eco-friendly nature of CLT mass timber as a green building material increase the benefits of the choice of building material over its counterparts. As a result, it has been shown that CLT mass timber has high benefits in terms of environmental sensitivity as green building material compared to other counterparts.

***Keywords*:** Green Building;green material; sustainability; mass timber; cross-laminated timber (CLT); North Nicosia

ÖZET

Yeşil yapı malzemeleri, günümüz mimari tasarımlarıyla buluşmaya devam ederken, yaşam döngüleri boyunca çevresel olarak güvenli olan çok çeşitli yapı malzemeleridir. Masif ahşap yeşil bir yapı malzemesidir ve bina inşaatlarındaki diğer emsallerine göre sera gazı salınımını azalttığından sürdürülebilirlik açısından kullanılmaktadır. Bu tezde, Çapraz Lamine Ahşap (CLT) yapı ürününün farklı özelliklerine ilişkin potansiyeli detaylı olarak incelenmiş, sürdürülebilir bir yeşil yapı malzemesi olarak önemi ve Kuzey Kıbrıs'ta sürdürülebilir yapı üretimi için kullanılması amaçlanarak, detaylı bir biçimde incelenmiştir. Bir örnek incelemesi olarak, neredeyse tamamen betonarme olarak inşa edilmiş mevcut bir bina, masif ahşap bir yapıya dönüştürülmüştür.Büyük ölçüde CLT yapı malzemesi kullanılarak plan yeniden düzenlenmiş ve binanın hem iç hem de dış yönlerine odaklanan 3 boyutlu bir modeli yapılmıştır. Sürdürülebilir bir yapı malzemesi olan CLT'nin önemi ve etkisi, sistematik olarak çelik ve çimento gibi diğer yapı malzemeleriyle karşılaştırılmalı bir biçimde değerlendirilmesi, nitel bir yaklaşım yöntemiyle gerçekleştirilmiştir. Sonuç olarak, CLT masif ahşabın yeşil yapı malzemesi olarak çevreye olan duyarlılığı ve diğer emsallerine göre faydalarının yüksek olduğu ortaya konmuştur.

***Anahtar kelimeler*:**Yeşil Bina; Yeşil Yapı Malzemesi; Sürdürülebilirlik; Masif Ahşap; Çapraz Lamine Ahşap (CLT); Kuzey Kıbrıs

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LIST OF ABBREVIATIONS

BIM:	Building Information Modelling
CLT:	Cross Laminated Timber
CORRIM:	Consortium for Research on Renewable Industrial Materials
CO:	Oxides of Nitrogen
$CO_{2:}$	Carbon Dioxide
EPI:	Emulsion Polymer Isocyanate
FAO:	Food and Agriculture Organization
GBCA:	Green Building Council of Australia
Glulam:	Glue Laminated Timber
Hz:	Hertz
LCA:	Life Cycle Assessment
MIT:	Massachusetts Institute of Technology
MUF:	Melamine Urea Formaldehyde
NLT:	Nail Laminated Timber
PLP:	London-BasedGroup of Architects
PUR:	Polyurethane Adhesive
SCL:	Structural composite lumber
SHGC:	Solar Heat Gain Coefficient
SP:	StatensProvningsanstalt
UK:	United Kingdom
UBC:	University of British Columbia
UNECE:	United Nations Economic Commission for Europe
US:	United State
USA:	United State of America
USGBC:	United States Green Building Council
XLT:	Cross Laminated Timber
X Lam:	Cross Laminated Timber
3D:	Three Dimensions

CHAPTER 1
INTRODUCTION

1.1 Background of the Study

Wood exists more than a building material, it also reflects the cultural background of the people in the case of the tree huggers sometimes hugs wooden material to reflect good luck. Michael Green points out that the nature prints are shown in wood material with the fact that there are no two pieces of wood with the same print. The recycling of wood by its decontamination processes to produce new wood materials thereby improving the sustainability of the wood is of environmental significance. Wood has also shown to be differentiated with different characteristics which makes it unique for different applications. Thus, there are several factors that contribute to wood as a potential building material;

1. Species of the tree
2. Location of the tree
3. Environmental and Climatic condition of the ecological niche of the tree
4. Location within the structure of the tree

Other contributing factors of wood as a sustainable building material involves the following;

✓ Regeneration of wood as a raw material
✓ Environmental impact assessment such as reducing carbon dioxide storage
✓ Life cycle assessment
✓ Lower thermal conductivity

Another significant speciality of wood is the wooden beams in which wood are used as background furniture items for ornamental, decorative functions. They are stacked from the ground used in several levels of the house such as living room, lounge and other befitting areas. mass timber is a broad class of wood products that possess similar properties as steel and concrete, therefore, pose as their alternative. Generally, mass timber family is applicable to all thick panel products, block-laminated products, or large section of linear elements glued together. Mass timber due to their intrinsic “green” eco-friendly

property, economic and technical manipulative capabilities, has gained high interest amongst engineers, architects, environmentalist and others.

Cross Laminated Timber (CLT) was developed by a timber producing company in Austrian in the early 90's. Due to the lack of technical knowledge in the field, it took many years for the product to enter into the building construction market. However, it was still relatively unknown how to particularly apply Cross Laminated Timber to the residential constructions and the standard structural resistance still had to be studied in detail. Even though it had to take intensive studies on the performance of CLT and a new focus on the sustainability of erected buildings, CLT still gained popularity in Europe.

After the time has passed on since its introduction in the 90s, CLT has been the subject of intensive research, this, in essence, has led to the development of new product standards and design guidelines. Cross Laminated Timber (CLT) has significantly gained prospects over the years in the rest of the world due to its high durability, strength, versatility and sustainability. The significant impact of CLT over another choice of building materials is incorporated in its strength, affordability of materials and most especially its renewable source of alternative energy which has contributed to its usage in the construction of several parts of a building.

Research survey carried by UNECE/FAO Forest Products Annual Market Review in 2015 reported a 90% CLT production worldwide in locations around Europe, with the production of 560,000 m^3 volume in 2014 alone. 650,000–700,000 m^3 productions was estimated in the year 2015. Since then, several Production plants have recently opened or are planned in Canada, the US, New Zealand, Japan, China and other parts of Europe for the production of CLT. To the good of these rising industries, several buildings have been erected using the CLT technology, for many ranges of buildings. In the United Kingdom, over a hundred buildings have been constructed within 2003 and 2011. The attention of the media has caught up with structures that are over 50 high-rising and tall buildings between the range of 5 to14 storeys in height which has been completed. Several building constructions with CLT material is under construction including an 18-storey student residence in Canada with taller buildings planned. The advantages of CLT of mass timber is examined in this thesis, CLT was also compared to other building materials such as

concrete and steel thereby reporting their environmental life cycle impact as a sustainable building material. Furthermore, the thesis focuses on future directions towards the construction of building construction most directly for Cyprus, including the various challenges that may be encountered. CLT mass timber forms normally the wall element of building and the structural floor, this approach has been used successfully to build up to nine storeys building in the United Kingdom. The cross-grain movement of a systematic engineered CLT mass timber is usually controlled by its cross-lamination, to ensure a stabilized dimension. The formation of CLT which can also be called; X-lam because of the very fact that it issynonymous to that of 'glulam' where glue-laminated timber beams which are used by combining small sections of timber bonded together with permanent adhesives under high pressure to allow the removal of unnecessary knot to perfect the timber and ensure high timber performance such as strength and stiffness of the mass timber. Glulam can be easily differentiated from CLT with the simple fact that the formation of CLT occurs in a panel from where that of glulam occurs in beams. Meaning, the layer of mass timber is bonded perpendicular to the other which in turn gives a stronger dimension thereby improving the structural integrity of the stability of the mass timber dimension.

1.2 Problem Statement

A building requires assembling different materials through its construction. Some of these materials include concrete, timber (wood), steel and glass and so on which have been found not to be environmentally friendly. However, the world is evolving into the green age era, where the life cycle of all materials is ensured to be a friend to nature.

Cyprus is a small populated country with building construction mainly on concrete which estimated the cost of production has been reported to be very high causing an unaffordable rent for the residents. The common materials of construction in Cyprus such as cement, concrete and steel are not eco-friendly as a result of their high energy consumption in their production. Also, building materials such as steel, and cement do emit pollutants thereby contributing pollution to the environment. For this reason, the alternative movement to a more eco-friendly green CLT mass timber is preferred for the building construction therein. Mass timber has significantly proven strong, tough, and resistant to fire in contrary

to what most people think. Thus, the thesis explains the green significance of mass timber over other types of building materials for the construction of building in Cyprus.

1.3 Aims and Objectives of the Study

This thesis aims at assessing the potentials of timber as a green building material for the construction of Cyprus buildings with a view to determining its comparative sustainability against other commonly used building materials such as concrete and steel. In addition to the thorough evaluation of mass timber as a suitable, sustainable, green, building material for the construction of tall buildings, the most common disbelieve of fire hazards towards mass timber was eradicated with research proves and cited references. The study objectives are to;

1. Give a detailed description of the qualities of CLT mass timber as an environmentally friendly construction material for building in Cyprus.
2. Examine the current challenges of CLT mass timber as a building material for the construction of three storey building in Cyprus.
3. Investigate the green sustainability of CLT mass timber for building construction in general terms.
4. Compare both quantitively and qualitatively using a three-dimensional structure; the benefits of CLT over steel and concrete as a sustainable building material for Cyprus buildings.

1.4 Thesis Methodology

A qualitative method is used in this thesis which covers a wide range of study compilation ranging from research reports, journals, review articles, technical reports, conference papers and other architectural-relating papers. The systematic evaluation of the significant impact of CLT as a sustainable building material was carried out by comparing CLT with other building materials such as steel and cement. Furthermore, the significant characteristics of sustainable building materials such as cost-effectiveness, environmental impact, life cycle impact were evaluated and compared in the thesis.

1.5 Importance of the Study

The significance of this thesis is to directly promote the use of CLT as a sustainable building material. The introduction of the affordable methods of building construction would improve building efficiency, costs and energy production in Cyprus. For ecological reasons, the use of green mass timber using CLT as a major example is highly sustainable as a building material. Its strength, toughness, and anti-fire properties ability has been discussed to promotes its usage over other unsustainable building materials.

1.6 Limitations of the Thesis

When Cross Laminated Timber (CLT) is used in the construction of buildings, different components of the building require that planks be merged at varying level of thickness. However, with the incorporation of other building materials like concrete and steel for adequate support, spans tend to be created and increases with the level of inclusion. This has somehow mandated the use of reinforced concrete or steel support when erecting tall buildings. Although, new ideas are coming up that will ensure that such structures are put in place with reduced use of unsustainable materials.

Furthermore, Cyprus being a small populated island reduces the import of CLT mass timber into the country for large construction purposes thereby hindering price estimation data of CLT mass timber in the country.

1.7 Scope of the Study

The entire study entails the replacement of the substantial proportion of a building with Cross Laminated Timber (CLT). An aspect also covers a brief discussion on existing CLT structures around the world and also the superiority of mass timber products over concrete and steel. information was gathered accordingly on the use of unsustainable building materials and how to ensure a seemliness transition from the conventional practice to the use of green materials.

1.8 Overview of the Thesis

The first chapter provides an insight on the general structure of work, the essence, scope and possible limitations to the successful execution of the project.

The second chapter considers the ongoing issues that persist in the building construction industry. Green building materials were examined as it dates back to its usage in ancient times. The various materials that make up this concept were also looked at as well as a comparison between the non-green materials (concrete and steel) and CLT.

The third chapter discussed extensively on Cross Laminated Timber (CLT) as a sustainable building material. The properties of wood products were discussed and also the advantages and disadvantages of erecting structures with mass timber products. Information was also provided on the production stages and prefabrication that are involved in the making of Cross Laminated Timber (CLT) ready for use and also the connections systems to be employed in fitting the different components.

Chapter four considers selected mass timber structures as prominent examples.

Chapter five gave geographic informationabout Cyprus. The case study was also analysed through to the materials that are used in its construction. Propositions were also made as to the possible replacement of major materials that are used in the erection of a building i.e. Cross Laminated Timber (CLT) in place of concrete and steel in the exterior and interior walls and decoration of the building.

In Chapter six, summary, conclusion, recommendations were presented.

In figure 1.1 thesis structure can be seen.

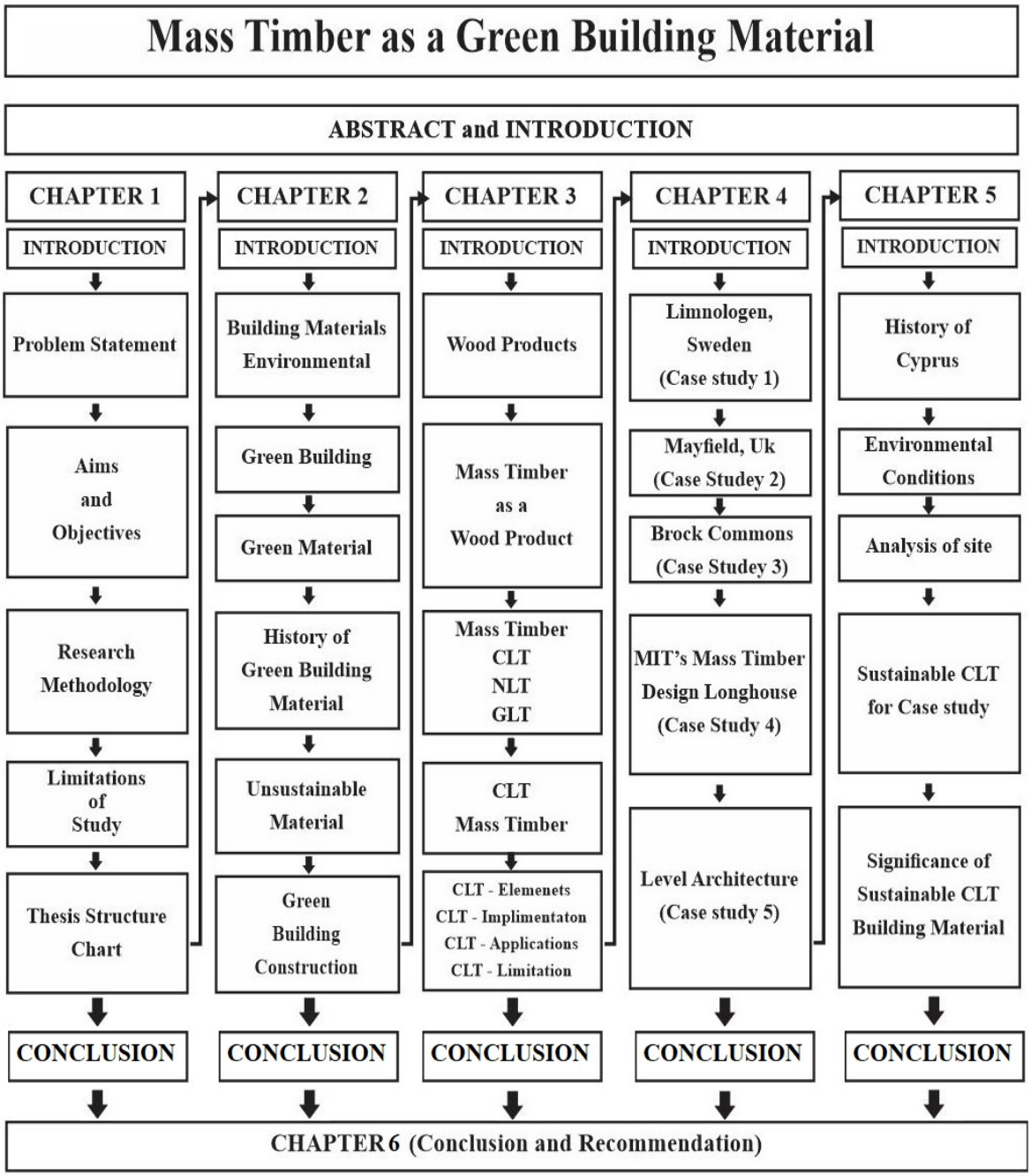

Figure 1.1: Thesis structure

CHAPTER 2
ENVIRONMENTAL ISSUES OF BUILDING CONSTRUCTION AND BUILDING MATERIALS

2.1 Introduction

The chapter focuses on the presentation of challenges of the usage of unsustainable (non-green) building materials that carefully consider the impact of green building as it involves the use and combination of natural resources in achieving a sustainable environment. Sustainable green building materials are famous for their eco-friendly nature reducing the use of toxic materials while also eliminating pollution. The further section of the chapter gives a broader description of green building construction briefing how green construction has evolved over the years and characteristic properties of sustainable wood material. Lastly, the chapter explains the life cycle of building materials with a focused comparison of unsustainable building materials such as iron and cement against cross laminated wood timber (CLT) as a sustainable building material.

2.2 Environmental Issues of Building Construction

The major issues of unsustainable construction are affected using energy and the waste of its construction, global warming due to contamination of the production of materials, including unsustainable building materials, which contributes to serious climate change. it is important to choose constructions and installations which produce low environmental impact with the use of unsustainable building material for building construction consists of several environmental impacts contributing to a large percentage of energy consumption, cost implications of industrial sector which are further explained as thus;

- ***Energy usage***

Generally, buildings account for about 41% of the world's energy consumption. The energy efficiency of timber is improved if the processing required is reduced. Also, buildings on their own consume a lot of energy through electricity, thus backing up the claim by United States Green Building Council (USGBC) and relegating the industrial

sector (30%) together with the transportation sector (29%) to the least behind that of building construction (Akadiri, 2012).

- ***Impact on the air***

All over the world, a leading topic to interest and discussion is the issue of global warming. This is aided to a large extent by the level of greenhouse gases that are emitted. The level of industrialization which is taking over the world tends to leave the environment with some extent of gas emission. Building construction is implicated in that it produces greenhouse gas emissions that have been leading climate issues. As a matter of fact, 38% of CO2 emissions are produced by building (Schimschar, 2011).

- ***Water usage***

A large chunk of water use is attributed to buildings but a large percentage of wasted water as well. Water used from various sources are wasted in some senses and while industries consume water to a large extent, building construction is also responsible for the wastage of a large percentage as well as it is estimated that buildings use 13.6% of all potable water, which amounts to about 15 trillion gallons of water a year, However, the planning for various water uses within a building is increasingly becoming a high priority, in part because of the increasing recognition of the water savings that can be realized through the implementation of water-saving initiatives (Akadiri, 2012).

- ***Construction materials***

In the process of producing building materials, factories generate a lot of emissions into the environment. This is due largely to the fact that bigmachineryis used in the process of making these materials available. Also, most of these materials are usually required to be moved from their area of production to where they are needed. This further implicates the transportation section as a generator of a large chunk of greenhouse gases (Akadiri, 2012).

2.3 Green Building

Green building entails the structural model, together with the on-going, occurrences and application of an entire building which relates it to the resources and components of an environment through its existence.Figure 2.1 shows the typical layout of a green building. This ranges from planning to design, construction, operation, maintenance, renovation, demolition, recovering and recycling.

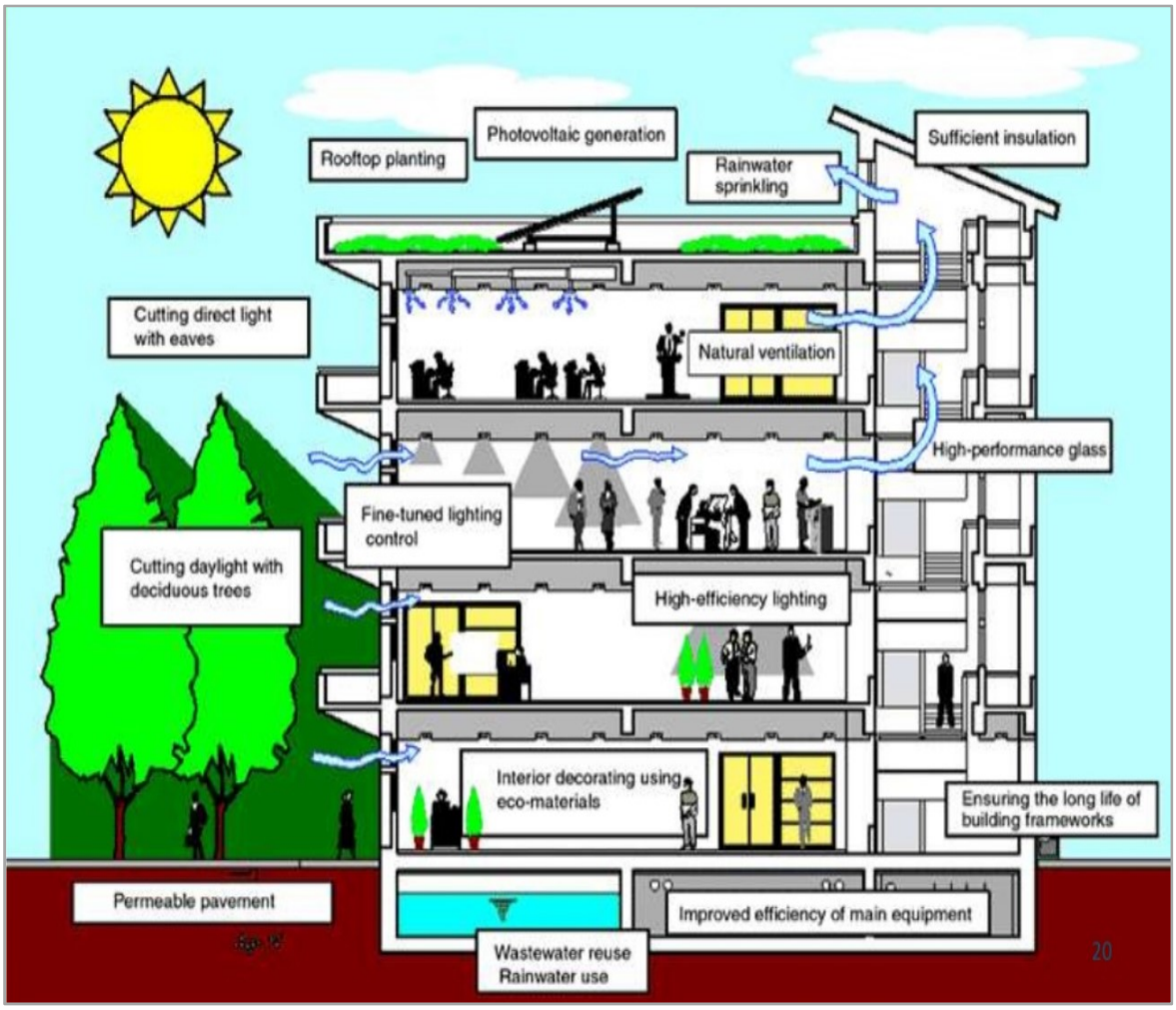

Figure 2.1: Typical layout of green building (Green, 2013)

The various features which are installed in a green building are interrelated in one way or another just as detailed in the layout above. Part of the rooftop is fitted with planting materials like pots which allows for little cultivation of small crops and vegetables. They are watered artificially when there is no rainfall and not when there is. Raindrops falling on

the building are collected through a channel that runs into a storage facility. The water is stored and made ready for domestic use like flushing and watering of trees around the building. Deciduous trees are planted around a green building. They trap sunlight and reduce that which is felt in the house through the shade that is provided by its evergreen leaves. Eaves are constructed above the windows of a green structure. What they do is prevent direct sunlight from gaining access to the building. Even though daylight is experienced indoor, hotness is greatly reduced (Flint, 2012).

Another part of the rooftop may also be installed with solar generating panels. These provide adequate lighting in the building. The level of power generated is also carefully utilized as the panels run with smart lightingcontrols that detect the presence of people in a room and only comes on then. This also creates a kind of highly efficient lighting condition as during the daylight, the light goes off and power is conserved for the night time.

The type of windows used in a green building sort of gallows to be closed during rainfall and can also be open to allow natural ventilation access into the building. This means the air therein is recycled and always kept refreshed. Also, the pavement is made of permeable materials which dampness of the building at all time especially when rain falls on it.

Green building could be successfully established when its principles are carefully incorporated to properly manage, energy, water and air. Some essential components of green building are given below;

- ***Efficient solar power generation***

When the sun ray falls on a building, it is either absorbed or reflected. The portion which is trapped is felt in the building as heat. Sun rays that falls into a building are felt as heat within. When solar radiation enters through glass and is released as heat inside a building, this particular phenomenon is called Solar Heat Gain Coefficient (SHGC). The logic goes thus, reduced SHGC leads to reduced heat felt within a building. The lower the SHGC, making the building cooler. Electricity cost is thereby reduced as the cooling systems relieved of its duty to an extent (Yudelson, 2016).

- ***Harnessing of exhaust air***

In buildings that are found around today, the air conditioning system is usually fitted in buildings to provide fresh air, especially during the hot season. This system, however, is operated solely on electricity. In fact, it raises the cost of running a building even when the generating set is employed as much fuel is consumed. In the green building setting, an enthalpy wheel system is employed which traps consumed air and recycle for fresh air allowing the dehumidification of outside air. There is proper cost management in the generation of good quality ventilation, ensured to properly designed walls also contribute to regulating the level of moisture in the air (Brandner, 2013).

- ***Daylight-controlled lighting systems***

Smart working lighting systems are used to generate light in the building. The lighting system is well able to detect when the daylight comes on and its sensors switch off and on accordingly (Brandner, 2013).

Energy consumption is greatly reduced this way. People within a structure are however forgiven if they neglect the act of switching off and on the light within the daylight (Yudelson, 2016).

- ***Spot-on people detectors***

This lighting system requires no switch to put it on or off as the presence of individual triggers it on. This same technology is that which is found in some electric sliding doors escalators that activate only when people enter into them (Yudelson, 2016).

- ***Water management***

Unlike the conventional modal of flush system, a new mechanism is employed which traps rainwater in a nearby structure and effectively uses less water. Aside from flushing the toilet, the trapped water is also used in watering plants and supplying cooling towers (Akadiri, 2012).

- ***Waste sorting system***

A Waste Sorting System is employed that allows the refuse generated from. A building to the segregated into different forms for easy disposal.

Different waste disposal cans are provided for wastes to be sorted (Akadiri, 2012).

- ***Plants and trees***

This is an important component of the green building. Space is provided around the structure for greens. This plays a big role in controlling climate change. Runoff is curbed in that vegetation cover make use of excess raindrops (Ashuri&Durmus-pedini, 2010).

- ***Site sustainability***

The architects and engineers handling the construction of a green building are encouraged to work hand in hand in putting in place structures with reduced environmental effect on components of the environment (Akadiri, 2012).

Construction of a green building needs the key stakeholders to work hand in hand through the execution and implementation phases of a project. This includes right from the Owner, the Urban and Building planner, Architects, designers down to the site developers. Sustainable design must develop a respect for the landscape and expend more effort understanding the interrelationships of soils, water, plant communities and associations, and habitats, as well as the impacts of human uses on them (Akadiri, 2012).

Even with the introduction of smarter ways of operation within the different parts of a building to serve as an improvement on the systems that are already in use, the main goal of erecting a green building which is to create a much more enabling and habitable environment through;

- ✓ Proper management of natural resources
- ✓ Ensuring good health condition for inhabitants
- ✓ Limiting ecosystem destruction

2.3.1 History of green building

This can be traced back to the olden days. The early man employed the use of eco-friendly resources in putting together their structures. While some non-sustainable materials are used as roofing materials in the present day, there is a particular concept which is used by man if the past. the tend to leave in caves. This way, natural dirt provides roofing over the structure and goes well with the local environmental settings.

The implementation of green building can be described as an act that ensures that construction of structures together with surrounding components are effectively managed. Green building also centres on the activities that are involved in the establishment of a structure or during the period of its existence on human and the ecosystem at large (Quarry Oaks, 2015)The green building shift has gained a large interest over the years, experiencing a real surge in its acceptance and popularity in the 90's. David Gissen, an architecture and designer, explains that the London's Crystal Palace (Figure 2.2), Milan's Galleria Vittorio Emanuele II (Figure 2.3) and the National Building Museum (Figure 2.4) structures were used to decrease the environmental impact.

Figure 2.2: London's Crystal Palace built in 1851 (www.britanicca.com)

Figure 2.3: Milan's Galleria Vittorio Emanuele II built in 1867(www.musement.com)

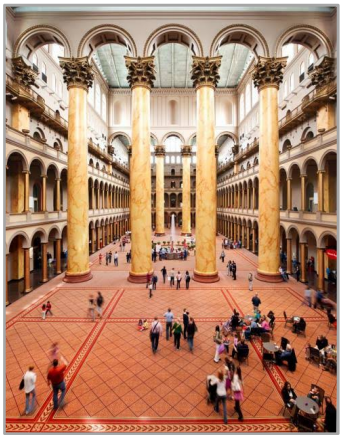

Figure 2.4: National Buildingmuseum built in 1887(www.wshingtn.org)

The construction of the Carson Piece Scott department store in Chicago (Figure 2.5), Flatiron building (Figure 2.6), and the New York Times building (Figure 2.7), implements roofing systems like ventilators and underground air-cooling vent which were usedfor the regulation of temperature during the early twentieth century.

Figure 2.5: Carson Pirie Scott department store built in 1899(www.britannica.com**)**

Figure 2.6: Flatiron Building built in1902 (www.skyscrapercnter.com)

Figure 2.7: New York Times Building built in 2007 (www.mycentrersey.com)

Policies can be put in place by the government of a nation to help in the receptiveness of people towards green building and aid its acceptance. They could stimulate the interest of people about going green with friendly rules and regulations. an example is that of the US that provides a support scheme for people who pick interest in the act.

The 3D architectural design of a green building built mostly with the cross-laminated timber (CLT) is shown in (Figure 2.8) which is described as an eco-friendly building by Michael Green Architects. It is known as the T3 Minneapolis having the derivative name from *timber (CLT*), transit and technology. It was completed in September 2016 with majorlycross-laminated timber wood structural system. The constructing team reported that the firmness of the wood timber allows a faster construction over steel or concrete of similar sized. The building project was completed in less than 10 weeks.

Figure 2.8: T3 Minneapolis (Green, 2016)

2.3.2 Green building construction

Green construction is a detailed idea that stresses the fact that general act of putting a structure in place does have a telling impact on the occupants of a building and the ecosystem entirely USGBC (UnitedState Green Building Council). The definition explains that the practice entails the use of eco-friendly resources in putting together a building with a minimal negative impact on society.

The construction of the building was perfected arguably by the Romans, with the fact that most of their structures still stand today. While their structures stood still over a long period of time, the main materials used are concrete, concrete still remains the strongest materials created by man, and was ultimately lost during the fall of Roman Empire. After the fall of the Roman Empire, concrete became scarce and largely abandoned. However, today's architects and civil engineers are reviving modern building practices to re-incorporate mass timber as a primary structure in construction material. New innovative technologies are currently being studied in an attempt to replace steel reinforced concrete structures with green mass timber housing. Research Universities like MIT and the University of Maryland among others are currently investigating new techniques to reinforced green wood timber in

building construction.Although steel has gained significant interest in its use for the construction of high rise building as it contributes to the increase the lifespan of the building. Most people do not plan on living in a small house for a very long period of time by planning to upgrade to bigger floor space. The recent demand for big and spacious houses is increasing, thereby smaller houses are being demolished for the reconstruction bigger and spacious buildings (Rethink Wood, 2016).Figure 2.9shows seven storey build on a concrete floor tested at the E-Défense Laboratory in Miki in which R-factors for resistance against earthquakes in CLT building are shown.

Figure 2.9: A 7-Story mass timber CLT house construction tested at the E-defence laboratory (FPInnovations, 2015)

Timber constructions have also proven aesthetically significantly pleasing and when harvested appropriately, it is also considered to be a renewable resource because of its carbon storage. With the population of the world increasing at an astronomical rate, and

also the influx of the majority of rural dwellers into the void making it difficult to meet up to the increasing level of demand for energy these days (Frangi, 2008). The entire processes that revolve around a building are implicated on the use of 40 percent of entire worlds energy (Gerard, 2013).While there are many reasons for the substantial amount of energy used to build and maintain buildings, one of the major environmental concerns arises from the fabrication of cement, one of the basic ingredients in concrete (Robertson et al., 2012). It is a utilitarian material used in the fabrication of bridges, skyscrapers, and residential foundation, among many other uses. But the cement industry is one of the worst contributors to pollution. The rising importance of embodied energy, when considering high-performance building designs was echoed in a literature review that analysed 60 building cases throughout nine countries and considered the relationship between operating energy and embodied energy, (Sartori & Hestnes2009). Its production is responsible for 5% CO_2 released into the atmosphere worldwide (Dolan, 2014).

2.4 Building Materials

The survival of human requires the construction of building materials which are the material foundation that all architects use in construction engineering. The building materials discussed involves the sum up materials used in all facets of the building construction. This involves a wide variety of building materials which can be categorized based on application and description. The classifications based on the chemical components and functions of the material is the most common means of classification;

- ✓ In Accordance with the chemical components of building materials, they can be classified as either inorganic materials, organic materials and/or composite materials.
- ✓ They can also be classified according to the function of the building material which involves structural materials and functional materials. Structural materials, mainly used as load-bearing members such as the materials used for beams, plates and columns. Functional materials mainly possess some special functions in construction, such as waterproof, ornamental and heat-insulating functions.
- ✓ A sort of balance should be created between energy usage and environmental conditions, this along with prices, product efficiency and use.

- ✓ All stakeholders and interested parties should be well informed and carried along in any procedure involved in providing a sustainable product.

The structural materials of choice should however not only tilt toward the satisfaction of the aesthetic desire why the structure is put in place but also be mindful of the short- and long-term implications as they affect humanity and sustainability.

When carefully examined and put into consideration the environmental issues in construction and the impact on the life cycle, a product can be responsible for up to 90% of a building's effect on its surroundings. The different product's usefulness should be well examined and weighed to the varying elements that determine the effect of the product on the environment. Another system of carrying out environmental system assessment is estimating energy use at different stages of building erection (Berge, 2009).

2.4.1 Life cycle of building materials

Usually, the cradle-to-grave analysis of life cycle is a qualitative analysis. Literature background shows that there is a significant implication of other life cycle both at the "on-site" and at the product's end of life stage. This assessment is summarized in Table 2.1 (Robertson,et al., 2012).

Table 2.1: The qualitative analysis vs the quantitative analysis of stages of life cycle (Robertson, et al., 2012).

Quantitative (well definedwith numbers)	**Qualitative (defined based onliterature reviews)**
1. Extractions of raw materials	On-site building construction
2. Processing and manufacturing	Transportation
3.Effects of Transportation (cradle to grave life cycle)	End of life (reuse, recycling,energy recovery

The environmental impacts of the building materials are also assessed during the life cycle, Figure 2.10 shows building material's life cycle schemes of different production stages.

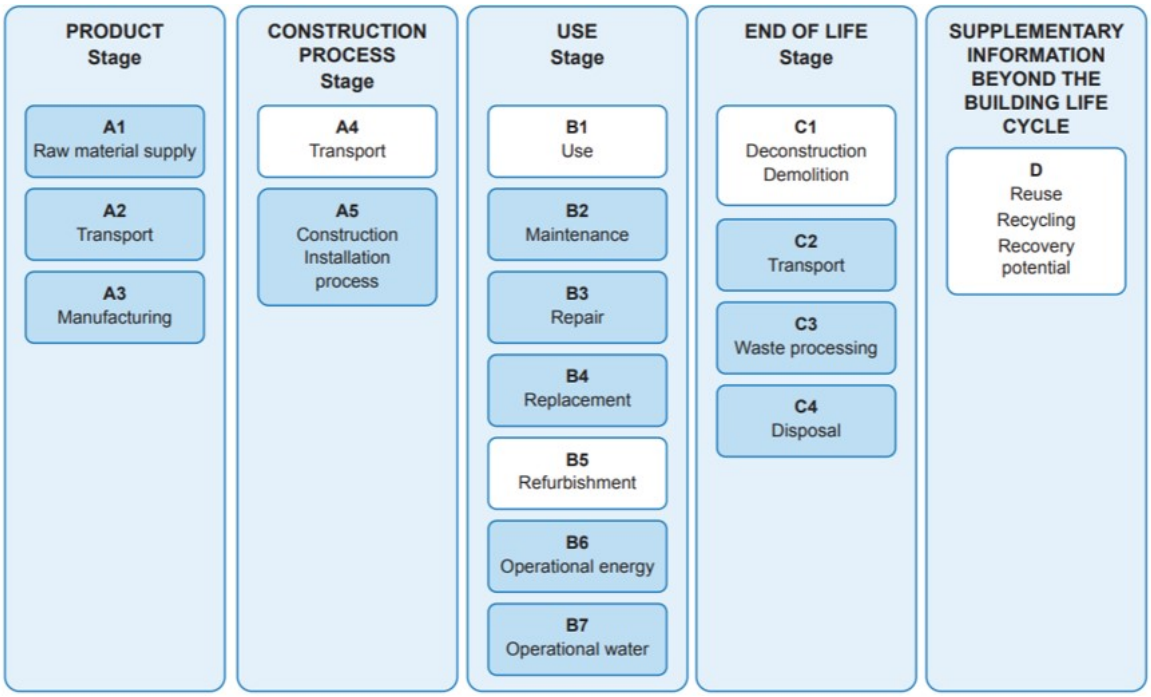

Figure 2.10: Building material's life cycle schemes of different production stages (Robertson, et al, 2012)

To strengthen this, the comparison (Figure 2.11) within concrete steel and other building material give an overview ofthe broader perspective of the advantages of using sustainable CLT materials over concrete and steel. The fabrication system can exist as reinforced concrete or may exist as a combination of two or more building materials such as concrete with CLT. Environmental impact of the material is also accessed. The result shows mass timber having a low negative impact on the environment over concrete and steel. Through the analysis of 11 impact categories, cross-laminated timber shows the highest sustainable rate of 71% on pollution effect and effect of global warming surpassing its counterparts (Gerard, 2013).

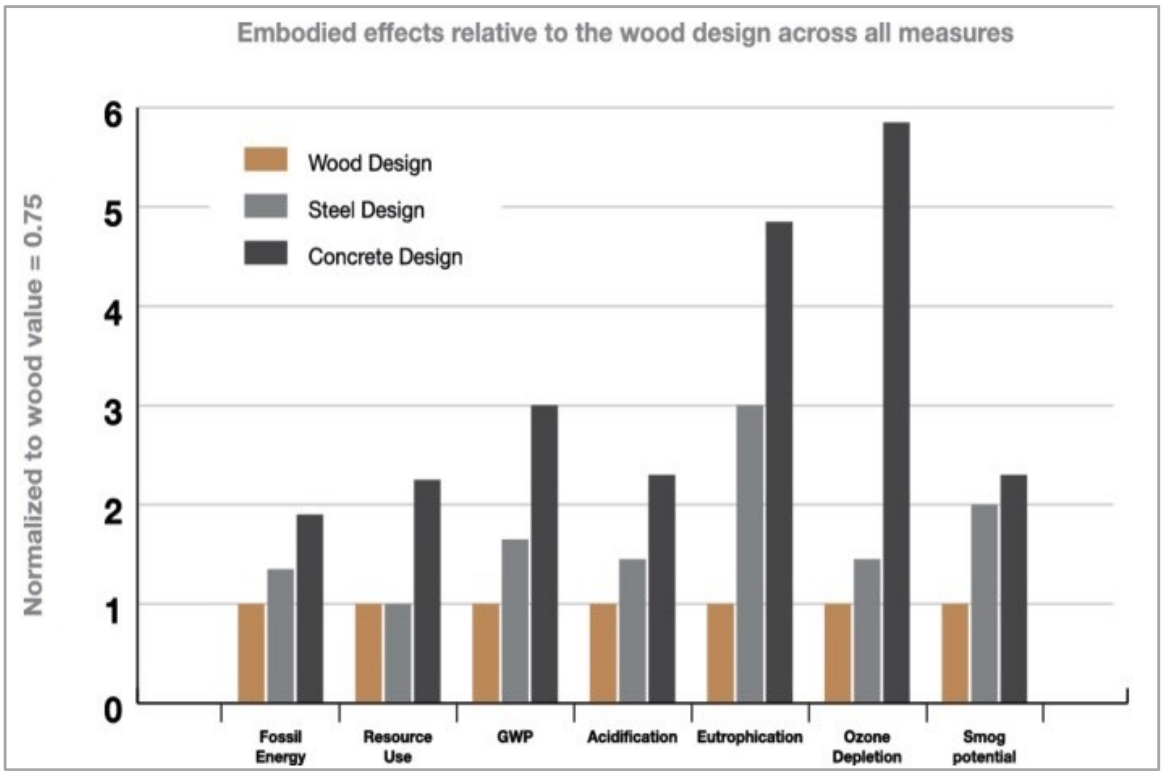

Figure 2.10: Comparison of the environmental impact of concrete, steel and wood mass timber (Robertson,et al, 2012)

2.4.2 Green building materials

The suitable qualities of mass timber over its counterparts cannot be overemphasized. Its toughness, rigidity, flexibility, strength, and most prominently, it's astonishing fireproof ability makes it a better candidate for tall building material among its peers. Green-wise, mass timber is known to store carbon, saves energy for its production and also reduces pollution in its usage. These qualities ensure a sustainable ecosystem making mass timber a preferred candidate for tall building construction (Brandon, 2015).

Within the level of the earth's endowment, it is imperative on man to keep finding ways to improve its existence. and more so the reason why the concept of sustainable development is gaining ground floor, popularized by (Our Common Future), a world program that preaches the theme. The concept of Sustainable Development means the ability of the present generation to harness the earth's resources in meeting our need and solving our

problems without compromising that of the future generation(Gray, 2010) or in the words of another report, Sustainable Development is the meeting of our present need without compromising the ability of the future generation to meet theirs.

This implies that sustainable building material is the one that does not have much negative impact on the environment, for example, CLT, has a 22% lower global warming potential than an equivalent building constructed using reinforced concrete as the main structural material. In addition to the sustainability benefits, one of the primary benefits of CLT construction is the use of offsite prefabrication allowing for high-quality certified production, independent of the weather. It also means the utilization of resources available to the present generation without depriving the future generation of resources for their effective living.

According to Okereke (2006), a sustainable material should possess the following characteristics;

1. Easily available and affordable, preferably locally.
2. Meets with the requirements as specified in National Standards; in terms of durability and maintainability; should be environmentally friendly and should not constitute any health hazard.
3. Should be versatile in usage, that is, it could be used for different purposes (as walling materials, flooring, etc.).

As lifestyle changes the architectural design requirement changes also, there is a new trend in the demand for bigger buildings and the new concept of the architectural plan. There has been the demolishing of old buildings for the reborn of new green ones, thereby affecting the average lifespan of a building in decreasing amount. An alternative approach is to use balloon construction methods in which the walls are continuous from floor to floor and the floors are supported by steel brackets connected to the walls. But the many of the buildings which are cleared away are destroyed long before their useful life expires. Demolishing concrete structures however results in several problems of its own, such as its tendency to leach into and poison topsoil and water bodies and another type of pollution and environmental hazards (Harte, 2017).

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Green building materials are of wide range and available from place to place. However, they all possess some or mostly the same properties, which are listed below;

- Recyclable
- Biodegradable
- Good ventilation
- Strong with minimal maintenance
- Reuse of used materials
- Uses eco-friendly materials
- Locally made
- Processes involved in getting them ready should also be eco-friendly

2.5 Comparison Between Steel, Concrete and CLT

For the green building construction, mass timber is processed from wood material which is very light and at the same time strong, and it possesses insulation property without requiring additional resources. Concrete, however, is a poor insulator and requires additional material to keep it better insulated, unlike wood. Concrete is typical, unsustainable, expensive, but for large buildings, steel and concrete have been the preferred materials for building construction. With Young's modulus of elasticity around 12,000Nmm^2, CLT is about three times as flexible as reinforced concrete. In recent times,

however, new technologies are very improving the durability of timber, making it more environmentally and economically viable than its concrete counterpart (Brandon, 2015).

The suitable qualities of mass timber over its counterparts cannot be overemphasized with its enhanced mechanical testing regimes and greater sample sizes related to the material performance characteristics of both the horizontal and vertical CLT elements, making an accurate structural design property. The choice of building materials may markedly influence building fire safety. The mechanical and thermal properties of building materials change at elevated temperatures. This change of material properties has an important influence on the structural behaviour, toughness, rigidity, flexibility, strength, and most prominently, it's astonishing fireproof ability makes it a better candidate for tall building material among its peers. Green-wise, mass timber is known to store carbon, saves energy for its production and also reduces pollution in its usage. These qualities ensure a sustainable ecosystem making mass timber a preferred candidate for tall building construction (Brandner, 2015).

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According to a study led by (Consortium for Research on Renewable Industrial Materials) (CORRIM) the lifecycle of concrete and steel results in 26% to 31% more greenhouse gas emissions than that of mass timber. The alarming change in weather, the ozone layer depletion becoming more vital than ever, thereby all attempt is to reduce greenhouse gasses. With the movement and introduction of carbon taxes and other similar pollution tax, switching green may also be other saving incentives for the construction companies to make the transition.

2.6 Conclusion

As every individual and government are be enlightened, and the level of their understanding keep rising about the various negative impact that is posed on the environment by the use of unsustainable construction materials such as steel and concrete, while in the same vain realizing the friendly environment impact that green building construction can produce with considerate cost and energy effectiveness, it is statistically expected that the level acceptability of sustainable building materials will increase at an exponential rate most importantly considering the damage that earth has already been exposed to due to pollution. Buildings can achieve the same level of performance as steel and concrete as the technology develops to a standardized approach of structural design to support the wider use of CLT construction. For these reasons, erecting structures with wood either in collaboration with other sustainable building materials would in no doubt improve the longevity of the building structure. Where the next chapter will examine the cross-laminated timber (CLT), which is one of the best building materials and construction, which have many advantages.

CHAPTER 3
CROSS LAMINATED TIMBER (CLT) AS A SUSTAINABLE BUILDING MATERIAL

3.1 Introduction

This chapter focuses onand studies wood, which is one of the most important sustainable green building materials.

After that, it was studied in terms of its characteristics and classification. Of which CLT was chosen after proving its strength, efficiency and many advantages. The classification, production and distribution were explained and the CLT applications were explained and implemented.

3.2 Wood products and its properties

The steady increase in the use of strong grained timber has impacted several areas on construction. Its strength, thermal properties, moisture properties, fire properties and acoustic properties have significantly increased its choice of selection as a sustainable building material. Figure 3.1 shows the wood products (Oldfield, 2015).

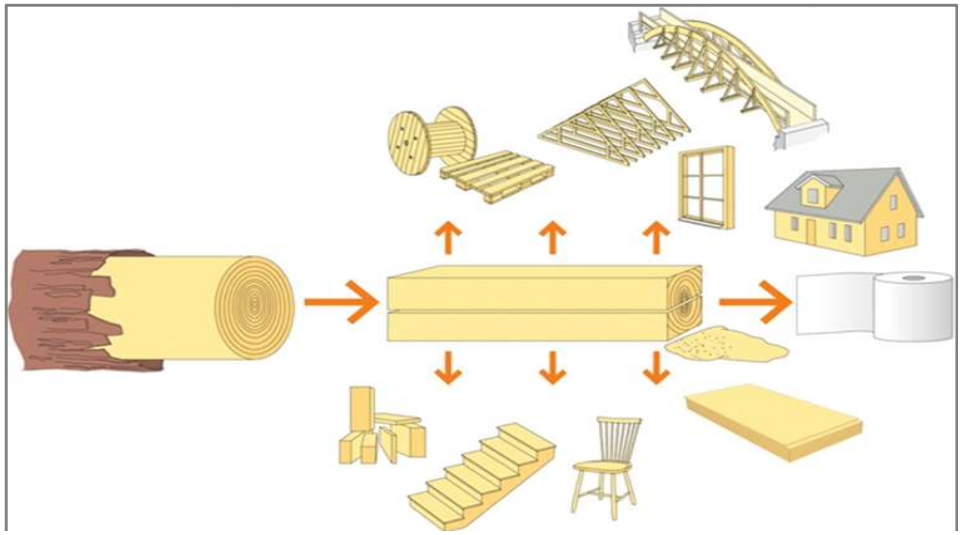


Figure 3.1: Wood products (https://www.swedishwood.com/aboutwood/sustainable constructionmaterial/accessed December 2018)

3.2.1 Strength properties of wood products

The strength of wood is in direct proportionality to its density i.e. as the strength of wood increase a steady increase in density is observed. To evaluate the density of wood, the amount of water content (moisture) in the ratio of mass to volume can be estimated. The density of wood can also emerge as a dry density in which the wood's mass is estimated in its dry proportion and the volume saturation point is at a higher level (Newman, 2009).

The durability of the wood is not a dependent factor of density as the spruce and birch of the wood increases slightly into the core to the surface of the wood. While the density and strength of the wood decrease from the base top. Another significant factor that affects the strength of the wood is the direction of the grain. The bending strength is usually in proportion to the density of any given wood.

The tensile strength having the direction of the grain is about 15 times greater than that that is perpendicular to the grain. Furthermore, the shearing strength of wood is about 15% of the wood's total strength which is in the given direction of the grain shearing strength.
The elasticity and durability of the wood, however, allow a steady increase as the density of the wood increases steadily. The elasticity and durability of wood also increase with a steady increase in the density.

3.2.2 Thermal properties of wood products

Due to the porosity of timber, the thermal conductivity of wood is low. This property decreases as the density of the wood decreases. For this reason, an increase in the moisture content of the wood increases the thermal conductivity of the wood.Although as the temperature of the wood decreases, the strength of the wood usually decreases. Therefore, the heat storing ability of the wood depends greatly on the density of the wood, the moisture content and the direction of the grain (Hill, 2007).

3.2.3 Moisture properties of wood products

The hygroscopic property of water allows it to absorb water through the cell lumens as molecular diffusion in-between the cell walls. There is a direct relationship between the mass of water and the mass of the timber without the water.

3.3 Mass Timber

Elaborating on the different types of wood products with their intrinsic properties allows for the selection of crooks laminated timber (CLT) as innovative solid wood panels for larger scale design options. Several texts have defined mass timber. CLT is lightweight, tough and durable selection such as the solid engineered wood panel. However, the most common definition of mass timber encompasses its property as a solid wood panels which are strongly glued together perpendicularly under pressure to ensure compressive strength and stiffness.

Another contributing factor for the selection of CLT it's the low environmental impact of CLT as a sustainable building material (Espinoza, 2017).

3.3.1 Classification of mass timber

Mass Timber is classified into several forms, but the three major ones are;

1. Cross Laminated Timber (X-lam)
2. Glue Laminated Timber (Glulam)
3. Nail Laminated Timber (NLT)

3.3.1.1 Cross-laminated timber CLT (X-lam)

The most common of all classes is Cross Laminated Timber (CLT) which has gained higher attention over its counterparts because of its controllable tailored mode of property. CLT has layers of wood known as solid lamellas set at 90-degree angles to each other. The strength of CLT is achieved by intertwisting each layer to achieve a more rigid solid structure. Currently, CLT is the mass timber commonly used. It is an engineered sandwich-like layer of wood products, engineered from a minimum of three layers which are usually cemented together under high pressure using adhesive glue. The strength of CLT is associated with its large thickness and stiffness of layers alternating together. The design of CLT panels showed in (Figure 3.2) allows it for a wide range of applications such as roofs, walls, floors and other load-bearing components (Brandner, 2013). Its low environmental impact also promotes its usage over other building materials such as steel, concrete and masonry. The prefabrication of CLT allows easy fenestrations and precise cuttings when used in doors and windows.

Figure 3.2: Panels of CLT (FPInnovations, 2016)

Some of the important advantages which are offered by CLT according to (Mohammad et al., 2012) are;

- ***Fast and Efficient Installation***

The use of CLT materials in construction helps to keep the time short in that the panels are fabricated beforehand with pre-cut fittings for various spaces be it stairs, windows, doors or ducts. Also, the building schedule is well managed as they are usually transported from straight for the producer to the site of construction.

- ***Flexibility of Design***

The use of CLT is not limited to just a few portions of a building. instead, it can and has successfully been used for an entire building and even flooring or ceiling construction. This is aided by some of its important qualities such as lightweight and other characteristics which makes it highly flexible and adaptable to different types of designs, projects and site conditions like soft soils, unlevelled ground or close proximity to a side placed building. CLT elements can also be combined with other building materials, enabling flexibility in design, style and finish architecture. In addition, when there is an urgent or on-site need that changes be made, it can be easily effected with simple tools.

- ***Cost Management***

Light wood frame construction is still the most economical wood system for low-rise projects. However, when compared to other materials in a different form of building type, CLT was found to be cost competitive in the overall study carried out by FPInnovations in 2010 where the coat procured in the usage of CLT was compared with that of others such concrete, masonry and steel.

- ***Fire protection***

CLT' possesses a thick cross-section that gives it adequate protection against fire outbreak as it's panels tend to form char slowly with the attack by fire. Once formed, char protects the wood from further degradation.

- ***Seismic performance***

Due to their dimensional stability and rigidity, CLT panels when used in building construction processes an effective lateral load resisting system. When small and multiple connectors are used to hold it together, it exhibits good ductile behaviour. Researchers have conducted Extensive studies by researchers on the seismic of CLT found panels to perform exceptionally well with no residual deformation, especially when used in multi-storeys structures.

- ***Environmental performance***

CLT provides a number of environmental benefits in addition to energy efficiency as it is manufactured from forest Timber. Wood is available by nature and is renewable. While growing, trees are able to trap carbon materials within their structures. With this, the tree tends to have a lighter carbon footprint and their manufacturing requires less energy and results in less greenhouse gas emissions. Carbon storage is an important attribute of wood structural components, which typically stay in place over long periods. With CLT, the stored carbon mass of the wood is significant. Life cycle assessment (LCA) studies also show that wood outperforms steel and concrete in terms of embodied energy, air pollution and water pollution, and LCA studies are underway on CLT specifically.

- ***Resource efficiency***

One of the ways by which CLT contributes to efficient use of resources is through the use of small dimensional materials that may be otherwise be a waste.

3.3.1.2 Glue laminated timber (Glulam)

Glulam, known as Glue Laminated Timber (GLT) is majorly made up of wide parallel layers of strong wood gathered together which are mainly selected based on their strength. The design of GLT panels showed in (Figure 3.3). Usually, glulam is mainly used as trusses, beams, but rarely for columns. The building material is highly innovative widely used in aesthetics function of buildings. Glulam has been shown to be of greater strength and stiffness than steel. Its cost-effectiveness has also supported its motive of use for simple beams projects and headers residential construction of over 500feet. It is preferred in applications such as home roofing designs, curved design of churches, and other open spaced related architectural design (Kempna, 2019).

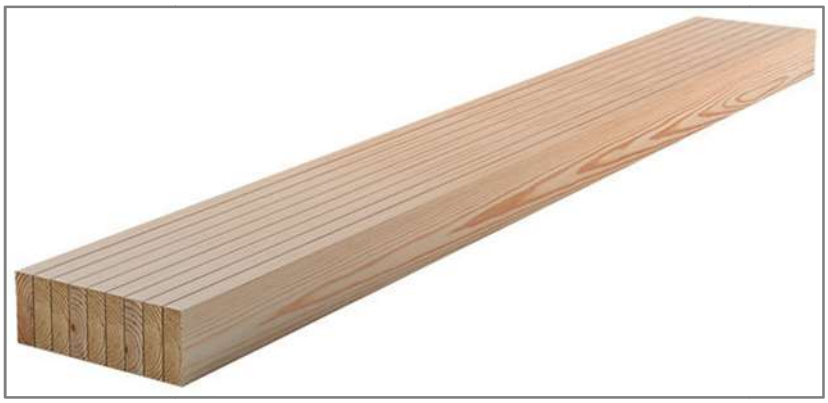


Figure 3.3: Panels of Gleam Laminated Timber (Kempna, 2019)

3.3.1.3 Nail Laminated Timber (NLT)

Nail Laminated Timber is another timber product which is very similar to Glue laminated timber but slightly smaller in volume, size and functions. Because of its small size, it is frequently used as timber floors, decks and elevator. Structure craft (2018)explains that for building construction of cheaper material than the CLT, NLT does the job perfectly. It is easy to fabricate by almost anyone with just hammer and a nail. Figure 3.4 shows the architectural design by NLT.

Figure 3.4: Architectural design (Green, 2018)

3.3.2 Advantages and disadvantages of mass timber products

The use of wood-based products has a lot of benefits among which is their Sustainable nature. They serve as the best form of building materials due to their eco-friendliness and the fact that they can easily be recreated by replacing harvest trees with another. On the other hand, mass timber products are however not without their negative side in that they are not as trusted as the traditional building materials i.e. concrete and wood especially in the erection of large structures (Structure craft, 2018). The different forms of wood timber-based materials have their own peculiar up and down in usage which are given below.

Table 3.1: Advantages and disadvantages of mass timber products (www.structurecraft.com)

MASS TIMBER PRODUCT	ADVANTAGES	DISADVANTAGES
CLT (Cross-Laminated Timber) 	Easily stable Standard dimension Easy mode of fabrication	Material becomes too soft due to its cross lamination Structural efficiency is low
GLT (Glue Laminated Timber) 	Similar structure to CLT Efficient structural panels	Small width dimension of panel Unstable panels
LVL (Laminated Veneer Lumber) 	Very stable wood product Wood product is tough	Small thickness of panel nel size is limited
LSL (Laminated Strand Lumber) 	Highly stable wood product Connecting property of wood is highly developed Economical wood product	Limited thickness Visual finish sometimes unacceptable Issues with moisture penetration unless careful detailing and protection.
 **PSL** (Parallel Strand Lumber	Dimension of wood is verystable Strong and tough Highly adaptable	Very heavy wood panels Constraints width of wood panels

3.3.3 Production of CLT mass timber

All the major companies that are involved in the manufacturing of cross laminated timber follows the same plastic processes. All in all, they ensure the selection of wood materials

that are sorted based on their quality. Production, however, does not necessarily start from within the factory as perceived by the general public.Figure 3.5 shows the production of CLT mass timber, but from the forestry in which harvesting of the tree took place by ensuring that another set of trees are planted in place of the harvested ones (Sutton et al., 2011).

Figure 3.5: Production of CLT mass timber (Sutton et al., 2011)

3.3.4 Production stages of CLT mass timber

The manufacturing process of CLT mass timber occurs in the stacking of three or more layers usually of different thickness at a 90-degree angle to each other. This orthogonal method of arrangements allows for the stability of the wood product.

The production of CLT is in two major stages which are ;

Planing: When the board arrives at the factory, it's edges are trimmed to improve glueing efficiency and also to reduce oxidation in the material. Figure 3.6 shows the mass timber wood quality chart flow.The boards are then processed to have finger joint edges by a machine. Two boards of finger joint edges are then connected together to form a lamella.

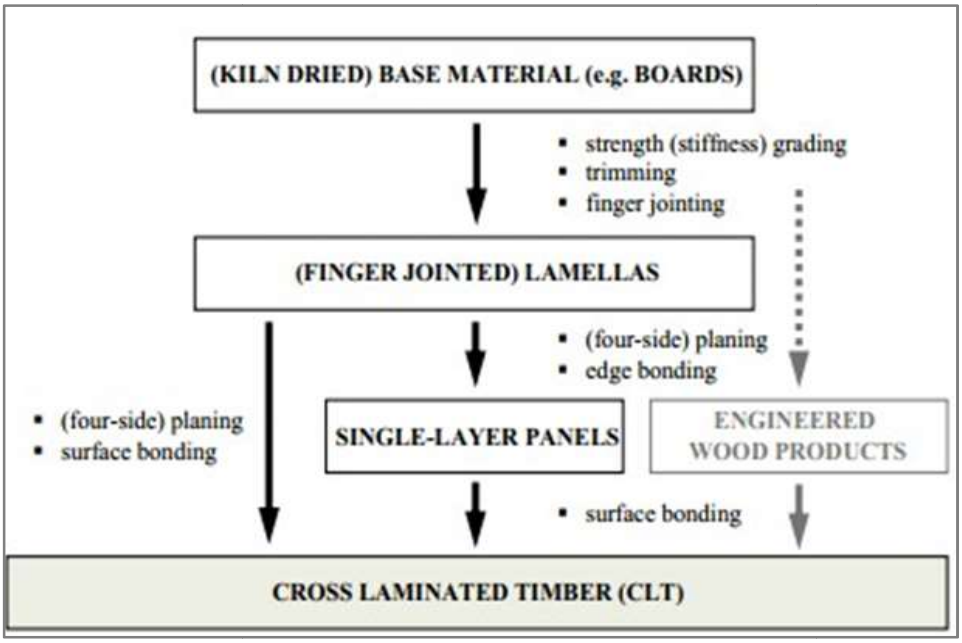


Figure 3.6: Mass timber wood quality chart flow (www.google.com/perspectives/building-better-box/for-web_2017_05_11-mass-timber-presentation-brochure_p5/accessed November 2018)

Glueing: It was recommended by Jelec (2018) that during the joining of the finger-shaped joints, it is best to use adhesive substances that have the same mechanical. He noted that the most commonly used adhesives are; melamine urea formaldehyde (MUF), polyurethane adhesive (PUR) and emulsion polymer isocyanate (EPI).

Since there is a possibility of cracks as a result of possible shrinking and swelling caused by changes in temperature and moisture, Brandner et al., (2016) advised against the application of glue along the narrow end of the lamella. This is done by some manufacturers when cross laminated timber elements are made without spacing. When the adhesive is applied to the lamella, they are subjected to a hydraulic pressing machine, after a while, the formed CLT is brought out to dry. The planning, cutting, gluing and drying stages of CLT production can be regarded as the major step in the manufacturing process. There is also a phase that allows for the cutting of the panels into forms that fits in openings like doors, windows, flooring and others as required by the building design.Figure 3.7 shows the manufacturing process of CLT mass timber.

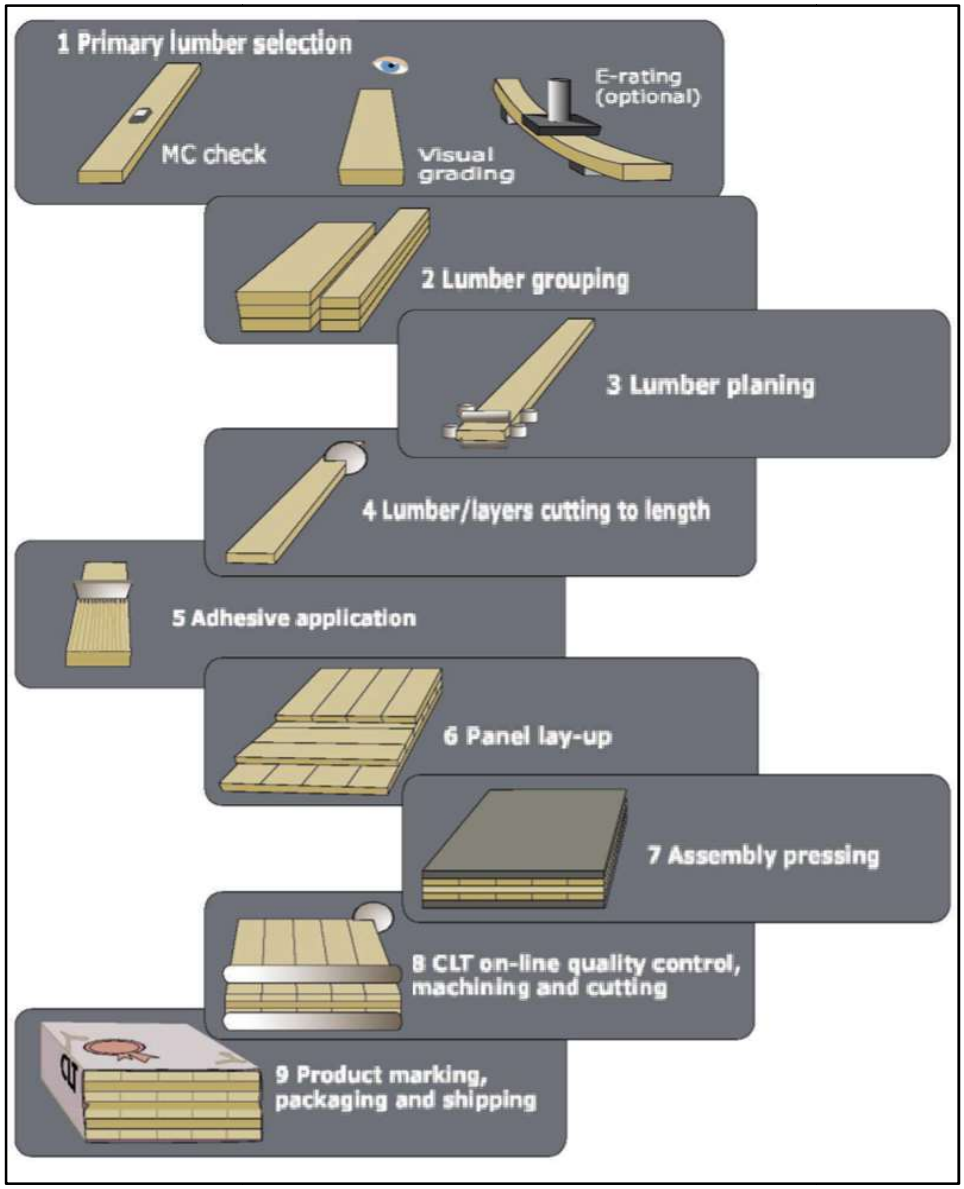


Figure 3.7: The manufacturing process of CLT masstimber (FPInnovations, 2013)

The volume of CLT entering the timber market every single year is increasing. This has not only to call for the need for more studies to be carried out as regards the product but has also called for its Standardization and harmonization most especially in forefront countries in Europe such as Canada, United States among others. A European CLT standard was however introduced in 2016 with international standard (Brandner et al.,). Table 3.2 shows the general European standard geometrical characteristics of CLT.

Table 3.2: General European standard geometrical characteristics of CLT mass timber (Brandner, et al., 2016)

Strength class of basic material T14, $f_{t,0,l,k}$ = 14,0 , $E_{0,l,mean}$= 11000		CV [$f_{t,0,l}$], 25 ± 5 %	
Reference	**Mechanical properties of CLT**	**CLT strength class**	
		CL 24 h	L 28h
Unterwieser & Schickhofer 2013	Stretch capacity * Varies on test material in question	24*	28*
Unterwieser & Schickhofer 2013	Tensile strength parallel to edge $\mathbf{f_{t,0,CLT,net,kZ}}$ * varies on test material in question	16*	18*
EN 14080	Tensile strength perpendicular to edge $\mathbf{f_{t,90,CLT,k}}$	0.5	
EN 14080	Compressive strength parallel to edge $\mathbf{f_{c,0,CLT,net,k}}$	24	28
Brandner & Schickhofer 2014	Compressive strength perpendicular to edge $\mathbf{f_{c,90,CLT,k}}$	3.0	
Brandner, 2015	Net shear capacity of packed CLT$\mathbf{f_{v,net,k,ref}}$	5.5	
Flaig, 2013	Gross shear capacity of packed CLT$\mathbf{f_{v,gross,k}}$	3.5	
Blaß & Görlacher 2002	Torsional capacity of packed CLT $\mathbf{f_{v,tor,k}}$	2.5	
EN 14080	Shear strength parallel to grain $\mathbf{f_{v,CLT,k}}$	3.5	
Ehrhart, 2015	Rolling shear strength $\mathbf{f_{r,CLT,k}}$	0.8 - 1.4	
EN 14080	Elastic modulus parallel to edge $\mathbf{E_{0,CLT,mean}}$ E0,CLT,mean = 1.05 · E0,l,mean ; E05,CLT = 5/6 · E0,CLT,mean	11600N/mm2	
EN 14080	Elastic modulus perpendicular to edge $\mathbf{E_{90,CLT,mean}}$	300	
Brandner & Schickhofer 2014	Elastic modulus for compression out-of-plane $\mathbf{E_{c,90,CLT,mean}}$	450	
Brandner 2015	Shear modulus parallel to edge $G_{CLT,mean}$ (* without joining edges of lamella that are not wide [59], ** with joining edges of lamella that are wide)	450* 650**	
Ehrhart 2015	Rolling shear modulus $\mathbf{G_{r,CLT,mean}}$	65 - 100	
EN 14080	Density$\rho_{CLT,mean}$ρCLT,mean = ρl,mean, ρCLT,k = 1.10 ρl,k	420	

CLT and layers of homogeneous CLT: strength and module in (N/mm2), density in (kg/m3)

When used as an outer component, there is usually a need for a protective coating to placed over it. It also offers the advantage of prefabrication before being transported to the site. Delay in inner touches is eliminated when the CLT panels are set because it offers a sort of environment which is protected against inclement weather conditions. The use of lintels also are not usually required. Figure 3.8 below demonstrates the monolithic nature of cross laminated timber (CLT) which is used to form solid panels and floor slabs.

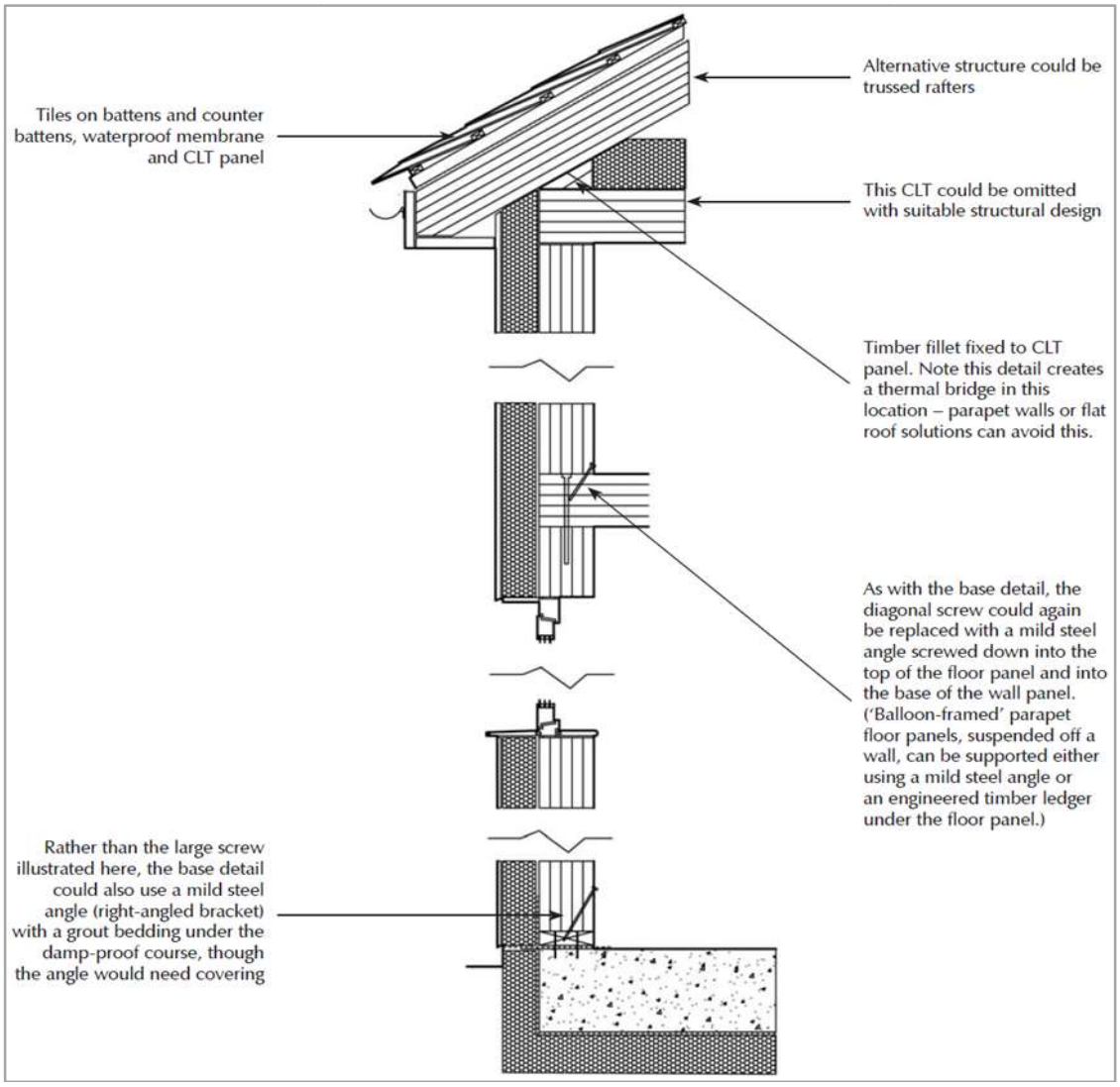


Figure 3.8: Solid panels formation of cross laminated timber (Sutton et al., 2011)

3.3.5 Stigma of mass timber

Several factors hindered the proliferation of Mass Timber throughout the international market. In many states in the United States, there isa local building code which prevents the construction of wood framed buildings that are above six storeys without special considerations. This is mainly due to the historical performance of the old wooden frame as opposed to the new systematic mode of engineering woods nowadays. The major restriction of the usage of wood in construction is their flammability which scares most people from using CLT timber. This is actually what is responsible for a great number of the regulations on the timber construction.

Table 3.3: CLT mass timber building material properties (Hindman& Bouldin, 2014؛ Brandner, et al., 2016؛Chiniforush, et, al., 2019)

Undoubtedly, the use of CLT panels in buildings has been on the upward trajectory in Europe is not too long years ago. The pattern of structures to have followed this trend shows that CLT construction has a place today, especially in moderately sized to large structures. All around the world, dried wooden materials in its unrefined form is used as a source of energy. In the large scale by rock miners, combustion engines, bakeries, and in small scale when used as a cooking material usually in rural settings.

The Stigma on wood-based products remain in that if no special treatment is administered, wood is also rather flammable, an undesirable trait especially when considering large complexes and their safety. Wood is also susceptible to discolouration and mould, however, with proper intervention, damage can be minimized for hundreds of years (Fell, D. 2010). On the other hand, mass timber is inherently fire resistant due to the charring effect of the material in bulk. The fact that the advantages of using CLT outweigh the traditional disposition of people about it, it still remains and will continue to be for the time to come.

3.3.6 Properties of CLT mass timber

Architects and builders have begun research, about aeco-friendlier product that isenvironmentally friendly. The research gave promise with a new innovation wood material previously known as “super wood” which is now referred to as CLT. Its combined physical and chemical properties enable it to be more a sustainable product than other building materials like concrete, cement and steel. CLT Mass timber being a natural, renewable, eco-friendly material requires low energy in its fabrication. As part of its physical properties, CLTpossesses high strength to weight ratio which helps to increase its durability and rigidity. On the Chemical aspect, its ease of disassembly allows the material for proficient life cycle i.e. the material is reusable. Green mass timber in addition to the discussed properties has a significant carbon lifespan which allows it in the storage of mass carbon again being friendly to the environment as a profound chemical property (Harris, 2013). In addition to the strength and stability in which these qualities add to the CLT, other existing properties ofthe *super wood*are seismic resilience, acoustics, high thermal performance, fire resistant, moisture management; low environmental impact.Table 3.3 shows the CLT mass timber properties characterization.

CLT	PROPERTIES	REMARKS
VISUAL	▪ Shape	▪ Rectangular shape, odd number of layers between 3, 5, 7 and 9.
	▪ Dimension	▪ L= up to 18.5m, L max= 30m W= up to 3m, W max 4.8m,varies according to the number and thickness of the layers ~ 20-40 mm, from 60mm to 360mm.
	▪ Color	▪ Has natural wood color, can be painted, anti-dusting &smooth surface.
	▪ Surface Texture	▪ Has wood surface texture and the glossiness of the wood is associated with the moisture content of ~ 12% +/- 2% at the point of delivery.
PHYSICAL	▪ Density	▪ Typical panel of 10000/250/120 mm has1500 kg weight, density varies from 400 - 500 kg/m3, weight depends on density and size, ranging from 100kg up to 7000 kg.
	▪ Moisture & water	▪ Moisture & water content is enhanced in the fabrication of the material (10% - 14%). Vapour permeable (breathing) and vapour retardant. Depending on the moisture content, diffusion resistance value = μ40-80.
	▪ Thermal properties	▪ Large hygrothermal inertia allows heat transmission and storage, thermal conductivity k value (μ) ~ 0.13 w/mk (spruce tree).
	▪ Acousticproperties	▪ Has a good acoustic performance, but care must be taken for flanking sound (flanking noise) in the building.
CHEMICAL	▪ Heat & fire	▪ Fire protection in accordance with the En13501 report provides fire of 0.67 mm/min attack, resistance is based on the possession of the insulating layer of the panels.
	▪ Organisms& corrosion	▪ Moisture activate fungus and other biological materials causing corrosion. Chemical treatment against corrosion, fungi and insect.
	▪ Radiation	▪ Does not contain radioactive substances.
MECHANICAL	▪ Tension&compression	▪ Bending strength of 24N/mm2 and a modulus of elasticity of 11,000 N/mm2 according to EN 338. Compressive strength parallel to grain 8.5-13 N/mm2.
	▪ Shearing strength	▪ Shearing strength allows for large amount of bending allowing its usage in a wider range of application as opposed the other building construction materials, 0.24 %per1% change in moisture.
TECHNOLOGICAL	▪ Fracture &impact resistance	▪ Fracture of shearing analysis of CLT reveals the major contributing factor.Several studies have revealed that CLT can withstand pressure without deformation which allows it for tall building construction will lesser fracture and increase impact resistance.
	▪ Abrasion	▪ Abrasion of CLT building material does not have effects on the mechanical property of the building material.
	▪ Swelling & shrinkage	▪ The swelling as shrinkage of the building materials is to be considered during the building construction when using CLT as the building material.
HUMAN HEALTH	▪ Health & safety issues	▪ As regrading health, a total of 1643kg CO2 was sequestered per tons by reducing the use of toxic chemical substances.
	▪ Emotional	▪ Warming, cosy material havingpsychophysiological positive effects on emotional state of people like calming effect, drop in blood pressure and pulse.
	▪ Weight effect	▪ Possessing light weight structure, fire safe building construction and ease of modification it does not only improve on the weight effect of building material but also increases the safety issue during the usage of the building. Has a good smell, promote human health wellbeing of mind and body.
ECONOMIC	▪ Reserve source	▪ The reserve source allows both in aesthetic nature and sustainable purposes.
	▪ Production cost	▪ CLT is light in weight, requires less transport (production) energy overall making its economic resources highly efficient.
	▪ Transportation, storage, maintenance & repair cost	▪ The economic transportation propertyallows a faster speed in both the production and transportation. Storage cost is reduced as CLT is directly transported for on-site usage. Maintenance& repair costs are minimal when compared to concrete and steel.

Furthermore, the research focuses more on the analysis comparison of the case study; CLT timber against reinforced concrete with regards to greenhouse impact with respect to the gaseous emission caused from the production of the material, manipulation and its

transportation to site for its usage. In contribution to greenhouse effects, acid rain caused by the acidification of chemical compounds could arise from compounds of the production of the building materials as elaborated in Table 3.4.

CLT mass timber in all ramification produces lesser amount of unit environmental impact quality when compared with reinforced concrete as a concrete erection requires more energy, costs, power in its production and implementation whereby CLT timber emerges as an eco-friendly sustainable building material.

Table 3.4: Life cycle assessment of building materials (Linnan, 2017)

QUALITIES	UNITS	CLT TIMBER	REINFORCED CONCRETE
GREEN HOUSE	CO_2/kg	40806.99	297361.126
IMPACTS	CH_4/kg	11.19	4.592
	CO_2eq/kg	41041.98	2974575.558
ACID RAIN	NOx/kg	456.26	599.65
MEASUREMENT	HCL/kg	0.000652	15.567
	SO2eq./kg	323.1673	972.97
ENERGY	Electricity/ Kwh	41278.5	101064.4
INTENSITY	Gasoline/L	151.6	305248
(ENERGY	Diesel/L	64890	6472360.2
PRODUDCTION	Biomass/kg	140976	NONE
REQUIREMENT)	Natural Gas/m^3	2890.95	16525.1
	Fuel Oil/L	8962.6	21789086

3.4 The Sustainability of CLT Mass Timber

CLTis an eco-friendly material which designed as a low-carbon alternative to heavy construction materials such as concrete and steel. These new technological construction means of green construction using CLT has significantly reduced pollution by reducing the carbon emission building in terms of both material production and on-site time and energy consumption Figure 3.9 show the CLT mass timber used in a construction site (Brandon, 2015). The first evolvement of CLT happened in Germany and Austria around the year 1990. The green advantage of CLT emerges as an interesting factor as green material with asustainable life cycle is. A study by (Krogmann et al., 2009) revealed that the stage that involves putting of materials in place (i.e. raw material extraction and manufacturing)

account for about 41% of the total primary energy utilization when examining a new sustainable structure selected as a case study in the USA. The above finding has hinted that while the world is slowly moving towards and embracing green building, with global warming, climate change and acidification of water bodies still critical issues, the choice of material becomes important so as to limit or better still reduce the impact of the building on the environment. One of the most important advantages of using wood generated products as opposed to others like concrete and steel in erecting giant structures is its inherent bank of renewable energy.

Figure 3.9:CLT mass timber used in construction site
(Style Architects, 2016)

Asides its height strength to weight ratio, CLT biggest advantage for the green building would be its subsequent carbon storage. Normally, as trees grow, they tend to pull in carbon from the atmosphere and store it in the wood. Also, the amount of concrete that would erect such structure would result to 1,215 tons emission of carbon. The construction of building with green mass timber of building demonstrates excellent workability, durable lifecycle and a more sustainable ecosystem (Wolski, 2013). Figure 3.10 shows an approved architectural design made mostly of CLT mass timber for, its construction while Figure3.11 shows the University of Massachusetts green architectural building design in Amherst, Masochist.

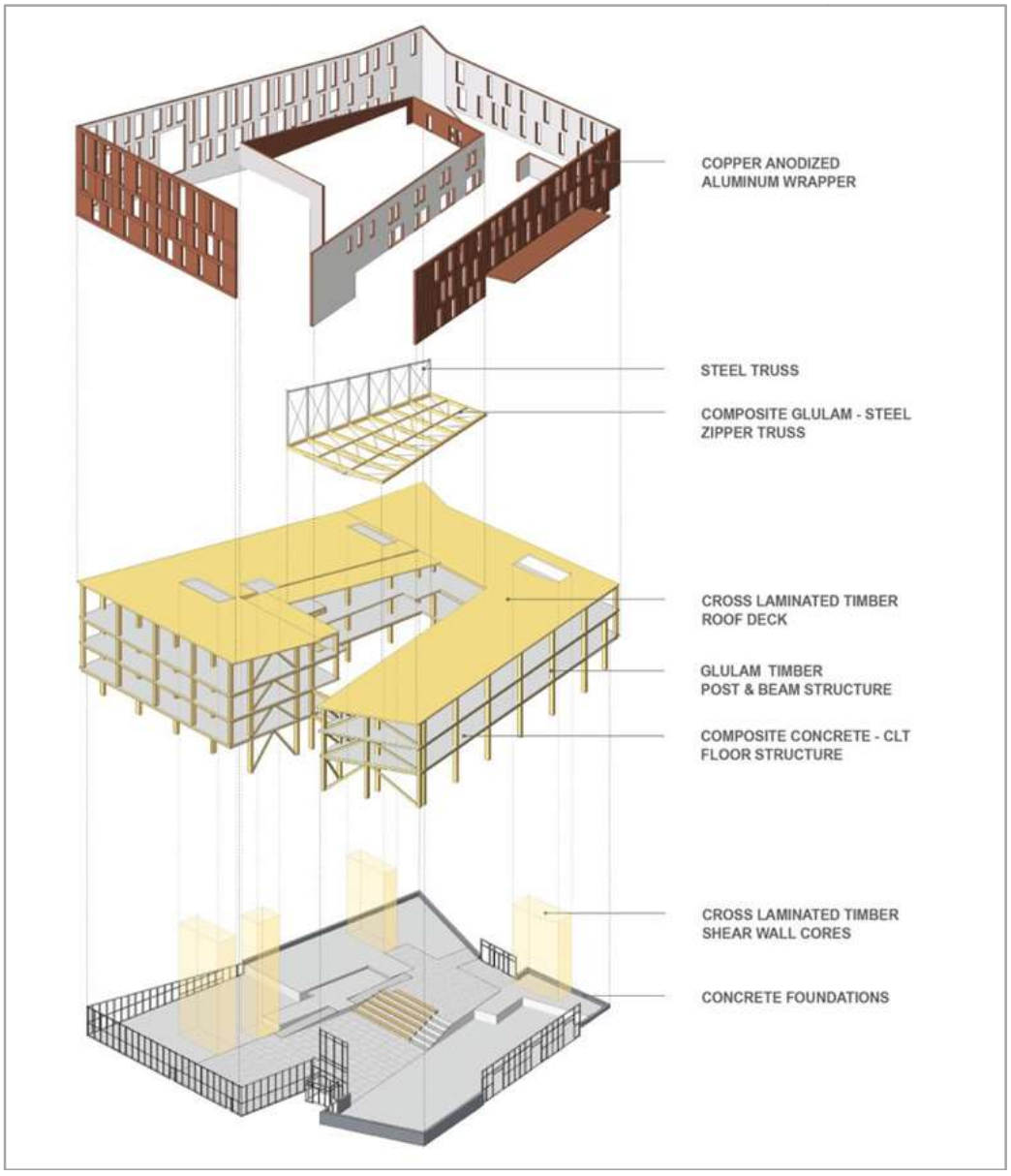


Figure 3.10: Architectural plan designs of timber construction(Note, 2017)

Figure 3.11: University of Massachusetts green architectural building design (www.designbuild-network.com/features/torontos-tree-tower/attachment/toronto-tree-tower/)

Furthermore, CLT as opposes steel, cement and other building materials which their production generates a large amount of carbon dioxide (CO_2) during their production, carbon dioxide is absorbed during the production of wood even after it been turned into lumber. This storage of carbon mass of wood is significant, and studies have shown that one cubic meter of wood will store one ton of carbon dioxide as shown in Figure 3.12(Kawin, 2015).

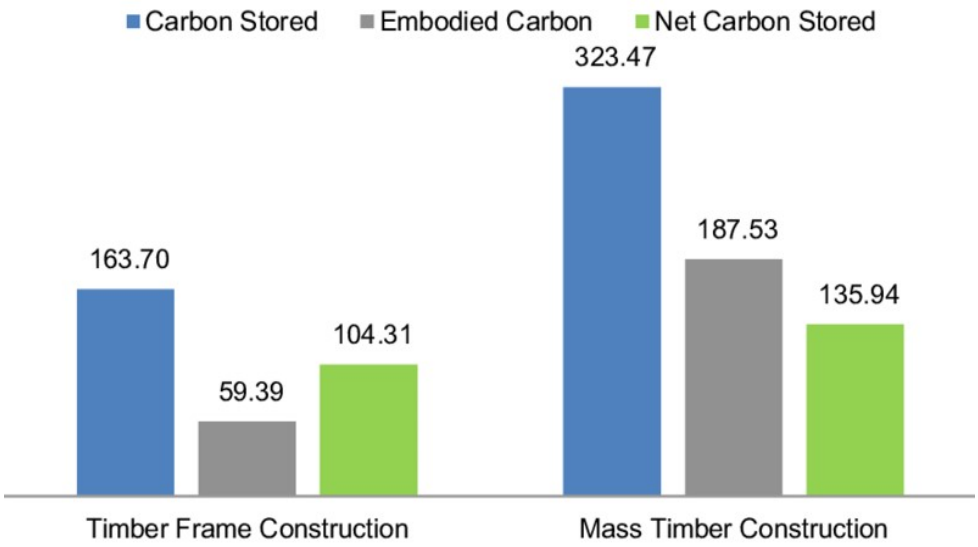


Figure 3.12: Net carbon storage of mass timber, (Kawin, 2015)

Asides the eco-friendly sustainability of mass timber, there are other significant importance of mass timber which makes it better than its counterparts. The ease of manufacture and production of the panels of CLT makes it a better choice of building material. It can also be easily transported directly to the work site from the manufacturing site. The popularity of CLT is rising due to the advantages it possesses such as time-saving, cost-effectiveness, with buildings constructed using Cross Laminated Timber also offering energy and operational efficiencies due to the solidity nature of the panels.

Several studies in an attempt to quantify the environmental benefit of construction in timber using life cycle analysis procedures have shown that during the lifespan of the building, there are forest rotations which usually take place with further carbon sequestration in the forest (Robertson et al., 2012). In addition to the green eco-friendly sustainability benefits of mass timber for buildings, the significant is the importance of CLT mass timber is prefabrication which allows for the production of high-quality standard, regardless of weather or temperature conditions.

3.5 CLT User requirements in Building Constructions

The survey and questionnaire carried out by Espinoza, et al., (2016) in regard to the CLT user requirements in Europe which can be used as a subset for a larger population sample. They based their study on a web survey with respondents from various wood related fields such as; construction managers, civil engineers, architects, and researchers in general with the aim of increasing the underrated significance impacts of CLT mass timber. Figure 3.13shows the corresponding questions and result simultaneously from their survey concluding the exponential rate of increase usage in central Europe with developed European countries such as New Zealand, Australia picking up interest in the usage of CLT. Thereby initiating Cyprus towards the adoption of the suitable usage of CLT as a quicker, greener, cheaper, and faster building construction material.

Topic	Question	Type of response
Demographics	Kindly select your profession	Multiple selection
Awareness	What is the level of awareness about Cross Laminated Timber (CLT) in Europe among the following professionals (owners/initiators, contractors, construction managers, engineers, and architects) in your opinion?	4-point Likert scale: “very high” “high” “low” and “very low”
Possible barriers to adoption	What do you think is the bottleneck of note that has prevented against the wood product from finding its place in the building construction industry in Europe? (Options are volume of wood required, availability in market, cost, availability of technical information, compatibility with building, misperceptions about wood/CLT, and CLT’s performance as building material)	3-point Likert scale: “large barrier,” “may be a barrier,” and “not a barrier at all”
User requirement	Please rank the following areas of research about Cross Laminated Timber (CLT) in their level of increasing priority. (Research areas listed are structural performance and connections, thermal performance, environmental performance, moisture performance, acoustic performance, and market/users)	Ranking from most (1) to least important (6)
Comments	Kindly state that area Cross Laminated Timber (CLT) which u think more studies should be conducted on to allow for further upward rise in its acceptability among the people.	Open question
	Other comments you may want to add?	Open question

Table 3.5: Summary of questionnaire, (Espinoza et al., 2016)

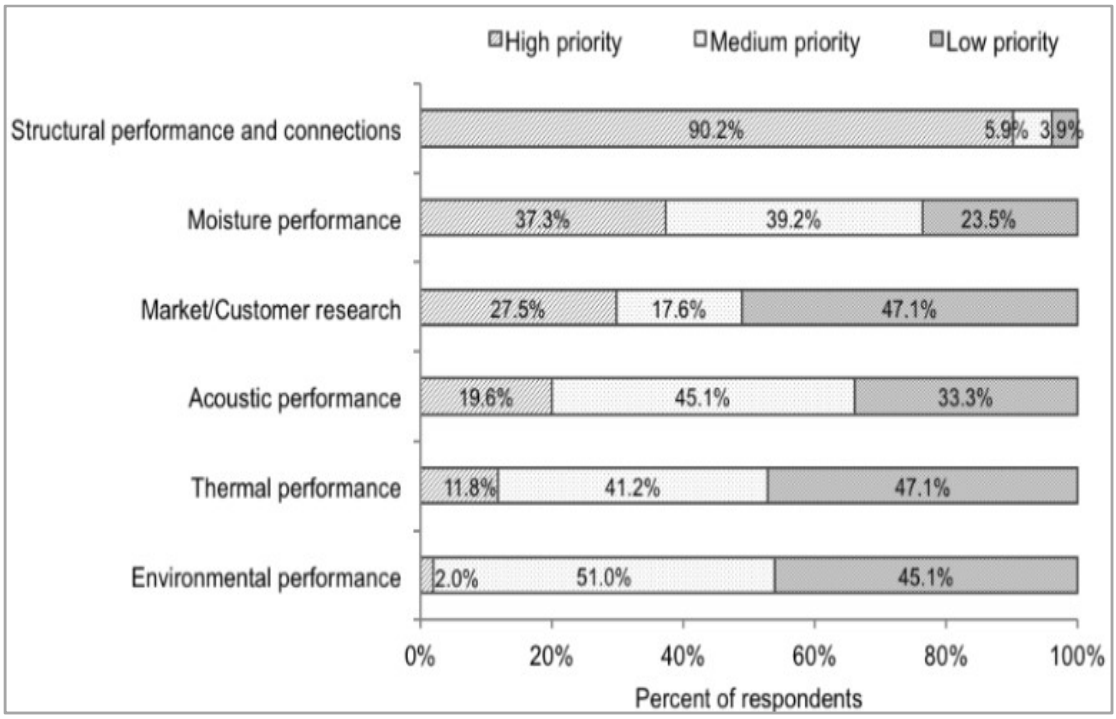


Figure 3.13: Ranking of needs of CLT (Espinoza et al., 2016)

3.6 CLT Elements and Implementation

Cross laminated timber is widely used as a roofing system, floors, and walls. they can also be engineered with other wood products, concrete, steel and masonry to increase distinct desired properties. The panels of CLT are usually vertically oriented for load-bearing walls and shear, while horizontally oriented for load-bearing roofs or floors for longer spans and unduly heavy loads timber-concrete composite floors provide an economic solution (Sikora, 2016). On each level for the construction of low-rise buildings, platform construction is widely used, where CLT walls are strongly erected in a cellular arrangement and the floor is placed on top for a stronger framework system. The floor, therefore, acts as a supporting platform for the next level as seen in Figure 3.14. With an increase in the height of the building, the compressive force from the above walls would tend to act on the floor below it in the perpendicular angle in an attempt to increase the support system. In other to prevent excessive deflections of the system however, the force is usually transferred to either the column or wall below it by using self-tapping screws or other steel connectors. Otherwise, the use of balloon construction methods can be

implemented. In which case, the walls are continuous from floor to floor and the floors are supported by steel brackets connected to the walls. This system gives room for high compressive loading perpendicular to grain issue thereby also avoiding scaffolding support to the floor.

Figure 3.14: Platform construction (Chulain, 2016)

For out of plane elements such as floors and roofs, the serviceability limit state deflections and vibrations limit generally govern the design. An important consideration that arises from the cross-lamination of members is the shear flexibility of the cross layers. Because of the flexibility ability of this timber, its deflection calculations based on several methods following different examples; shear analogy method, gamma method and Timoshenko shear flexible beam method.

The Timoshenko's analytic method was introduced in the late 2000's by (Schickhofer et al.,2016) to be a sort of easy supplementary method to those that are already in use. The Gamma method can be applied to panels with varying numbers of layers up to about 9. It is arguably the most used method in Europe. When using this method, the shear deforestation is neglected even though they are still calculated through analysing of bending stiffness which is a function of well the longitudinal layers are joined. The Timoshenko's method, however, can be applied to panels with an increased number of layers since calculating the

bending stiffness does not require for the adequate length of the beam. The Shear Analogy may be the most accurate of all 3 methods. This is also regarded as the most intensive is arriving at. This method uses the joining of 2 beams of wood but constrained to have the same vertical effects at any point along their length (Christovasilis, 2016).

The general overview of all these methods is that they give comparable results of span-thickness ratio exceeds. For the calculation of the stresses, for simplicity, only those layers oriented perpendicular to the axis of bending are assumed to contribute to load resistance.

3.6.1 Connection systems in CLT

Normally, when CLT panel is to be used either alone or in conjunction with other building materials in the construction of a multifaceted building, various forms of fasteners and holding tools are called into action to provide the necessary action needed. In the construction of a building, contractors have always used joining materials such as bolts, nails and screws to a good result. When the structure in question is one to bear big loads, it is usually advised to use split rings, shear plating and tooth plating's. Even as Cross Laminated Timber is gaining popularity in usage all over the world, more interesting innovative connection materials are finding their way to the CLT construction market. They generally employ the same concept as the existing forms and possess the same very interesting qualities for use. They include glued-in rods and other systems that adopt similar ideas. These kinds of system make the use of CLT in building construction have a good future prospect. All in all, the choice of the type of connection to use depends largely on the type of assemblies to be connected, this may be the joining of one panel to another or walls to floor and so on, it may also be the general settings of the manipulation of panels employed (Gasparri et al., 2015). Some of the joining equipment that are commonly used when CLT is being assembled are Below;

❖ **Screws**

This in one of the most popular fasteners around in the assemblies of CLT panels. It has some important qualities that makes it so acceptable among builders and developers alike. This includes the fact that they are in sizes that are easily handled when the need for such arise, they can be easily taken off already made connections and they can also be used in

joining axial and lateral structures. Together with self-tapping screws, these forms of joining materials come in a variety of sizes and specific features.

❖ **Nails**

Nails are not as popular as screws when putting together Cross Laminated Timber in building construction. Nails that possess pin head are not as widely accepted as those with specific surface features such as grooves or helically threaded surfaces. Most timber design standards employed by builders and engineers do not allow the use of nailed connections in the end grain of wood-based products for removal forces.

❖ **Bolts**

Bolts and dowels are commonly found in heavy timber construction. Though they can also be used in the assembly of Cross Laminated Timber panels, most especially when cross room packing is needed. If installed in facets with numerous small openings, care must be observed during the designing, of CLT panels with bear edges in the middle of wooden sheets in a batch.

❖ **Joining hooks**

Structural composite lumber (SCL) is also a derivative of wood whose demand is not really on a high. Its families include; PSL, HST and glulam. They employ another form of holding equipment which differs from the traditional ones. Bearing-type connections can be made use at certain points depending on the position of the fasteners with regards the CLT layers and the type of effort package.

❖ **Newly invented fasteners**

A new set of fasteners are coming into the building construction market such as self-tapping screws and glued in rods. As regards Cross Laminated Timber, G-in rods can serve as a very good alternative for joints that are subjected to distance altitude or cross room duties. and also, to reduce the splitting potential (Augustin, 2008). Cross-laminated timber allows for easy connections between by using the simple steel connectors and self-tapping screws. There are some commonly used models for joining panels to other panels. Other connections such as linking walls to floors,panel-to-panel edge connections and self-tapping screws as connectors of CLT.

are shown in below figure 3.15 These said joining. can be carried with respect to the existing Eurocode 5 systems.

(a) Self-tapping screws (b) Steel angle brackets

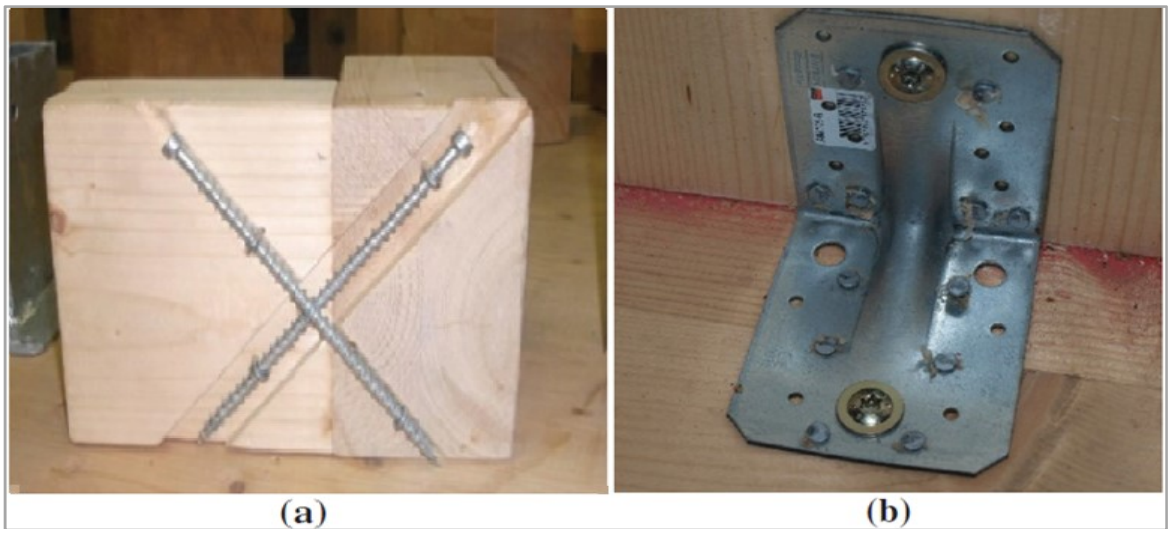


Figure 3.15: Panel-to-panel edge connections self-tapping screws (a) andsteel angle brackets as (b) connectorsofCLT(Tomasi, 2013)

3.6.2 CLT mass timber as a roofing system

The use of CLT in solid wood construction as a roof system offers a wide range of merits over other building materials due to its excellent soundproofing property, load bearing ability, and earthquake-proof construction makes it suitable as a roofing system shown in Figure 3.16. The method is applicable to the connection of screws with a simple static model. The engineering systems is established through the splines of engineered wood products.

Figure 3.16:CLT mass timber used as a roofing system (www.holmesstructures.com)

3.6.3 CLT mass timber as a flooring system

The fabrication and construction techniques to implement new design structures using CLT mass timber for flooring system in Figure 3.17 promises of alternative building construction material to steel and concrete. The connections that support the framework of CLT mass timber can be expressed has a pin-pin support condition. This model is such that there is no movement between the connecting layers of the CLT. In the year 2014, a team of scientists from Oregon State University combined the characteristic ability of concrete and CLT as a floor system by using a hybrid structural floor system composing of a concrete slab as the base topped with a composite layer of CLT mass timber.

Figure 3.17:CLT mass timber implementation of floor system (www.holmesstructures.com)

3.6.4 CLT mass timber as a wall system

Wall elements with CLT Mass Timber are installed with insulation board to achieve desirable characteristics in Figure 3.18. Structural systems of the wall used CLT panels where the fibres run parallel to a load of gravity thereby maximizing the vertical walls load capacity. Currently, under the U.S. building codes, CLT is permitted in all types of combustible construction, which includes type IV buildings.

Figure 3.18:CLT Mass timber implementation of wall system **(**www.holmesstructures.com)

3.7 Prefabrication System of CLT Mass Timber

According to Gasparri, (2015), the design set up includes all façade layers of the external construction. The external wall design was divided into two parts in which the first CLT part is load bearing and the second part is using the CLT as a facade. To achieve this, the façade contains a water shedding surface and a water resistive barrier to prevent water from entering internal construction. Gasparri et al.(2015)discuss other possibilities of cladding, and another fixing system (concealed or exposed) with other finishing materials such as metals, ceramic, woods. For horizonal joint design, Gasparri et al. (2015)analyses three methods as shown in Figure 3.19, the left image shows the joining of the facade being placed at the upper side of the slab of the floor which allows easy transportation of the panels. The middle image shows the placement of the floor slab in the middle while the right side shows the location joint at the bottom part. The bottom joint allows tightness of water but may not be easy to transport.

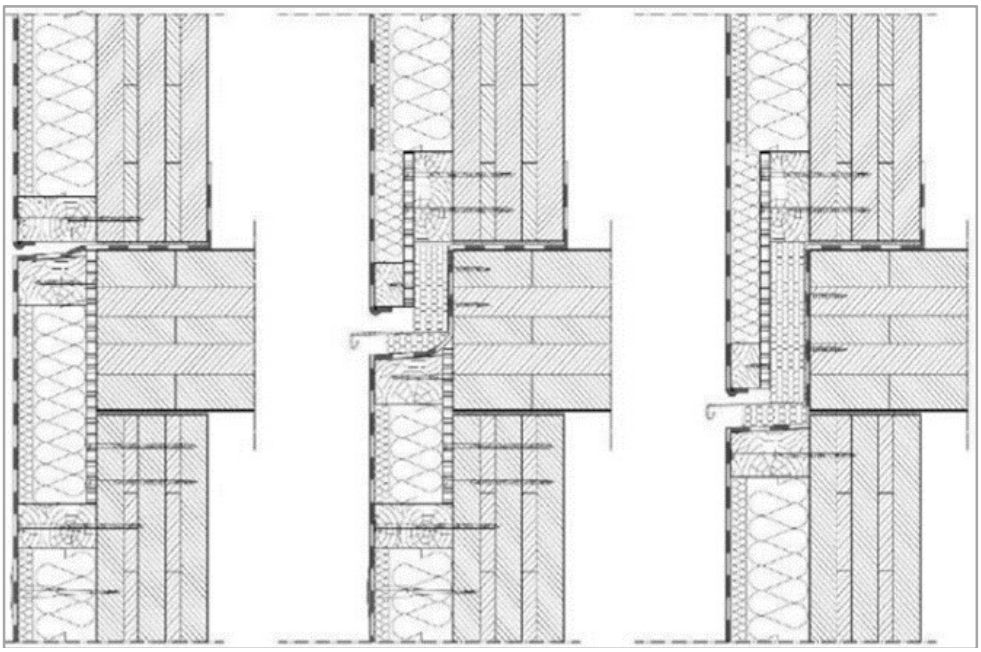


Figure 3.19: Vertical cross-section joining position (Gasparri, 2015)

The wooden strip is installed inside of the building to connect wall panels together. The prefabrication installation follows the installation of the load bearing wall system that is, mounted on the floor. Following this is the installation of the upper floor which is

supported by the wall. Finally, this joint is completed from the airtight position. as in Figure 3.20.

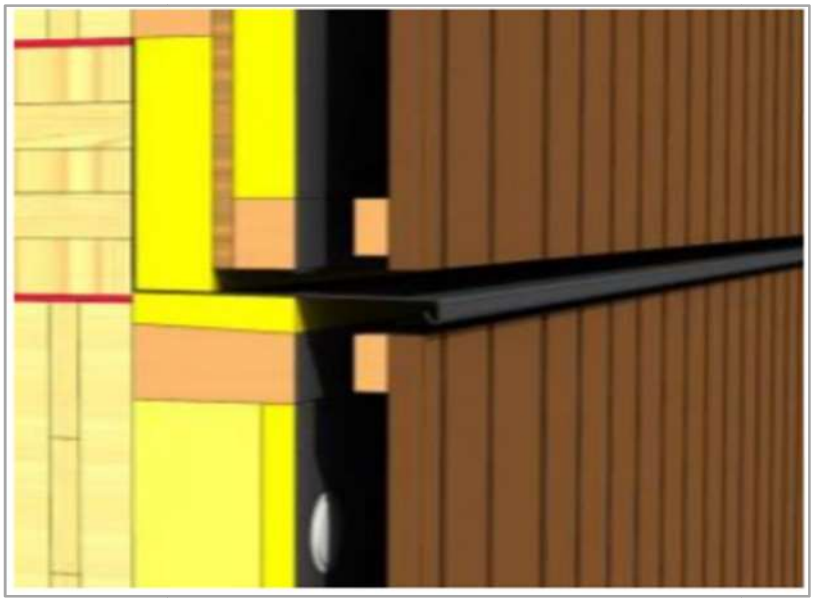


Figure 3. 20:3D visual of horizontal joint (Gasparri, 2015)

3.8 Limitations of CLT Mass Timber

As advantageous as CLT is nevertheless, there exists few concerns and problems. Firstly, CLT is highly dense in which its transportation and handling may pose certain difficulties. Moreover, the panel of CLT's thermal conductivity property could be considered lower that the state code of North America which request extra wood materials to cover for the inefficiency of the thermal resistant of CLT. It also demonstrates a larger vibration in low frequency range of 50-100 Hz. meaning CLT based system would be lacking the ability to reduce noise thereby requiring development. Wood is renowned for shrinking and swelling due to changes in moisture content. The effects are noticeable in even small constructions of residential housing. Dry wallers often wait a few days or more for newly framed houses to settle before attempting to finish any wall. If the drywall is placed before the house settles, it will almost certainly crack(Brandner,2015).

3.9 Conclusion

The various products that can be derived from mass timber also help to include some sort of versatility in the usage of wood in building construction. Having established mass

timber as a sustainable building material in the previous chapter, the subsets are closely reviewed and put into perspective, together with being sustainable, the fact that it offers an advantage of prefabrication at the production point makes room for quick installation when they are eventually transported to the construction site.

CHAPTER 4
APPLICATION OF CLT MASS TIMBER AS A GREEN BUILDING MATERIAL (EXAMPLES)

4.1 Introduction

Over the years there have been several completed buildings with the usage of CLT mass timber in its construction most especially in Europe. CLT, is an engineered wood product, is being used over in Europe in buildings upwards of eight storeys and proposals up to seventeen storeys. Initially, the usage CLT mass timber began with just the construction of family spaces which quickly expanded to the development of the extended family, school / educational building, complex residential building all using CLT mass timber as the larger percentage of the construction.

The chapter focuses on the description of several lists of building accomplished majorly with the usage of CLT mass timber in the construction.

CLT Mass timber exists naturally which contributes to its green sustainability, it is warm in texture, very attractive in its appearance, architects have been able to modify mass

timber to the desired shape with smooth edges. Its ability to store carbon, thereby reducing pollution has contributed largely to its use as a better choice of selection among its peers.

4.2 Example 1: Limnologen apartment complex, Växjö, Sweden

In Sweden, a town in Valle Broar region preferred the increase of CLT mass timber in construction, an initiation which began in 2002. The movement states that in all region of the town, all construction must be majorly composed of timber or wood products. As a result of an architecture competition, the Limnologen complex was born. It consists of four eight- storey apartment buildings, with a concrete foundation on the first floor and a seven floor of timber constructing material Figure 4.1 shows the limnologen building apartment. The Swedish government pose the building construction design as a base of research and development where the Linnaeus University and the SP Technical Research Institute have access to Vale Broar projects construction due to the uniqueness of the building.

Figure 4.1: The Limnologen building apartment, Sweden (Serrano, 2009)

- ***Structure***

Cross laminated timber elements form the basic component of the material bearing the load. Both walls and floors can be built using CLT timber. The walls separating apartments

and some others are made with traditional timber frames. The Limnologen buildings have a complex geometry of some sort, thereby requiring optimization of the construction of the building. The base floor is made with concrete. This is because of the additional weight with which it will sustain. The vertical loads of the building construction are adopted by the exterior walls and interior. The parts of the building that provides the stabilizing effect include the floor, the exterior walls that separate the other walls. The floors act as stiff plates where the horizontal loads are transferred to the walls. Engineers do make a note to supplement the bearing system with adequate glulam columns and beams in order to reduce possible deformities in the required part of the room (Serrano, 2009; Harte, 2017).

- ***Stabilization***

For the lift up, 48 tie rods were erected in all constructed building. Tension rods pick their base from the concrete up to the bottom floor, thereby extending in height and eventually into the walls of the interior. By doing this, there is a transfer of forces the foundation of the elements of the wall (Serrano, 2009). Due to possible steel relaxation, deformations, wood drying, tension rods must be retightened occasionally. (Harte, 2017).

- ***Fire management***

In case of a possible outbreak of fire, the Limnologen complex is equipped with residential sprinklers. This is usually not required according to the law guiding selfish building construction, but it has allowed for the implementation of some unusual designs. This is evident as revealed by a publication that the appearance of the wood, the distance of the windows can also be minimized with the use of wood CLT in the balconies (Serrano, 2009). There are more current fire performance tests indicating CLT is capable of being completely exposed and having adequate fire resistance ratings to meet code requirements (Schmidt, & Griffin, 2013).

- ***Protection from moisture and inclement weather***

The elements of the walls and floors can be manufactured inside before their transportation to Växjö in Sweden. The packaging of the wall element is ensured by simply covering it in a film made entirely from plastic recyclable material which then transported back in an upright position using larger trucks. The elements of the floors are typically wrapped using tarpaulins that are used to cover the truck. The forklift was used for the offloading at the

construction site and the elements are put on the ground before its transfer to the assembling department. A large tent was installed to provide shade against bad weather condition. Figure 4.2 shows an overview of the water system at the Limnologen building, Sweden.

Figure 4.2: Overview of the water system at the Limnologen building, Sweden (Gasparri, 2015)

- ***Walls***

The three (3) main wall types are used in the construction of the Limnologen are listed below;

(a) CLT exterior walls
(b) Separating walls
(c) Interior CLT walls (3 layers)

The facades are usually covered with panels of CLT wood timber with finishing touches from gypsum (Serrano, 2009).

- ***Floor structure***

The builders used lateral loading the CLT flooring diaphragm which can only be transferred in between the apartments at these connection points. Individual blocks were

designed to be structurally independent i.e. the way in which they are, they are not to carry the load of an entire structure (Reynolds, 2015). Each floor has a total of 30 floors elements. All levels of the building have the same plan except for the top floor. However, the floor elements in each storey are all different. The part of the floor elements that carry the heavy load has a CLT slab which its strength is increased using the glulam beams connected to the upper slap placed within a distance of 60cm. The entire building also employees a water-based floor heating system at Limnologen a floor heating system (water based) (Serrano, 2009).

4.3 Example 2: Mayfield School, Kent UK

This building was achieved in the United Kingdom which involves the expansion of a high school accommodating 1000 students in an attempt to expand it to accommodate an extension of 800 students extra including 80 more teachers. In total, the expansion would require about 8000m^2 area of expansion in less than 2 years. Because of these constraints, the structural solution chosen was CLT together with glulam beams and columns. Steel beams were used for particularly long spans in a small number of cases. The use of off-site manufacturing reduced the time on site and the superstructure was completed in 12 weeks. Figure 4.3 shows the buildings under construction (Hartmann, 2015) while Figure 4.4 shows the school building after construction. The lightweight timber significantly reduced the substructure works compared to a traditional concrete structure. Another key factor in achieving a shortened construction time was the use of an integrated building information modelling (BIM) approach.

Figure 4.3: The construction of Mayfield school, UK (Hartmann, 2015)

The lightweight timber significantly reduced the substructure works compared to a traditional concrete structure. Another key factor in achieving a shortened construction time was the use of an integrated building information modelling (BIM) approach. Where possible, the timber was left exposed, due to its aesthetic appeal, to provide a warm interior, and to take advantage of beneficial effect on learning provided by timber interiors (Harte, 2017).

Figure 4.4: The completion of Mayfield school, UK (Mayfield School, 2015)

4.4 Example 3: Brock Commons Student Residence

The construction of the student residence of the University of British Columbia (UBC) in Vancouver is an 18-storeys building will provide accommodation for over 400 students. The complex structure was made of a concrete ground floor with 17 story building on the concert ground floor made entirely of panels of CLT mass timber and glum as seen in Figure 4.5. A single crane was used to erect 17 timber structure in three months. The building construction also o serves as a laboratory ground for the students and researchers of the school. The 18-storeys building construction shows a drastic reduction in cost with the usage of CLT mass timber for its construction.

Figure 4.5: The UBC CLT mass timber construction
(www.archdaily.com/office/acton-ostry-architects)

- ***Structure***

This student building is born from the resultant element obtained from combining glulam woods and Cross Laminated Timber with a cement core. The building is constructed in a way that allows for CLT panels to spread in 2 directions with the support of beams. The units of repetitive house structure require a grid of 2.85 meters x 4 meters.Figure 4.6 shows The Brock Commons Residence under construction. With panels thickness of about 1.7 meters and 2.85 meters in wideness, about 12 meters' length. Using the measurement frame for the entire first up to the ninth floor, allowing steel for the roof structure (Fast, et al., 2016).

Figure 4.6: The Brock Commons Residence under construction
(www.canadianarchitects.com, 17February 2019)

- ***Wall and floor***

Beneath the XLT is an embodiment of 3 layers go drywall, and about 3 - 4 layers on the glue columns. The floor structure is made up of 5-ply cross laminated timber panels supported on glue (glulam) columns. The roof itself is made of prefabricated sections of metal and steel beams decking (Fast,et al., 2016)

For acoustical purposes, a layer of concrete is used to top up the CLT. Encapsulation is similar to that used when steel is the material of choice where gypsum board is used for fire protection purpose. With respect to the fire-resistant property of the CLT timber, much consideration has been associated with its usage for walls and floors in the building construction (Fast, et al., 2016).

- ***Stabilization***

The post installation process such as stabilization of the building construction requires the usage of the wood slab for the prefabrication of the wall panels located on the exterior in other to increase the rate at which the construction is moving, the glue laminated CLT slabs were fabricated off site and exterior wall panels were also prefabricated. In addition, it also decreases noise and construction interference.

The main work is prefabricated panels such as steel studs. These panels are used in the windows where they are boxed in a wooden compartment made with 70% of fibbers of wood (Fast, & Jackson, 2017).

4.5 Example 4: MIT's Mass Timber Design Longhouse

The group of researchers at MIT are Changing the mindset behind short-term constructions.This team of researchers at the university are using new and innovative initiative to investigate new designs of mass timber. Green mass timber wood-based buildings designed to be more efficient and cheaper than, yet just as durable as, concrete and steel buildings. The team proposes building mass timber longhouses – whose major component will be mainly wood products. Figure 4.7 shows the structure of the MIT Longhouse Structure.

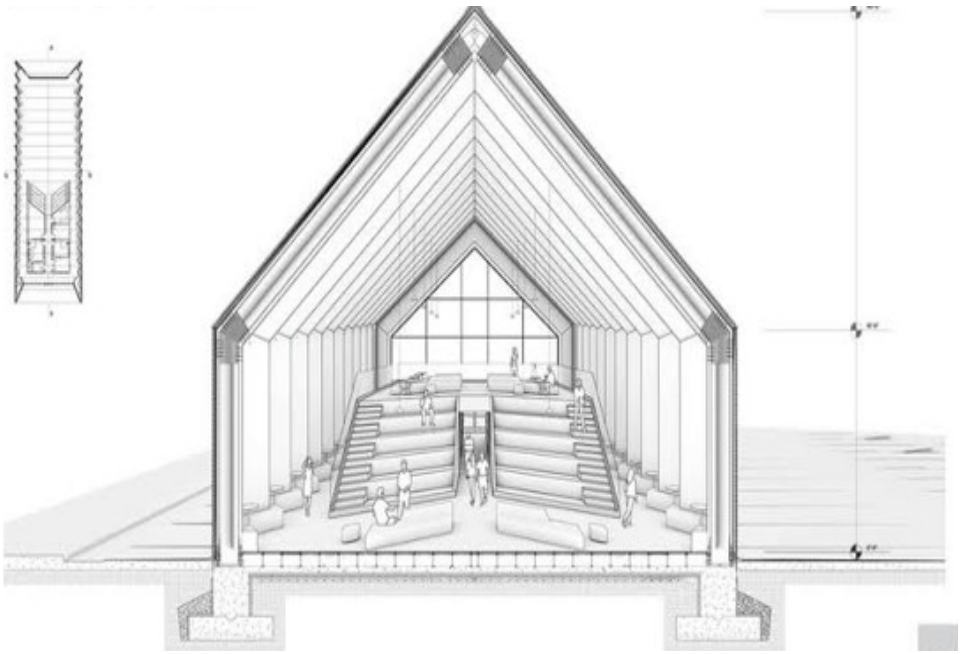


Figure 4.7: Structure of the MIT Longhouse Structure
(https://www.core77.com[Accessed:27,November 2018])

The proposed Longhouse building started by a team of the interdisciplinary committee of interest in mass timber. A workshop of MIT design proposes the exploration of the pportunities using CLT mass timber in architectural design. As a result of its efficiency, speed, versatility and precision in construction, green mass timber receiving significant

interest over the years for building design, and construction technology. Green mass timber buildings are gaining attention throughout the world, most importantly because of its green eco-friendly benefits of the environment with potentiality on medical health improvement as a result of great environmental air quality. The Green building prototype design shown in Figure 4.8 by MIT design team aims to explore the engineering potential and technological advancement of wood timber technology.

Figure 4.8: MIT Green Mass Building Prototype
(www.syr-res.com/pic_ret.php?id=39267&b=1)

The building is proposed to be on the MIT campus with modern technology that will consist of ideas from the past, they propose building a high-tech wooden multi-purpose building on theMIT campus. While it is taking a step back in time, the building will be outfitted to be producing energy. The team describes the building as a depth engineering design that traps solar needs with a window to wall ratio resulting low for allow efficient energy system of the building construction (Yee, 2010).

The engineering groundwork of the construction is based on a several understanding of CLT wood timber at large laid across short distances for the purpose of flexibility. Also, to provide support and rigidity for the entire building and reduce deforestation in the structure

the design uses a thin-walled triangular profile. For now, it is only an idea proposed to face the

concrete energy and pollution problem. As exciting as the project seems, other organizations and companies leading similar initiatives to incorporate sustainable timber designs as a long-term building solution.

4.6 Example 5: Level Architecture

Another company by the name of Lever Architecture has completed a12-storys wooden skyscraper in Portland, Oregon. Their design was approved in 2015 and completed in 2016. Figure 4.9 shows the building construction won the American first wooden and highest skyscraper(www.urbannext.net/wooden-skyscraper/).

Figure 4.9: Lever Architecture (www.urbannext.net/wooden-skyscraper/)

4.7 Example: Sumitomo Forestry

A leading timber company in Japan, Sumitomo Forestry has revealed plans to erect the world's tallest wooden building in Tokyo. As the building will be as high as 350-metre, it will easily be the country's tallest as well. The proposed project named W350, to be constructed to mark the 350th anniversary of the company in 2041, is set to be 70 storeys, made from hybrid timber material, will be almost 4 times higher than the current tallest

timber in the world, i.e. the 18storeys Brock Commons Student Residence in Vancouver, Canada. The skyscraper is designed by Sumitomo's Tsukuba Research Laboratory in collaboration with Tokyo practice Nikken Sekkei is an ambitious project to be marvelled at indeed. Figure 4.10. shows the Sumitomo Forestry.

Figure 4.10: Sumitomo Forestry(Kremer & Symmons, 2015)

- ***Structure***

The primary element in the hybrid structure is said to be timber (about 185,000 cubic meters proposed) and is expected to make up about 90% of the building. Other components will be steel, together with timber tube used in making columns and beams i.e. "braced tube structure" supplemented by additional diagonal steel braces. The multi-purpose tower will house offices, hotel, residential units and shops with a vegetation cover in and around the balcony.Figure 4.11. shows The Proposed Sumitomo Forestry building.

Figure 4.11: Proposed Sumitomo Forestry building
(https://inhabitat.com/japanese- Builder[accessed 26 February 2019])

Naturally, there are many solutions to the problem of construction-energy epidemic of the 21st century. While there are many new materials that hold promise to eventually change from concrete and steel buildings. The Green Building Council of Australia (GBCA) advocates across all levels of government to promote a green building agenda. As part of the GBCA 'Green Star' program several design tools and calculators are provided to developers, builders, and specifiers for the production of sustainable building practices and green rated built environments One of the major consideration of architects and engineers in building construction is the cost effectives of materials. However, there are several contributing factors to the decision of building materials. Some materials selection is based on the aesthetics characteristics of the building such as height for hotel construction, characteristics of the predetermined environment such as swimming pools, securities and possibly the longevity of the building (Kremer & Symmons, 2015).

4.8 Conclusion

All around the world, especially in the developed nations, the benefit of engaging sustainable materials in the construction of buildings is being known and high rising structures are constantly constructed with impressive results and added advantages. The positive values which have given mass timber products an edge over concrete and steel are exploited and long-term planning has been included into future designs and plans of important industries and companies of the world.

It has now done on the developing nations to further subscribe to this new idea of keeping the environment healthy while not limiting the aesthetic and natural comfort that comes with this set of improvement in the building construction industry.

CHAPTER 5
A CASE STUDY IN NORTH NICOSIA

5.1 Introduction

This chapter focuses on the detailed analysis of a building which was selected as the case study. In the north of Nicosia as a whole is discussed with respect to its geographic location and environmental conditions. In comparison with the existing building, which is built majorly with concrete and steel, these materials having successfully established them to be unsustainable in the previous chapters, this project establishes a template using 3D drawings and architectural modifications to replace or better still replicate the case study using mass timber based sustainable material. Lastly, the basic principles that were followed in the construction of different components of the building were discussed and the various connection systems to be used in linking joints of the different and same kind were also examined. The advantages offered by CLT as a sustainable building material over concrete and steel were subsequently put into perspective as well.

5.2 Cyprus Island and Geographic Information

The island of Cyprus is the third largest island located at the east of the Mediterranean.The largest and capital city of Cyprus is Nicosiaon at latitude 35.1856° N, longitude 33.3823°E. Figure 5.1 shows the Cyprus map.Cyprus is one of the few places on earth where geology has been the most important factor in the development of its natural environment and its socio-economic and historical evolution both in antiquity and in modern times. The resultant impressive topography of nearly 2,000 metres in height had a direct or indirect effect on the environment and all aspects of life on the island. It has a favourable impact on the climate and has resulted in a variety of microclimates. the mineral wealth and the strategies geographic position were the most important factors in the historical and cultural evolution of the island. The differential emergence of Troodos exposed all the rocks of the stratigraphy of the island and many of them were used as building stone from the Neolithic Era until the present time. This island has been existing since about 10 hundred years BC from which time substances were gathered from this

period confirmed the prior existence of the village of Khirokitia(Chrysostomou, et. al., 2003).

Figure 5.1: Map ofCyprus (Worldmap, 2016)

According to Britanica, Cyprus has a total land area 9,251 sq km^2 with a density of 132.2 person/sq km (https://www.britannica.com/place/Cyprus, accessed April 1, 2019). The island witnesses hot summers between June and September and rainy winter between November and March. The temperature varies between 37°c and of 40°c in summer , but can also be as low as 9°c during the winter. Figure 5.2 shows the Cyprus climate chart of Cyprus (http://kktcmeteor.org/meteorolojikbilgi/kibris-iklimi).

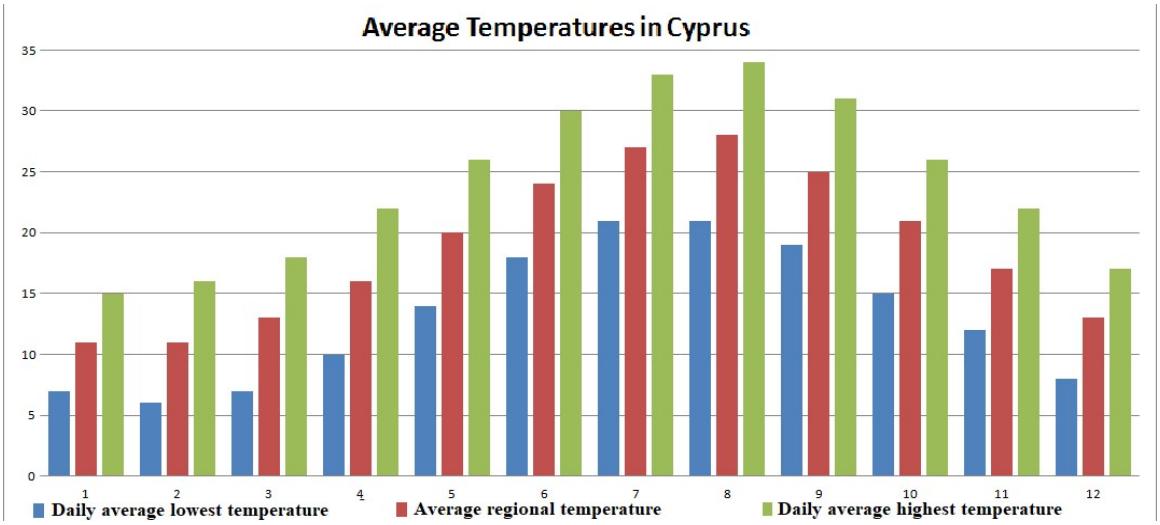


Figure 5.2: Climate chart ofCyprus (Worldmap, 2016)

Average humidity in Nicosia;

- On average, January is the most humid.
- On average, July is the least humid month.
- The average annual percentage of humidity is: 55.0%, (www.weather-and-climate.com).

Average wind speed in Nicosia;

- On average, the most wind is seen in July.
- On average, the least wind is seen in October, (www.weather-and-climate.com).

5.3 Environmental conditions in Cyprus

Cyprus has some features which make it similar and also set it apart from other countries of the world. The peculiarities of this country briefly discussed below;

***Climate change*:** Just like it's being felt all around the world, Cyprus is also experiencing climate change. Evidently, the effect of this is manifested in the different pattern in some trends in the society such as prolonged drought, size of water bodies, biodiversity e.t.c. This is however a big challenge since for over a decade, between the early 1990s and 2000s the rate of gases that were emitted into the atmosphere rises by 52%. This is related to the high level of industrialization and burning of fossil fuels. Despite the refusal of the country to lean towards the path of others, measures were put in place against greenhouse gas which includes power generation through renewable sources, monitoring and regulation of fossil fuels emission by cars, and proposal channels for solid wastes among others (Zachariadis, 2011).

***Nature and biodiversity*:** to preserve the natural habitat of most animals, to prevent their kinds from going into extinction, Cyprus has established sites of the community to interact and work in tandem with Special Protected Areas. This is part of the efforts initiated to aid conservation of plants and animals. The major challenges faced in the conservation of natural endowment is a direct impact of climate change together with other factors such as

poor land management scheme, the unauthorized sacking of forests and forest reserves (Gao, 2006).

***Air quality and air pollution*:** Industrialization and urbanization have decreased the standard of quality of which is expected for air which we breathe in. Gases that are unfit for inhalation such as oxides of Nitrogen and CO either through find their way I to the atmosphere either through direct or indirect sources. In essence, Anthropogenic gases are still a primary concern since they are a source of persistent air pollution. The country made provisions for generating data on the level of disturbances and the natural resources of the country that are further exploited (Kostopoulou, 2007).

***Waste*:** Cyprus is known for systemic ways of waste production management, the country adopts the recycling system which separates several wastes asides. Being an observant student residing in the country, the country gives room for proper disposal of toxic wastes with little impact into the ecosystem. The government ensures waste bins that separate plastics, cans, and paper apart. This recycling bin is located in all bus stop across the country

***Earthquakes*:** According to the Geological Survey of Cyprus, several earthquakes have occurred in Cyprus the first occurring on October 9, 1996, having a magnitude of 6.8 around the Eastern Mediterranean in Cyprus causing havocsin Nicosia, Paphos, and Limassol. Other minor earthquakes were also recorded with minor damages to the country. The data recorded demonstrated by the Geological Survey of Cyprus shows that the peaks of magnitude recorded in Cyprus compares fairly with the world calculated earthquake data (Kalogeras et,al., 1999).

5.4 Analysis of Case Study

The thesis case study focuses on three storeys building located in Nicosia, Cyprus. Cyprus is known to house several universities, enriching the country with diversity in culture as students from several parts of the world studies in the country.

The case study in question is Selba Homes apartments, located in Bolu Sokak Street, Nicosia, Cyprus. Analysing each level of the building provides detailed information about

the sustainability of the material used the location of the case study can be seen inFigure 5.3.

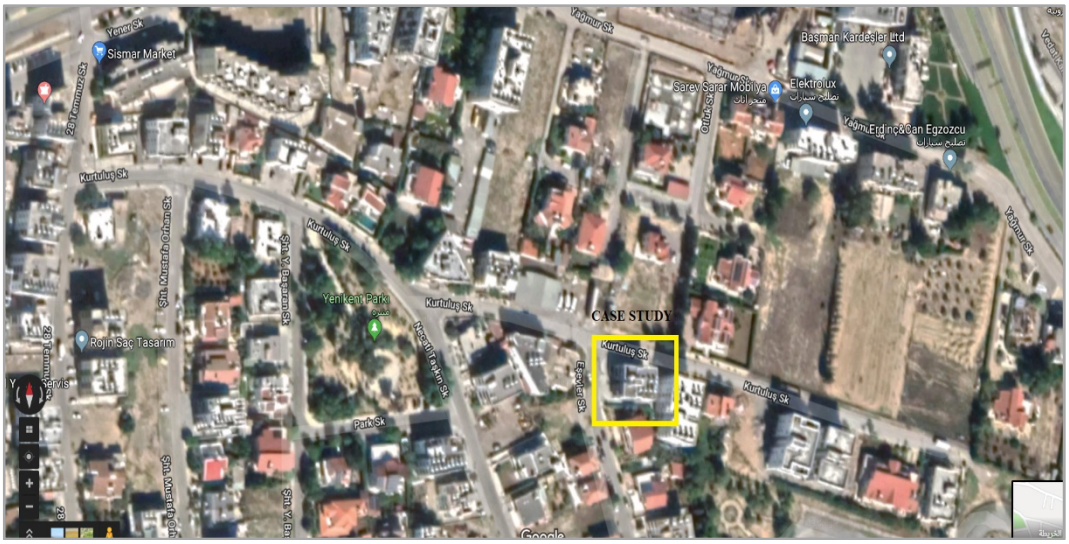


Figure 5.3: Location of the case study (google maps 2019)

To analyse the building with fair judgement, a 3D model of the building with its exact building material was created and summarized in Table 5.1 which would be replaced by the proposed CLT version. The studied building consists of three residential floors, with each floor containing two apartments with a total of six apartments while using the ground floor as a car park area. The building belongs to Selba Homes Company and has been reproduced for with his full permission for research purposes only. According to Selba Homes Company, the building was built in about a year starting its erection in February 2015 with finishing touches towards the end of the year 2016. The landlord also employed “Selba Homes Company " for the interior design of the entire building making it an ideal building for both tourist and international students. The construction materials employed in the building construction includes the following;

Case study building construction reinforced concrete: These are building construction materials that are made from a mixture of sand, gravel, cement and water. Majority of buildings that are erected in most major cities and town, these days will have any of their parts made up of reinforced concrete. The name reinforced came from the fact that during the preparation of the material, there is the addition of support or a form of reinforcement

to concrete to raise its durability, thermal capability, durability, and tensile strain. It is present by introducing steel materials prior to the addition of concrete. The supporting material can either be; steel (most common) and polymer. Figure 5.4 below shows a typical of the construction system that was used for the building (reinforced concrete frame system) (Broomfield, 2006).

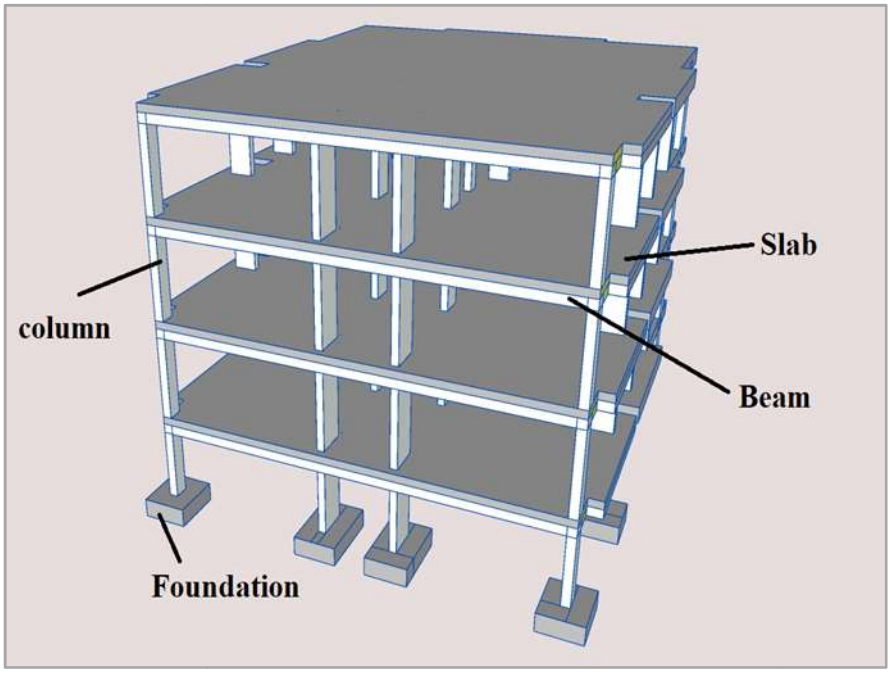


Figure 5.4: Reinforced concrete frame

It should however be noted that even though concrete serves some important roles in putting up a structural framework. It's can be plastering and holding structures together, strong pillars and points as the sole material. But when it comes to erecting a building properly, it’s close to impossible to implement the exact same procedure of using concrete only. The thesis deemed it necessary to evaluate the potentiality of reproducing the exact building of Selba Homes Company using almost entirely CLT mass timber to improve the sustainability of the building at large. Table 5.1: shows the case study analysis.

Table 5.1: Case study analysis

CASE STUDY PHOTOS	3D MODEL OF CLT	REMARKS
 North view	 North view	The north view of the case study building shows the detailed three - storey building in detail with the basement serving as the garage. The 3D model using similar fabrication system to the case study photo.
 East view	 East view	Similarly, the side picture illustration of the case study apartment shows the resemblance of the building with respect to the proposed three-dimensional model structure of the same building construction.

Furthermore, knowing the required dimensions of each segment of the building would allow offsite fabrication of the CLT panels as opposed to the other unsustainable building. Using adequate connection systems as discussed in chapter three, the building panels would fit into the appropriate spots and angles. The approximate initial calculations show that the difference between the quantities of non-green building materials and the quantities of green building material is very large, The difference is significant after

calculating the proposed building weight of the CLT and the reinforced concrete (RC) building of the study of as seen in Table 5.2.

Table 5.2: Required amount of CLTbuildingsand RC building

DETAILS	PROPOSED BUILDING		EXISTING BUILDING	
Building components	**AMOUNT of CLT (m^3)(3floors)**	**Weight (450 kg/m^3)**	**AMOUNT (m^3)**	**Weight (2400kg/m3)**
Roofing slabs (15mm)	~ 71m^3	31950 kg	(C25) 23.75m^3	57000 kg
Internal wall (10mm)	~ 74 m^3	33300kg	128032.3 Bricks = 96m3	88512 kg
Exterior wall (20 mm)	~ 85 m^3	38250 kg	10200 Bricks =76.50m3	70533 kg
Stairs	~ 9 m^3	4050 kg	9 m^3	21600 kg
Parapet ofthe terrace (20 mm)	~14 m^3	6300kg	2380Bricks=17.85m3	16457.7 kg
Total plaster	NO	NO	90 m^3	90000 kg
Concrete screed	NO	NO	90000kg	90000kg
Steel (S 420)	NO	NO	11.1 tons×3=	33.3tons
Total amount	~ 253 m^3	~ 113850 kg	RC 160 m^3Bricks 190 m^3	384000 kg

5.5 Sustainable CLT Building Materials for Case Study

Thinking about future generations is one of the most important priorities of good governments. Governments are working to provide a healthy environment for citizens at present and in the future. The road to creating a healthy and sustainable environment comes from the use of sustainable materials and does not adversely affect the environment. Several studies have reported health hazards as a result of the usage of unsustainable building materials. Therefore, the need to switch to a greener, the sustainable model cannot be overemphasized. Majority of the leading countries have already begun to resort to the use of greener building materials as fully discussed in the previous chapter. One of the

most important materials is cross-laminated timber (CLT) obtained finely from wood, considered one of the best sustainable building materials, in this thesis CLT building material is explained in detailed in chapter 3, CLT material will be replaced with reinforced concrete & bricks in the case study building. The entire stages of construction plan proposed are detailed below;

- **CLT at construction phase**

The prediction level of the CLT used will have to detail to an extent as the architects will keep in mind to make provisions for technical installations as detailed in Figure 5.6 that will later be made in the construction stages such as the elevation plans and connection methods. Plans will be concluded on the choice and type of arrangement to be made on mechanical, electrical and plumbing works that the house will bear which will be detailed out to the company to carry out the prefabrication. This will lead to the reduced time needed for the actual erection of the building.The case study building's typical floor and CLTreplaced typical floor plan is shown in Figure 5.5a andFigure 5.5b.

Figure 5.5a: CLT replaced plan

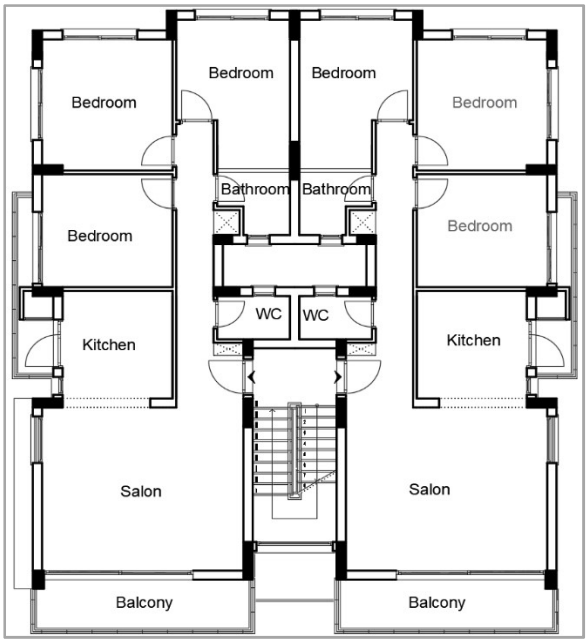


Figure 5.5b: Existing case study plan

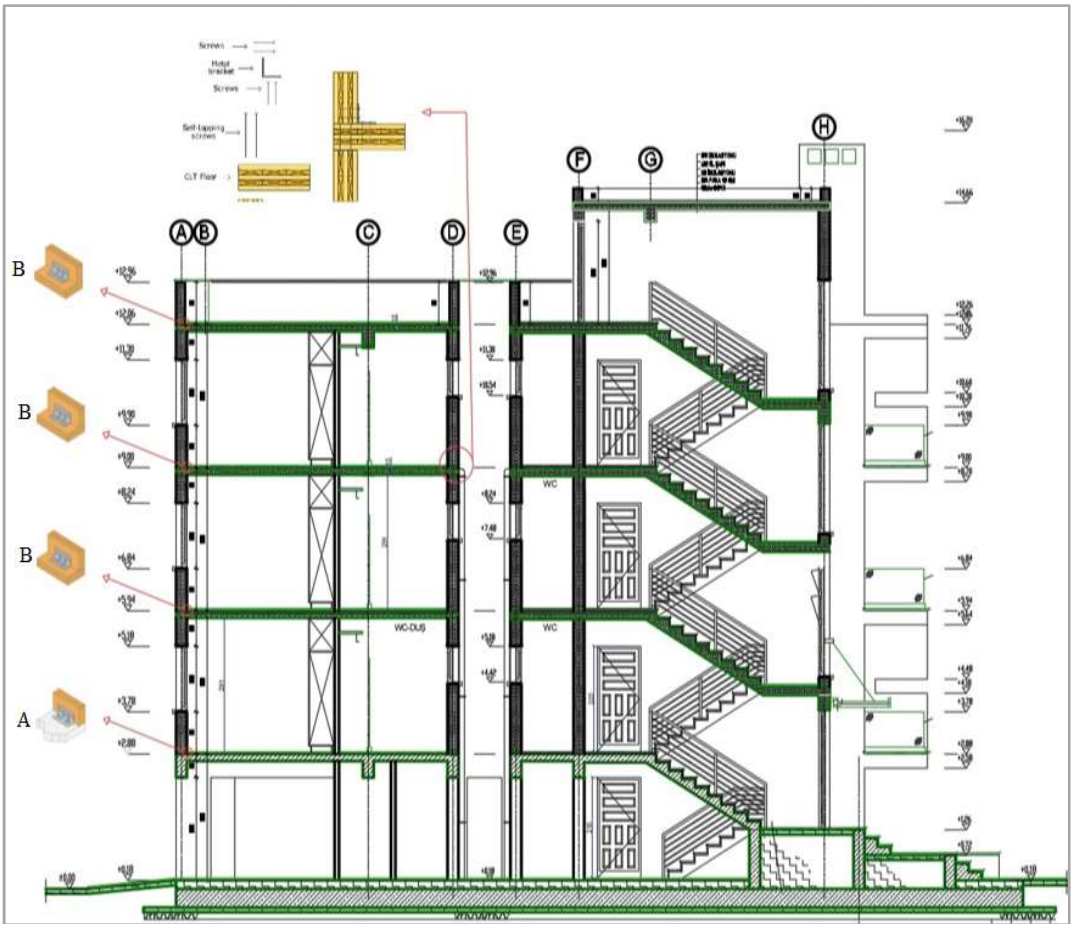


Figure 5.6: Section in the CLT building

- **Reinforced ground floor initiation**

Providing private parking lot for the occupants of the building, the building plan initiates a base grounded parking spaces that elevate the three-storeys building in a strong framework. Figure 5.7 below shows the ground floor of the building. This stage starts from putting the foundation in the ground which involves processes like excavation whereby sand materials, rocks or stones are removed from the ground to pave way for the introduction of mixed concrete, and steel. This will be allowed to cure for up to 15 days. Like in traditional construction of buildings, the lowest floor is still heavily supported by steel. Up to about 5 levels of Cross Laminated Timber panels are used together with reinforced concrete.

The major elements that also played in putting the first, second and third floor in place are concrete as done with the foundation. This will provide the building with rigidity and seismic performance. This is mainly due to the magnitude of the load which they will be carrying. This way, they can transfer the weight upon them to the base floor. The stair will be by CLT materials and this will be constructed at a time bridge provided at that point when the 2nd and 3rd label are being given a time gap too. The engineers will have to focus on the use of material first, which may be the concrete before the other as it will prevent the clash in equipment at the site.

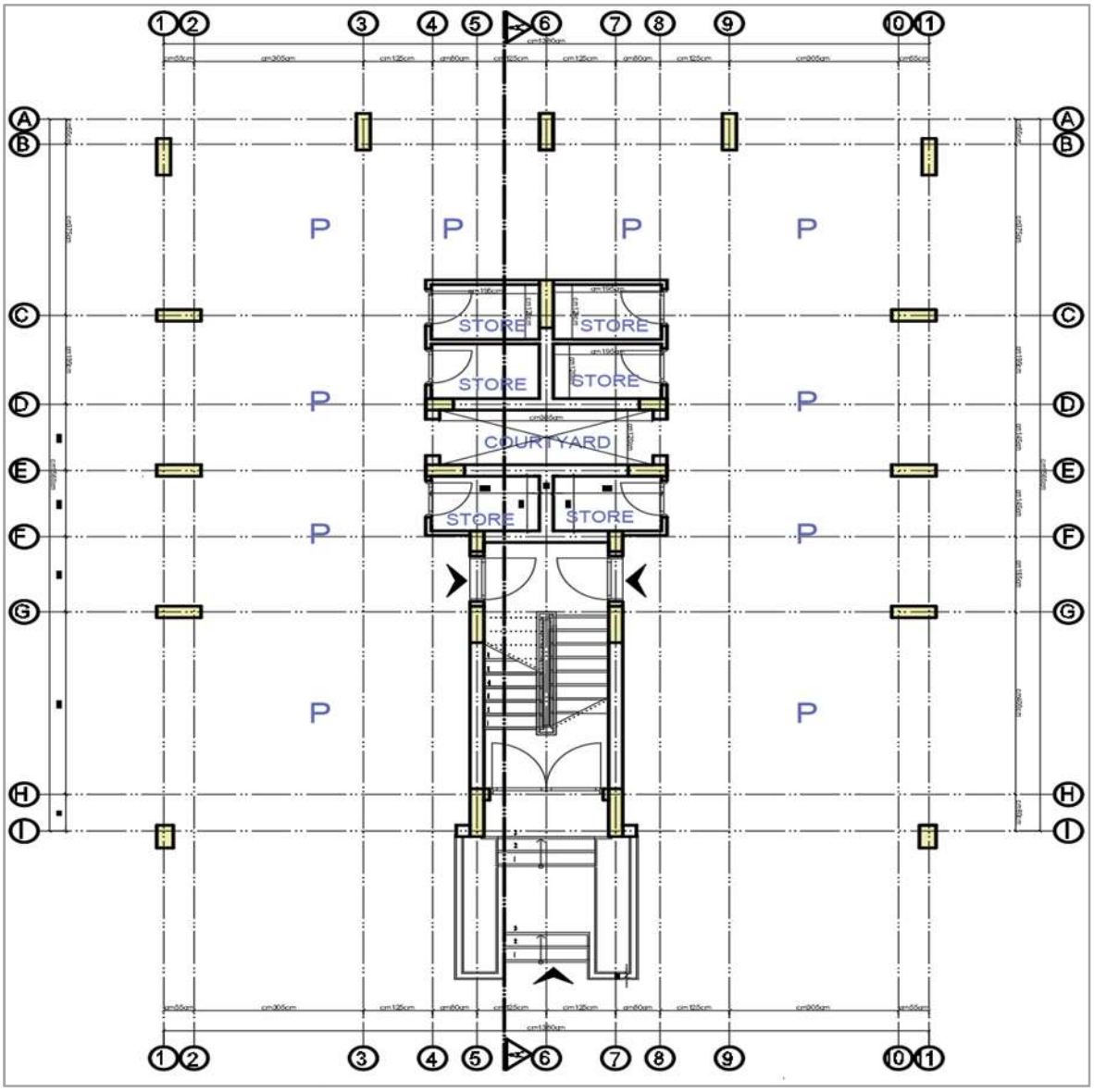


Figure 5.7: Plan of the ground floor

- **Implementing CLT on the walls and roof**

Varying parts of the building will be made of five layers of planks mostly the walls of the outer structures and three layers in inner walls. Workers will be stationed on each floor to receive panels that are transferred up by cranes thereby saving the time of construction by five folds as opposed the alternative building materials. Asides, CLT time conservation, the cost of implanting CLT on the walls of the building is 60 % less than the bricks used in the described building.

A similar model was employed in the roof as in wall using five layers of CLT panels will be placed on the already erected walls with the aid of viable joining materials. The weight provided by the roof was shared on the entire walls on which it rests. Reinforced concrete may also be used to be the first level of support which will then channel the weight of the load into the ground. The outside space of each level of the apartment opens to an outside space by using glass aligned with metal hooks and support. The material used for the construction of the roof is CLT ones which are able to last for decades and also possess important features such as fire resistance, durability among others.

CLT interior layout

The remodelled3D interior and exterior design of the Selba Homes Company building using mainly sustainable CLT building material is shown in Table 5.3. The initial work has to do with having windows and doors that open to different sections of the house fitted and also having protective sidings in place. Floor drains were installed in balconies, kitchens and bathrooms to prevent water. The selected material used in the interior space of the flats is by CLT however, the users are free to use ceramics and mosaic allowing a modern style of the interior architectural design of the building. The type of system employed for the technology works to be carried out in the building allows the panels to be cut into adequate forms and sizes from the factory. The interior partitions as seen in Table 5.3 are wood board, while the interior cabinetry and woodwork are laminate particle board.

Table 5.3: CLT 3D model fabrication

3D VIEW	INTERIOR DESIGN
 Front view	 Salon
 Westernview	 Bedroom
 Topview	 Bathroom

The final part of the operation involves fitting CLT designed cabinets, plastering of floors and also having the mechanical, electrical and plumbing workers put finishing touches on their work. Lastly, the inner part of the building will be painted at about the same time as the exterior. The entire plan has been well structured so as to prevent the hindrance of a phase by the delayed completion of a proceeding other.

5.6 Connection systems

When joining CLT components, it rests on the builders to be mindful of not only the load to be heated by the materials but also other features which are in play and they include thermal resistance, air tightness among others. These parts are glued together and also held in place at the point of linkage between the wall and floor illustrated in Figure 5.8 and Figure 5.9.

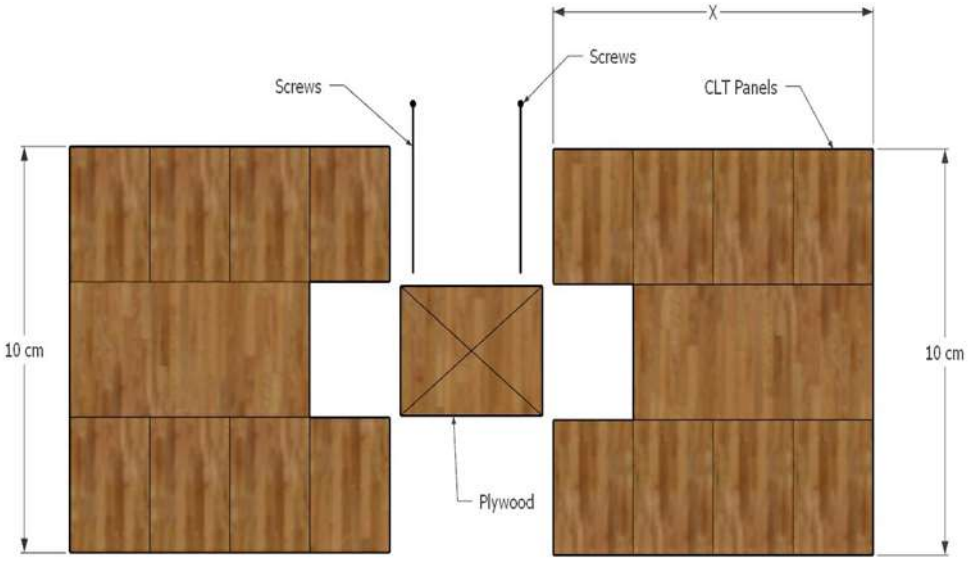


Figure 5.8: Lumber splines within 3 layers panels

As previously discussed in Chapter three, some of the connection materials that will be employed include self-tapping screws and nails. The self-tapping screws will be used to hold upright partitions inside a building or walls with floors. The interior walls that were used for the wood timber-based building are of three layers, while that which was used for the exterior walls were five layers thick.

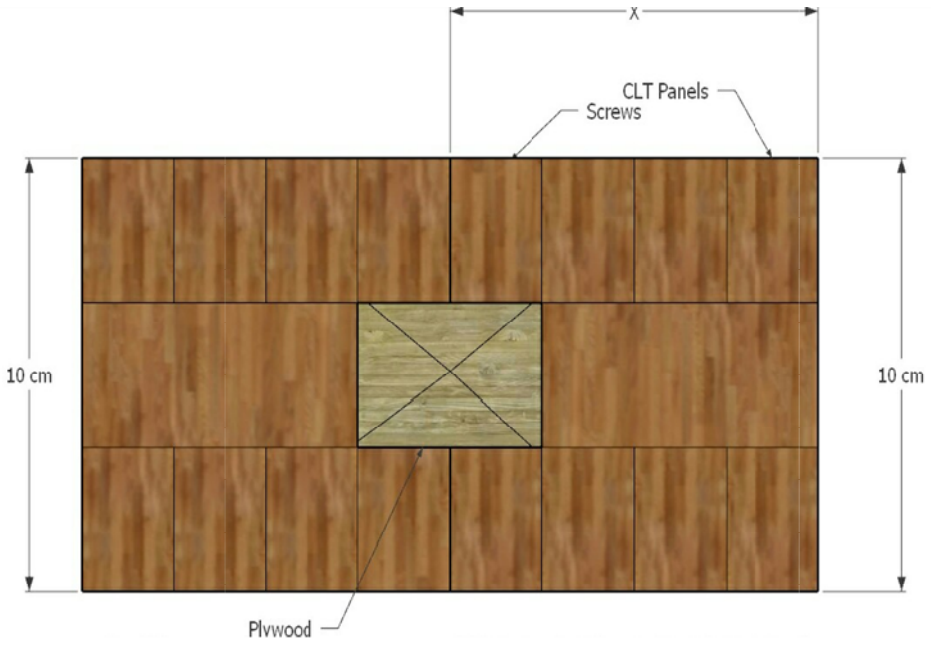
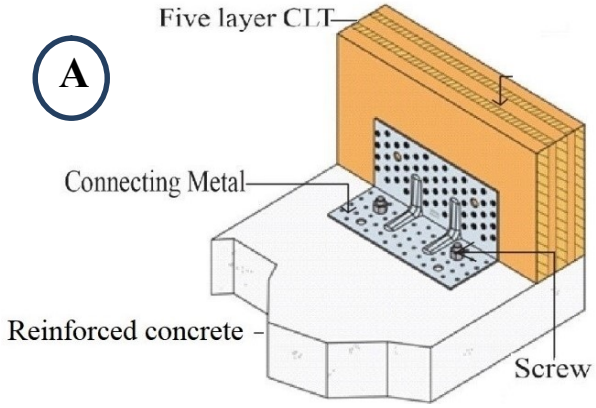
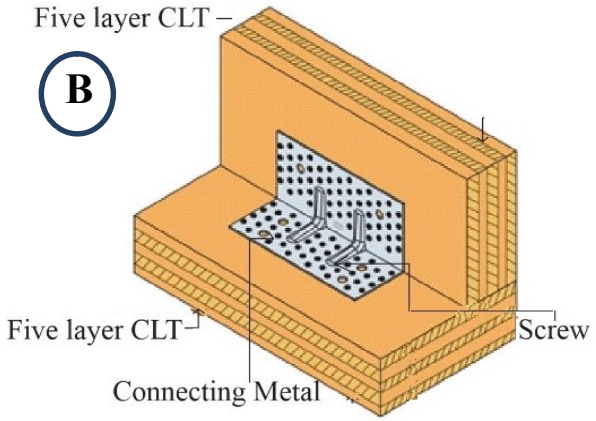


Figure 5.9: Connection of CLT with screws

They are placed within joints positioned at right angles and held in place with nails or screws. When roofs are joined to walls, screws and nails are used.

Lumber splines are to be used to hold two panels of CLT horizontally. The splines are either used within the panels on either or both sides of the surface. The walls are to be connected to the floor using metal screws. They are placed at the joints of panels and nail is used to establish the connection between walls and right angles. If the walls are to be connected with concrete as with the ground floor of the building, different forms of connecting systems are used which includes brackets and exterior metal plates. Table 5.4connection points of CLT panels (CLT with CLT slabs) and (CLT with reinforced concrete slab).

Table 5.4: Connection points of CLT 5 layers of panels and reinforced concrete

CONNECTION POINTS	EXPLANATIONS
	• **CLT with reinforced concrete slab** As represented in figure 5.5detail A, the sort of connection that exists between a CLT panel and a horizontal concrete surface. Usually found in the connections between the ground floor and the first floor.
	• **CLT with CLT slabs** As shown in figure 5.5 detail B, the sample connection that exists at various joints in the building where CLT panels are joined with Each other. The panels are held together with metal brackets before driving nails through.

In any case, joining the CLT and concrete could reduce the lifespan of panels. Instead, a small wood is fitted to serve as a link between the two. All joining materials to be exposed to the exterior will be galvanized to prevent quick degradation.

5.7 Significance of CLT Over Reinforced Concrete Building Material

According to Table 3.3 in chapter three the proposed building structure using CLT mass timber offers profound significant importance when compared to other building construction materials such as Reinforced Concrete in the case study building;

- **VISUAL**

CLT possess an advantage over RC due to its naturally occurring color and shape having a good effect on the users in all ramifications such as health, environmental impacts and aesthetic value, while the color of RC or bricks has a bad impact on users.

- **PHYSICAL**

The density of building materials explains the compactness of the materials; it shows how packed in mass per unit volume the building material is. Reinforced concrete having a compact density of 2500 kg/m^3 while Cross Laminate Timber has about 400 kg/m3 to 500 kg/m3. The given standard values explain that Reinforced concrete is tightly packed with is responsible for its heaviness.

For specific load bearing applications, the weight of building materials reflects the rigidity, toughness and overall strength of the building material. RC possess a unit weight (γ) of ≈ 25.0 kN/m3 while CLT has its unity weight $\gamma \approx$ 100Kg up to 7,000 kg.

Moisture is responsible for the hygrothermal simulation of building material, its allows easy turnability and fabrication of the building material for its required application. CLT is enhanced in the fabrication of the building material (between 10 -14%). Vapour permeable (breathing) and vapour retardant of the building material is also largely required. Depending on the moisture content, diffusion resistance value(μ) is typically around the value of 40-80.

CLT acts as a larger insulating layer over RC in terms of sound and vibration reduction. Having an acoustic property that prevents noise throughout the entire building. CLT has also proven to have a remarkable acoustic performance although, flanking sound (flanking noise) may be impacted. Reinforced oncrete is an excellent acoustic insulator from airborne noises.

CLThas a comparatively high specific heat capacity (thermal inertia). Usually it is around 1300 J/kg°C and compared to concrete which has about 880J/kg°C. CLT should be used more in construction because material is energy and heat effective and CLT can make positive climate changes.

- **CHEMICAL**

The detail analysis of CLT as a fire resistance engineered product according to the En13501 report provides fire of 0.67 mm/min attack, with its resistance based on the possession of the several insulating layer of the panels while RC in most cases, concrete does not require any additional fire-protection because of its built-in resistance to fire. It is a non-combustible material (i.e. it does not burn)

Corrosion is influenced by microorganisms that performs electrochemical reactions on building materials. CLT Moisture activate fungus and other biological materials causing corrosion while the Exposure of reinforced concrete to chloride ions is the primary cause of premature corrosion of steel reinforcement

Bricks made from concrete may contain minute amount of radioactive materials such as uranium and thorium. While the levels of radiation present in bricks are low, they are slightly higher than some other building materials. CLT shows no signs of toxic radioactive materials thereby allowing its safe usage for vast applications.

- **MECHANICAL**

Reinforced concrete has a compressive strength in the region of 4,000 psi, Reinforced concrete has a compressive strength in the region of 4,000 psi, the elastic modulus of the hardened paste may be in the order of 10-30 GPa and aggregates about 45 to 85 GPa. While CLT has a bending strength of 24N/mm2 and a modulus of elasticity of 11,000 N/mm^2.

The shearing property of building materials are important in the evaluation of the comparative mechanical property of the building material. CLT Shearing strength allows for large amount of bending allowing its usage in a wider range of application as opposed the other building construction materials, 0.24 % per 1% change in moisture. While that of RC shear strength of concrete when required stirrups are used in members made with fc' = 4000 psi concrete.

- **TECHNOLOGICAL**

CLT Fracture of shearing analysis of CLT reveals the major contributing factor. Several studies have revealed that CLT can withstand pressure without deformation which allows it for tall building construction will lesser fracture and increase impact resistance. Making RC a better selection over CLT.

CLT building material has the potential to be combined with other building materials, allowing its increase ability of properties which does not allow abrasion of CLT building material to have effects on the mechanical property of the building material as oppose to RC where the abrasion of reinforced concrete have effects on the mechanical property of the building material.

Records has shown that storey building material of CLT are susceptible to shrinkage. The swelling as shrinkage of the building materials is to be considered during the building construction when using CLT as the building material. For RC, shrinkage is one of four phenomena that are considered as causing volume changes in concrete.

- **HUMAN HEALTH**

CLT as regarding health, a total of 1643kg CO2 was sequestered per tons by reducing the use of toxic chemical substances, making CLT a safer health impact option than the latter. RC is one of the main sources of carbon dioxide emissions, which bears a large part of the responsibility for global warming. Between 5 and 10 percent of total global CO2 emissions are related to the production and transport of cement used in the main elements of the reinforced concrete used in building.

CLT building material having a positive biophilic impacts of physical and psychological well being is responsible for a warming, cosy material effects on emotional state of people like calming effect, drop in blood pressure and pulse as RC have a bad effect on the feelings of users, must be painted to get good psychological comfort.

CLT Possessing light weight structure, fire safe building construction and ease of modification it does not only improve on the weight effect of building material but also increases the safety issue during the usage of the building. Has a good smell, promote human health wellbeing of mind and body? Because of its strength and dimensional stability, mass timber offers a low-carbon alternative to RC that hasheavyweight structure, fire safe building construction and hard of modification it does not only improve on the weight effect of building material but also increases the safety issue during the usage of the building.

- **ECONOMIC**

Determining the true cost of a building material requires evaluating the product over its life cycle and taking into account environmental as well as monetary costs. By these measures, wood frequently offers significant overall efficiencies over comparable materials such as concrete and steel.The reserve source allows both in aesthetic nature and sustainable purposes. Whilereinforced concrete is non-renewable and the cost of sustainability is expensive **.**For production cost, CLTis light in weight, requires less transport (production) energy overall making its economic resources highly efficient.RCis heavy in weight, requires more transport (production) energy overall making its more expensive than CLT.
In consideration of Transportation, storage, maintenance & repair cost, the economic transportation property allows a faster speed in both production and transportation. Storage cost is reduced as CLT is directly transported for on-site usage. Maintenance & repair costs are minimal when compared to reinforced concrete.

When these trees are harvested, there are careful plans in place to plant a new set of trees in place of the ones removed. Carbon which is generated from the use of others such as Steel and Concrete contributes to global warming and climate change. In contrast, the carbon footprint of the tree is light as they are able to take it in during its growth stages. Many trees are cut daily for furniture, where wood is used very much. While CLT panels can be reused for furniture manufacturing and with great quality. Table 5.5explains Construction building by CLT compared to Construction building by reinforced concrete.

Table 5.5: Construction building by CLT compared toConstruction building by reinforced concrete

Criteria	CLT	Reinforced Concrete
Speed	The building can be constructed within 5 months after the material arrives at the site	The building was built in about a year
Sustainability	CLT is characterized by the carbon uptake of the air and storage as well as the longevity of its use as it has an inexpensive life cycle	The reinforced concrete used in the building is one of the substances that negatively affect nature, in addition to the high cost of reuse of this material
Renewable Resources	CLT is a rrenewable energy building material is wood with constant recycling ability	Reinforced concreteUses a non-renewable resources material.
Acoustic Properties	CLT successfully proved soundproof allowing a peaceful home usage	Reinforced concrete can be fabricated to be soundproof but with highly cost
Strength	A strong CLT building with excellent capacity especially the reinforced concrete was used in the ground floor and foundations	The building that was built by reinforced concrete is very strong because of its tremendous durability and the great strength of reinforced concrete
Cost Implications	Affordable building materials with three times (3x) less building construction cost than concrete and steelwhere the cost per cubic meter of CLT is about $ 55 with the transportation to the site	Mode of fabrication increases its cost. Mode of transportation does not necessarily affect the cost
Fire resistance and safety	The building that was built from the CLT has excellent fire resistance due to the strength of the CLT panels with each other and has a very high stability ability during earthquakes	Anti-fire building properties with excellent durability

5.8 Conclusion

As well as other countries of the world, Cyprus is tipped to witness a change in the construction industry that involves the transition from the use of non-sustainable building materials such as concrete and steel to natural green building materials. In this chapter, an existing building in Cyprus constructed with non-sustainable materials, majorly concrete and steel was examined and how another of its kind will be erected in its place albeit with green building material. The entire plan to be used for the proposed structure together with the 3D designs of the exterior and also wood-based interior design are detailed therein.

Cross Laminated Timber (CLT) is a derivative of mass timber and possess several features which have ensured it finds its way in the thought of engineers and builders. One of the most important attributes is its ability to reduce the level of carbon generated and released into the atmosphere especially in this age where climate change is a global topic of interest. Its ability to form char when attacked by fire over a long period of time also makes it a desirable product. CLT panels can also be prefabricated off the side into different sizes and shapes and in essence, reduces the length of time needed for the complete erection of buildings. Lastly, the materials used in the construction of the existing building are however not of disadvantage in some cases as the proposed CLT building also has some of its components made of concrete and steel. Parts like the foundation and basement involves heavy usage of these materials.

CHAPTER 6
SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

The thesis aimed to explain in detail the significance of CLT mass timber as a sustainable green building material to improve the construction of building in Cyprus. The first chapter of the thesis explains the aims and research of the thesis, as the second chapter explained green building materials. The full discussion of CLT mass timber was explained in the third chapter while the application and case scenario of CLT mass timber in building construction was fully elaborated in the fourth chapter of the thesis. Several case studies adopted in developing countries where CLT usage is being implemented was fully elaborated in chapter four of the thesis. The fifth chapter adopted a local building in Cyprus, this building built almost entirely with reinforced concrete was remodified in to a CLT mass timber construction using three-dimensional analysis of the building. The 3D model of the model focuses on both the interior and exterior aspects of the building thereby describing the significance of CLT mass timber usage as a sustainable building material over other types of building material such as concrete and steel.

6.2 Conclusion

The usage of CLT as a sustainable building material cannot be overemphasized for efficient building construction of green building design with quality air impact. The use of CLT mass timber being a naturally occurring material creates a healthy, sustainable interior as well as fast exterior building construction. Its strength, durability, and cost-effectiveness over other types of building construction material make it an excellent choice for green building construction. More so, CLT mass timber is recyclable with ease of fabrication allowing its selection for multi storeys building construction. Comparing CLT with other building material such as concrete and steel shows the prestigious advantage

CLT has over other types of building materials in terms of pollution, conservation, cost, strength, life cycle impact, and other discussed properties.

The significance of using CLT mass timber most specially to improve the sustainability of the environment as it allows the usage of already manufactured building wood material that absorbs carbon unlike the alternative building material such as concrete, steel, and others. Greenhouse emission has a great reduction when wood material such as CLT is used in replacement of non-wood building materials. CLT can also be processed as a "ready-made" building material, tailoring its process to the precise required measurement to reduce wastage of building material.

Recyclability of the CLT mass timber is an essential property of the sustainable green building material which makes it a better option in placement over steel and concrete. CLT mass timber has the ability to utilize the waste biomass of its leftover panels which could be sent back to the manufacturing company for re-processing of other building panels. The strength of the building materials also makes it a better choice of building material. CLT mass timber has an incredible strength to its relative weight, weighing one-fifth of reinforced concrete. This allows easy fabrication during building construction allowing a faster period of construction. The durability of CLT mass timber has also been discussed during the chapters, it allows a compilation of layers of wood panels to improve on the toughness of the building materials due to the engineering ability of the wood product.

Conclusively, the eco-friendly nature of CLT mass timber as a green building material increase the benefits of the choice of building material over its counterparts. Comparing CLT wood mass timber with reinforced concrete and steel shows the less production of greenhouse gasses than both concrete and steel, evidence also shows as discussed in the previous chapter that CLT mass timber requires lesser amount of water, energy production, costs, and fossil fuels than both concrete and steel creating a larger benefit at a small scale usage and for the entire ecosystem at large.

6.3 Recommendation

The significance of CLT mass timber as a sustainable building material has been discussed in detail. Its adoption in the developed parts of the world has also been elaborated.

However, CLT usage in Cyprus is considerably low due to lack of awareness and information regarding the sustainable building material.

A collaboration with CLT firms in other parts of Europe would improve on the introduction of the sustainable material other parts of the world. Informative seminars, conferences, and workshops should be held in Cyprus by both institutions and companies with vast knowledge in the field to improve on the wood technology in Cyprus.

The author also recommends the initiation of a CLT construction building plant in Cyprus to allow ease of access to the sustainable building material to allows its wide distribution usage all over Cyprus and Europe at large. Cyprus has large tracts of untapped land which are very fertile. The author recommends that these lands be cultivated with the most important trees used for the manufacture of cross laminated timber such as Beech, a hardwood, Pine.

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