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Research Article

A Numerical Approach on the Performance of Hybrid Building Structure using Mass Timber

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ABSTRACT

The most commonly used material for construction is reinforced concrete (RC), and the key element of it is cement. The production of cement requires lots of energy, and it releases a huge amount of CO2 into nature. In addition to that, the recycling process of concrete is very challenging, and not all types of concrete can be recycled. Therefore, as a solution for an economically advantageous alternative, the hybrid structure can be used. A hybrid structure contains different types of structural material for construction to provide better performance by taking advantage of their respective strengths, and it also presents a sustainable, durable, and better choice to conventional materials used in the construction. Considering the above points of view, this paper presents an analytical study on the performance of a hybrid building structure consisting of RCC as column, GLT (glue-laminated timber) as beam, and CLT (cross-laminated timber) as wall and roof. The modelling, load calculation, and analysis of the total hybrid structure under service load are carried out by means of STAAD PRO software. Based on the achieved results, the paper points out the suitable accuracy and fidelity of the hybrid building structure. This research further delves deeper into the complex ramifications of replacing a concrete building with a mass timber hybrid structure in terms of climate advantages. These benefits extend beyond the reduction of greenhouse gas emissions. We show that although a shift to hybrid mass wood can balance the global carbon cycle, there are other associated effects that could increase, decrease, or neutralize that effect on climate. To drive this transformation in a climate-friendly path, practitioners and scientists will need to work together.

Keywords: Hybrid structure, GLT, CLT, finite element analysis, structural integrity.

Introduction

Nowadays the World is dealing with two major issues- ‘Global Warming’ & ‘Climate Change’. These issues are mainly caused by emission of the Green House Gases. Many factors are identified as active contributors to these issues. Among the major contributor, one is the construction industry and buildings. Roughly 40% of the total emission of Green House Gases is accounted that emit from the construction industry. The use of Reinforced Concrete in the construction of a building structure leads us several negative impacts on the Environment. The Reinforced Concrete is the most commonly used material for construction in INDIA. The key component of this material is ‘Cement’. Cement production is not an eco-friendly process and takes lots of energy to manufacture. This is the third ranking producer of CO_2 in the world. In addition to that Cement also has a high alkalinity which can be damaging to the environment if it gets into rivers, lakes or streams (from run-off). Cement is a building material made by grinding calcined limestone and traces of clay and gypsum. Its key use is as an ingredient for concrete or mortar. Cement is also a binding agent and is used in mortar, life (for example plaster), and stucco. Cement hardens when mixed with water, which causes a reaction called hydration. Apart from the Cement production, the Transportation and construction of concrete consumes a large amount of energy, especially given the weight and bulk of the materials. As a result, it causes emission of $CO_2$from the transportation and machinery during construction. Mining for aggregates and limestone can lead to habitat destruction, loss of biodiversity, and changes in local ecosystems. The creation of quarries and mines disrupts the natural landscape and can result in soil erosion and pollution.

In the construction of a normal RCC building consisting brick walls, despite being favoured for their strength and beauty, brick walls have a number of drawbacks and have a detrimental effect on the environment. Building a brick wall can be costly because of the cost of the materials and the work that is needed. Brick is a hefty material, which may make handling and shipping challenging. To sustain the weight, a solid foundation is also needed. Comparatively speaking, CLT Wall & Roof panels need less time and work to build than brick walls. Brick production uses a lot of energy. High carbon emissions result from the energy-intensive, usually fossil fuel-based, kiln fire process used to make bricks.

The potential of hybrid structural systems to include the best attributes of many materials while delivering structural efficiency and sustainability has received a lot of attention in recent years. A possible solution to today's building difficulties is the combination of glue-laminated timber (Glulam) beams, cross-laminated timber (CLT) walls and slabs, and reinforced concrete (RCC) columns. These solutions leverage Glulam's strength and low weight, RCC's fire resistance and compressive strength, CLT's prefabrication advantages, and Glulam's sustainability. The performance of hybrid structure materials (RCC, GLT, and SLT) has been investigated in a number of studies, with an emphasis on environmental impacts, seismic resistance, load distribution, and structural stability. Because of its remarkable compressive strength and durability, reinforced concrete has long been a basic component in structural engineering. The application of RCC as the main load-bearing component in hybrid buildings has been the subject of several research. According to **Smith et al.'s (2018) [1],** investigation of the performance of RCC columns in high-rise buildings, they may offer significant stiffness and fire resistance, especially in seismic zones. Their research indicates that the overall stability of buildings may be greatly enhanced by using RCC columns in hybrid systems, especially when combined with lighter materials like wood.

Adel Younis et al [2], investigated relevant life cycle assessments (LCAs) to estimate the carbon footprint of CLT structures, providing an overview of their potential for sustainable construction. These investigations showed that utilizing CLT rather than traditional building materials, primarily RC, for multi-story structures significantly reduced GHG emissions by 40% on average. When carbon sequestration was considered in the assessments and appropriate/greener assumptions were made for end-of-life wood products, there was a significant reduction in the greenhouse gas emissions linked to CLT construction. This study examined many relevant life cycle assessments (LCA) that addressed the carbon footprint of CLT structures to give an overview of the potential of using CLT to achieve sustainable construction. Furthermore, the LCA findings of CLT structures showed a high degree of heterogeneity. This diversity may be attributed to a variety of reasons, including the types of structures analysed, regional variations, the method used to treat biogenic carbon, changes in LCA methodology, and the data source used. Cross-laminated timber for building construction. **Brandner et al [3],** provide an overview of the existing technique for creating cross-laminated timber (CLT). The focus is on industrial production lines, although small and medium-sized firms are also included. The research focuses on cross-laminated timber (CLT), which is a stiff composite composed of surface-bonded, crosswise-structured single-layer panels or board layers. For timber engineers and the construction industry as a whole, CLT provides new perspectives and opportunities. Wood engineering is regaining popularity in our cities because to the promise of cross-laminated timber (CLT) in multi-story timber buildings for companies and houses. In comparison to mineral building materials such as reinforced steel, masonry, and steel structures, the development of CLT building systems and, consequently, the establishment of solid timber construction techniques with CLT are seen as the next significant step toward improving its economics.

Wang Z et al [4], review the most current innovations and advancements in China's CLT. Because of its unique structural and mechanical properties in comparison to other engineered wood products, CLT is commonly used in medium- and high-rise wooden buildings. Aside from Europe, other countries of the globe are focused on the development of CLT construction materials and structures. CLT materials will make heavy use of hardwood, fast-growing wood, wood-based panels, bamboo, and locally sourced wood. Because of the material's orthogonal structure and the orthotropy of wood, rolling shear characteristics have a significant influence on CLT mechanical properties. In contrast, the layer material, assembly structure, fabrication process, and testing technique all have an impact on CLT's rolling shear properties. The rolling shear properties of CLT can be successfully improved by mixing different layer materials, and AE technology may be utilized to examine the mechanism and process of CLT rolling failure.

Ren, H et al [5], in their article, explores the development status and application of CLT in Europe, focusing on its material properties and load-bearing capacities. The most current CLT-related findings are presented. The benefits of using CLT for the environment in the building industry are also discussed. Furthermore, the performance of the CLT components used and energy efficiency are highlighted. In compared to steel and reinforced concrete structures, our study shows that CLT constructions have much lower embodied energy and carbon. Finally, the future of CLT is addressed. **Kurzinski, S et al [6],** in their article aims to examine worldwide design standards for cross-laminated timber (CLT) and related wood buildings, as well as to provide recommendations for the future of CLT standardization. To do this, the following CLT and timber code standards—Europe: EN-16351, North America: APA/PRG-320, Japan: JAS-3079, and International Organization for Standardization (ISO)—are discussed in general terms. The CLT standards are as follows: SANS-1783/SANS 10163/SABS-0163 in Africa, NBR-7190 in South America, AS-1720.1 in Oceania, and GB-50005 in Asia. Each standard's current iteration is briefly discussed, along with background information on the applicable standard. There have been ideas for using other existing standards to develop standards in nations that have not yet established a CLT standard. The expanding usage of CLT in nations and locations throughout the world has resulted in substantial industry investment in engineered wood products. To build structural systems built of solid wood using CLT panels, product standards must ensure that the base material's strength and stiffness characteristics meet severe performance requirements. Design and production standards have yet to be created for this developing technology, which was first introduced only thirty years ago. Indeed, diverse ways of producing standards have been employed over the world with little consideration for harmonization.

The results of an experimental lateral performance examination on glued-laminated timber frames (GLT) infilled with cross-laminated timber (CLT) shear walls are presented by **Jianyang Xue et al [7],** in their article. To provide a trustworthy force transfer system for the construction, specially built steel connectors were used at the frame-to-wall connections. This structural system was subjected to lateral cyclic loading trials to examine the impact of opening dimensions, shape (e.g., door and window), and wall panel aspect ratio on the lateral performance of the structural system. The elastic and elastic-plastic drift ratios of the GLT frame were also determined when it was filled with CLT. The collaboration mechanism and lateral collaborative impact of the GLT frame and CLT shear wall were also investigated. The failure processes, hysteretic properties, lateral stiffness, energy dissipation, and bearing capabilities of the GLT frame with CLT shear walls were all comprehensively investigated. The inclusion of the CLT shear wall resulted in significant increases in the overall stiffness and strength of the GLT frame, with increments of 2.74-5.26 and 10.66-14.1, respectively. **Lucie et al [8]** conducted probabilistic research to analyse how the charring depth of spruce wood GLT beams varies over time when burnt. To provide the fundamental knowledge needed for the theoretical section of this paper, the results of a comprehensive experimental program were given first. This study examines how bonded laminated timber beams react to fire using both computational and experimental methods. We examine how the evolution of the temperature profile affects the temporal variation of charring rates under different fire conditions, fire durations, and beam cross-section sizes. A comparison is made between the charring depth forecasts made by simple charring rate models and numerical heat transport simulations. For the typical heat transfer model, the temperature-dependent material properties are found using a Bayesian inference in the absence of a mass transport representation.

In the face of growing concerns over climate change, recent research has suggested that natural climate solutions (NCS) have the potential to provide 30% or more of the mitigation necessary to achieve the Paris Agreement's objectives by 2030. Reforestation is seen as the single greatest NCS opportunity **Griscom et al. [9]**.

People who want to encourage more reforestation have been thinking more about how higher demand for wood products might help. They've also been thinking about how replacing wood products with other materials might lower the amount of carbon released by industrial materials **Leskinen et al. [12] and Soimakallio et al. [16]** and store carbon in long-lasting wood products or harvested wood products, **Johnston et al [11]**. The harvested wood from forests and other areas are carbon reservoirs as long as they remain in the form of a product or solid waste. These include all wood and bark removed for products including fuel and it does not include wood left out at harvest site **IPCC, 2006 [21] and Watson et al. [18].** The harvested wood in housing, construction or furniture can store carbon for more than 100 years **Haripriya [10]**.

The National Action Plan on Climate Change (2008) of India acknowledged that climate change has the potential to modify the distribution and quality of the country's natural resources, which could have negative impacts on the livelihoods of its population. The plan encompasses eight National Missions that serve as comprehensive, long-term, and integrated strategies to accomplish the primary objectives (Government of India, 2008a). The National Mission for a Green India primarily aims to improve ecosystem services, such as carbon sequestration, through afforestation and reforestation efforts. However, in order to achieve this potential, it is necessary to reforest hundreds of millions of hectares, which is a difficult and daunting task. Due to the rising interest in supporting reforestation, there is an increasing emphasis on using increased demand for wood products as a way to encourage more replanting. In addition, it is possible that replacing wood products with alternative materials could reduce carbon emissions in industrial material flows **Leskinen et al. [12]** and store carbon in durable wood products, **Johnston et al [11]**.

India's climate adaptation efforts are complicated due to its geographic diversity. Thus, it makes sense to emphasize consumption pattern of natural resources be urgently reshaped if climate change mitigation efforts are observed to reap some effect. India has a plethora of policies and strategies pertaining to Sustainable Consumption and Production (SCP) that are overseen by various ministries. The Ministry of Environment, Forests, and Climate Change (MoEFCC) has tasked an advisory body, the Resource Efficiency Cell, with assisting with its implementation. Every policy and strategy have a high level of ambition. The central government body NITI Aayog oversees SDG implementation and publishes regular updates via a dashboard, including reporting on several SDG 12 indicators.

In 2023, Indian government have evaded the 25 years old ban on use of timber and timber products in construction of public buildings and habitat projects. The removal of the ban was strongly influenced by India's Ministry of Environment, which alongside environmental benefits, is hoping for a growth in the wood-based industries. Goal 12 of the Sustainable Development Goals (SDGs) focuses on sustainable consumption and production. Target 12.1 specifically aims to encourage nations to develop, adopt, or implement policy instruments that assist the transition to sustainable consumption and production and gives the policy framework to promote use of mass timber in construction industry which will help is changing the consumption pattern at large. Promoting Adaptation in Urban Design, Energy and Material-Efficiency in Buildings, and Sustainable Urbanization. The main targets under this section are to establish Effective National Building Code, Energy Conservation Building Code, Eco-Niwas Samhita (an energy conservation building code for residential buildings). Though Mass Timber, CLT and GLT are not directly mentioned, but these seems to be an obvious alternative to steel and concrete for better reaped environmental impact off the construction industry.

One such promising solution is the use of hybrid mass timber systems, which combine the structural integrity of timber with the thermal performance of other sustainable materials. Cross-laminated timber has emerged as a leading mass timber product, offering a viable alternative to traditional steel and concrete structures, **Vilguts et al. [17].** This engineered wood product is manufactured through the cross-lamination of at least three plies, resulting in a material that is both strong and environmentally friendly. Compared to traditional construction materials, the use of CLT and glulam (glue-laminated timber) has been shown to substantially decrease the carbon footprint of buildings. The environmental benefits of mass timber construction extend beyond the material itself. Timber is a highly sustainable material, with a low carbon footprint and the ability to store carbon throughout the life cycle of a structure **Liang et al. [13]**. Additionally, the use of local timber resources and the potential for on-site production can further reduce the environmental impact of mass timber buildings. However, the environmental performance of mass timber buildings can be impacted by the choice of other building materials and construction practices. Careful consideration of the entire building assembly and supply chain is crucial to maximizing the environmental benefits of hybrid mass timber construction.

There are various processes that occur at each life cycle stage. According to the ISO 21930 standards, the life cycle of a building can be divided into several modules, labeled A1-C4, each representing a specific stage of the life cycle This modular structure provides a consistent and transparent reporting format for building assessments. The LCA system boundary is cradle to gate and includes the modules A1-resource extraction, A2-transportation of materials to product manufacturing, A3-Product manufacturing, A4 -transportation of materials to construction site, and A5-construction energy use. The building embodied carbon is the total global warming potential (GWP) associated with carbon emissions from cradle to gate of all the manufacturing of materials, transportation, and installation of construction materials. Embodied carbon, expressed as kg of CO2e, includes greenhouse (GHG) emissions released due to the manufacture of all materials, transportation, and installation of construction materials. **Metham et al [19] and Zhu et al., 2022 [20].** The expression is used to encompass the building life cycle assessment stage A1 – A5 within the system boundary. The total embodied carbon or GWP of timber building designs are reported as percentage to the concrete building designs

1.1 Mass Timber Structure

One of the first construction materials that people have ever used is wood. The use of wood in construction has decreased, meanwhile, due to the diminishing supply of naturally grown, great girth, durable timbers from forests and the availability of several substitute building materials. In the previous thirty years, steel, aluminium, plastic, and other materials have gradually replaced wood in a variety of building construction components. The building industry is currently searching for environmentally friendly materials, and wood is the preferred option, due to rising worries about the use of energy-intensive materials and the challenges posed by climate change. There is an increasing trend in using more wood in building construction. Large, solid wood panels, columns, and beams designed for strength and stability are used in the innovative mass timber category of building materials. It is intended to be the main structural element in structures, frequently used in conjunction with concrete and steel.

- Mass timber involves large-scale, prefabricated wood components that are manufactured off-site and assembled on-site, allowing for efficient construction and reduced labour costs.
- Various engineered wood products created for particular structural uses are included in mass timber. Layers of wood are bonded together to generate these goods, which are robust, sturdy panels and beams.
- Compared to conventional construction materials like steel and concrete, mass wood can have a less negative environmental impact when it comes from forests that are responsibly managed. Wood is a renewable resource.
- And also, large-scale timber buildings frequently highlight the inherent beauty of wood, resulting in cozy and aesthetically pleasing environments.

1.2 Objective of using Mass Timber in Construction

The growing awareness of the negative environmental consequences of traditional construction materials such as steel and concrete, the availability and renewability of wood, and the benefits of wood in mitigating climate change are the primary drivers of the trend toward tall wooden structures. Furthermore, very little waste is generated during the manufacturing of wood and wood-based products since almost all leftovers are used as energy sources or raw materials, making it more cost-effective to use more wood. Because of its multiple advantages, mass wood constructions are becoming increasingly popular in construction.

Sustainability

Being a renewable resource Mass Timber is more sustainable than other building material like Concrete, Steel. When timber is sourced from ethically managed forests, it can help to reduce carbon emissions. Mass Timber structures are becoming increasingly popular in building due to their numerous advantages. Mass timber is a less carbon-intensive solution. The ability of mass timber to retain carbon may be able to offset the carbon generated during the manufacturing process. Research suggests that replacing steel with wood might reduce global carbon emissions by 15% to 20%.

Structural Performance

Because GLT beams and CLT panels are stronger than RCC while staying lightweight, using mass timber reduces the overall weight of the structure. Additionally, this can reduce foundation costs and ease building, especially in areas with problematic soil types. With simple installation and exact connections, the number of people required on site may be reduced, and the project may be completed more quickly.

Thermal Performance

The timber structures are more energy efficient also due to exceptionally good thermal insulation properties of wood. Better thermal efficiency of wood means walls made out of mass timber and other panel products can be slimmer, releasing up to 10% more space than other building methods. According to the Canadian Wood Council, maintaining indoor temperatures in a finished structure made with CLT requires about one-third of the heating or cooling energy required for a steel or concrete structure.

Construction Efficiency

Easy processing, low energy requirements in its manipulation, amenable for industrialization with technological interventions have made it a preferred material for buildings. Simple assembly and proper connections may result in fewer persons on site and a faster project completion time.

1.3 Types of Mass Timber

To make larger, stronger elements, smaller pieces of wood are joined or laminated together to form mass timber products. Because mass timber offers cost-effective, versatile, and environmentally friendly alternatives to traditional building materials such as steel and concrete, it has transformed the construction industry. Mass timber objects come in a number of shapes that suit specific structural and aesthetic criteria, providing architects and builders with a wide range of design alternatives. The following is an overview of the main categories of mass timber.
There are several important types of mass timber products, including-

a) Glue Laminated Timber (GLT) or Glulam
b) Cross Laminated Timber (CLT)
c) Laminated Veneer Lumber (LVL)
d) Nail-Laminated Timber (NLT)
e) Dowel-Laminated Timber (DLT)
f) Parallel Strand Lumber (PSL)
g) Mass Plywood Panel (MPP)

Because each type of mass timber product has unique characteristics and benefits, mass timber is a versatile and ecologically responsible material choice for a wide range of construction projects. These products promote environmental stewardship and enable innovative construction designs. In this study we are using Glue Laminated Timber as Beam Member and Cross Laminated Timber as Wall and Floor Slab.

1.4 Glue Laminated Timber or Glulam or GLT

Glulam, commonly known as glue-laminated timber, a complex engineered wood product created by applying strong adhesives to many layers of dimensioned lumber. This process produces large, sturdy, and adjustable structural components that may be used as beams, columns, and arches. One of glulam's key advantages is that it can span a long distance without the need for intermediates, making it ideal for large, open spaces such as stadiums, airports, and commercial constructions. Glulam has several advantages over steel and concrete in terms of environmental impact, structural efficiency, and design freedom. It is a renewable and sustainable resource.

Fig. 1: Glue Laminated Timber or Glulam

(Source- https://lamisellbeams.com/images/frontpage/glulam.gif)

In order to manufacture Glulam, the following process can be followed,

- ***Laminations (Lamellas):*** After curing in a kiln, wood is classified based on strength. Splits and knots are removed, ensuring constant performance.
- ***Adhesive Bonding:*** Moisture-resistant adhesives, such as polyurethane or resorcinol formaldehyde, are used to bind the timber layers together under pressure to form a solid beam.

- ***Curing:*** To strengthen the adhesive bond, the assembled beams are cured at normal temperature or under controlled circumstances.
- ***Finishing:*** Before being utilized in construction, beams are sanded and cut to exact dimensions.

Glulam can be made in a number of forms and sizes, such as straight beams, curved arches, or tapered profiles, depending on the design specifications.

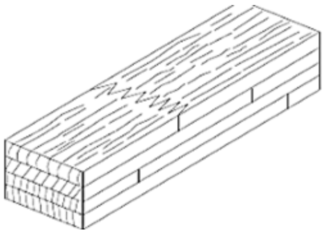


Fig. 2: Straight Glulam Beams

1.5 Cross Laminated Timber or CLT

Cross-Laminated Timber (CLT), a highly engineered wood product, has had a significant influence on modern buildings. Cross-Laminated Timber (CLT) panels, which are made by flipping the orientation of wood boards and holding them together using structural adhesives, are extraordinarily robust, stable, and rigid. The cross-laminating technique improves the structural integrity of the timber, making it suitable for a wide range of applications, including walls, floors, and roofing.

Cross-laminated timber (CLT) is an essential component of modern timber construction due to its longevity, strength, and dimensional stability, particularly in multi-story structures and environmentally friendly building techniques. CLT beams are less common than glulam beams due to their construction method, however hybrid and mass timber designs are increasing their popularity.

Fig. 3: Cross Laminated Timber

(Source- https://images.app.goo.gl/iTYt9C8cEBeK9v687)

CLT panels are formed by stacking wood panels, which are often composed of spruce, pine, or fir. This produces a cross-laminated effect in which each layer of lumber is placed perpendicular to the previous ones. This perpendicular configuration enhances mechanical performance and dimensional stability.

- ***Adhesive Bonding:*** To form a solid composite panel, the layers are glued together using strong adhesives and squeezed.
- ***Panel Sizing:*** CLT panels can be reduced to the size of smaller components, such as beams, although they are often built as large, prefabricated parts.
- ***Curing and Finishing:*** To increase the panels' resistance to moisture and fire, they are cured, finished, and occasionally treated.

Although CLT is commonly used for large panels, it may also be used as beams by cutting panels into sections that are the suitable size for beams. In contrast to Glulam, which may be created directly as beams, this limits its application as beams.

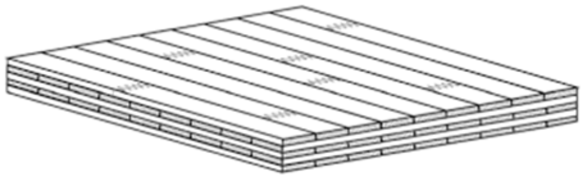


Fig. 4: CLT - Floor Slab

(Source- https://encrypted-tbn1.gstatic.com/images?q=tbn:ANd9GcSvbrLzOZpbJV0EivAlzB00OA5TtpbuqhUTMtMJ9M4KOt0yFfNw)

1.6 Environmental Impact of Hybrid Structure

Mass Timber constructions are generally considered sustainable as they bind carbon dioxide in the wood structure and as it is relatively easier to manufacture wood-based construction materials instead of masonry buildings. Efforts to reduce the energy intensity of buildings shift the environmental impact from the operational stage to construction materials. Therefore, the environmental performance of construction becomes highly dependent on the construction materials involved. The Hybrid Structure made of RCC as column, GLT as beam and CLT as wall and roof has a significant Environmental impact.

1.6.1. Carbon Sequestration

1. Trees absorbs CO_2during its growth process. This remains sequestered in the Mass Timber elements that can act effectively as a carbon sink and reduce overall carbon footprint of the building.
2. The use of Hybrid Structure can also help in reducing greenhouse gases emission compared to fully RCC or Steel structure as Mass Timber is a natural element.

1.6.2. Renewable & Sustainable Resource

1. When sourced from responsibly managed forests, timber is a renewable resource. Sustainable forestry practices ensure that forests continue to absorb CO2 and maintain biodiversity, while also providing a continuous supply of timber.
2. Concrete is a non-renewable material but when we replace it with Mass Timber it can reduce the demand of such non-renewable, material for construction.

1.6.3. Energy Efficiency & Reduced Wastage-

1. The production of timber requires less energy compared to the manufacturing of concrete and steel, resulting in lower embodied energy for the building.
2. Timber provides natural insulation, which can improve the energy efficiency of buildings, leading to lower heating and cooling demands and reduced operational energy consumption.
3. As Mass Timber can be prefabricated, it provides a clean on-site construction and more efficient use of materials, less waste, and reduced on-site construction times.

Hybrid structures using mass timber can have a significantly positive environmental impact, especially when the timber is sourced sustainably and the building is designed with lifecycle considerations in mind. The benefits of carbon sequestration, renewable resource use, and improved energy efficiency can make mass timber a compelling choice for environmentally conscious construction.

1.7 Application as a Building Material

(i) Glue Laminated Timber (GLT)

1. Because of its strength and lightweight construction, glulam is ideal for large-scale structures such as bridges, sports stadiums, and auditoriums.
2. Glulam beams are widely used in residential and commercial constructions for both structural and aesthetic reasons, particularly in exposed beam designs.
3. Glulam is often used to build large-scale agricultural constructions like as barns, sheds, and warehouses with wide, open spans.

4. Because of its strength, durability, and aesthetic appeal, glulam is used in both pedestrian and automobile bridges. Compared to steel or concrete bridges, it is highly valued for its environmental benefits.

(ii) Cross Laminated Timber (CLT)

1. CLT walls are used in home construction for both external and internal applications. When it comes to external walls, CLT provides superior insulation and structural support than standard frame solutions. Because of CLT's load-bearing characteristics, internal walls can have fewer load-bearing supports, allowing for more flexibility in interior design.
2. CLT is commonly used as a load-bearing wall system component in high-rise and multi-story constructions. These panels may be quickly built on-site after being prefabricated off-site, reducing both construction time and cost. CLT is a suitable material for tall buildings, as shown by the 18-story "Mjøstårnet" in Norway and other high-rise structures.
3. CLT is becoming increasingly popular in schools, business buildings, and healthcare institutions due to its aesthetics, biophilic appeal, and ease of installation.
4. CLT panels are an excellent alternative for roofing applications due to their ability to handle large loads, thermal properties, and long-distance transportability. Large prefabricated panels are typically utilized to construct a CLT roof. These panels may be readily assembled to provide a strong, lightweight structure.

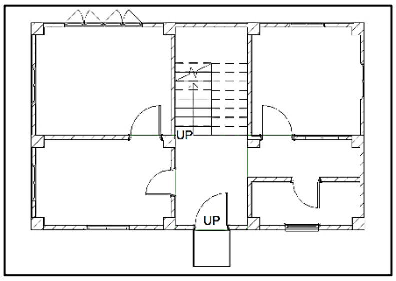


Fig.5 (a): Floor Plan of the Hybrid Building

Fig. 5(b): Front view of G+3 Hybrid Building Model Consisting RCC as Column, GLT as Beam and CLT as Roof & Wall

Fig.5(c): 3D View of G+3 Hybrid Building Model Consisting RCC as Column, GLT as Beam and CLT as Roof & Wall

Fig. 5(d): Back View of G+3 Hybrid Building Model Consisting RCC as Column, GLT as Beam and CLT as Roof & Wall

Methodology

2.1 Design Analysis by STAAD Pro

This research paper presents analysis and design of a hybrid structure of multi-storied [G+3] building consisting RCC as well as Mass Timber, using STAAD Pro software. The investigation focused on structural members' compliance, load-bearing capacity, deflection, and stress distribution. The building was tested for wind, seismic, dead, and live loads. The results show that the structure is stable and functions within tolerable boundaries. STAAD Pro, a popular program for structural analysis and design, here it is used to evaluate the structural integrity of the building. The objective is to guarantee the building's stability, safety, and adherence to pertinent requirements.

2.1.1 Features of STAAD Pro

1. Import/Export of Auto Cad 2D/3D files to start model
2. Model Development (Graphical as well as Input Editor)
3. Model Visualization on screen
4. GUI based Modelling
5. Isometric and Perspective view and 3D shapes
6. Analysis and design tool
7. Advanced automatic load generation facilities
8. Results as per Indian standards, American Standards, Canadian Standards and other Standards
9. Report Generation

2.1.2 Introduction to the Structure

Table 1 : Building Configurations

Sl. No.	Details	Data
1.	Type of structure	Hybrid Structure
2.	No. of stories	G+3
3.	Floor Height	3m
4.	Total Area of Ground Floor	49.5 m^2
5.	Grade of Concrete Used for Column	M25
6.	Grade for Main steel for Column	Fe500
7.	Grade of Secondary steel for Column	Fe415

2.1.3 Modeling of Structure

Modelling of 3-D frame is shown in figures step by step. It includes:

1. Modelling of frame
2. Assigning supports
3. Material Creation
4. Assigning properties to the structure
5. Load and Definition
6. Run Analysis

The STD input file allows the GUI (or user) to interface with the STAAD analysis engine. That input file is a text file containing a set of commands that are performed in sequence. The commands include either instructions or data related to analysis and/or design. The STAAD input file can be prepared using a text editor or the GUI Modelling capability. In general, any text editor is used to modify/create the STD input file. The GUI Modelling function generates the input file using an interactive, menu-driven, graphics-oriented process. First of all, a grid is generated using grid generator or just nodes are added to make plan and then with the help of add beam, the beams are added as shown in Fig 6.

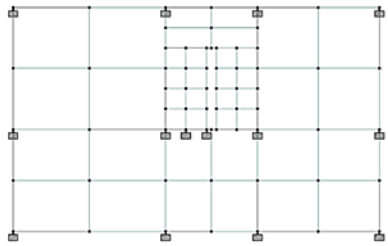


Fig.6: Floor plan of the building

2.1.3.1 Assigning supports

Supports have been assigned at the base of the frame's columns. Columns are often secured in place by the use of permanent supports. On a fixed support, movement in all directions is limited. Under "General," there is a support option. To offer support, first click support, then construct. This allows to click on any node in the frame and assign chosen nodes to them, as shown in Fig 7.

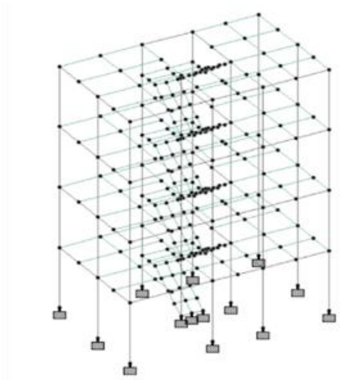


Fig.7: Assigning Supports to the Structure

2.1.3.2 Materials Creation

After assigning the supports, materials are created for Hybrid Mass as shown in the Fig 8.

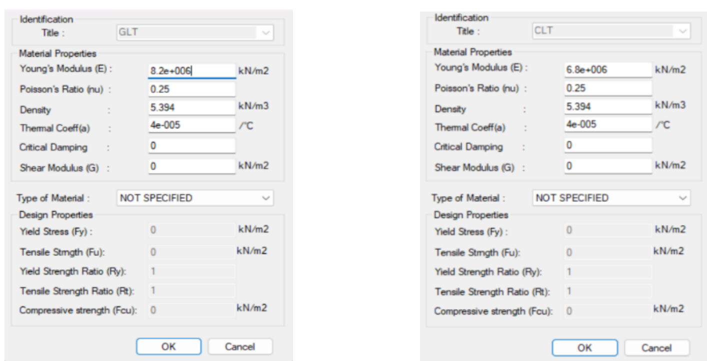
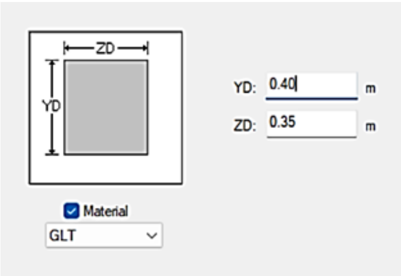


Fig.8: Material Properties of GLT & CLT

2.1.2.3 Assigning properties to the hybrid structure

Column and beam sizes are determined by span and load. In general, the beam depth ranges from span 10 to span 12. Similarly, the width of the beam should be smaller than the width of the column to prevent beam overhang. The depth of the beam should be enough to offset the bending moment caused by loading. If the section fails, the attributes can be altered. Assigning properties of the members by selecting "Property" and Defining the properties, then the depth and width of the Beam is defined and the material (GLT) is selected and then it is added as shown in the Fig 9(a)and Fig 9(b). Similarly, property of RCC Column and the thickness of CLT Slab is defined. To add slab thickness, go to "Thickness" option and thickness value of the slab is assigned as shown in the Fig 9(b).



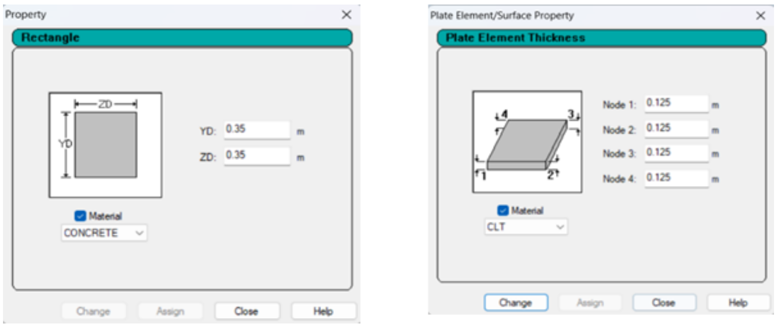


Fig.9(a): Defining Section Properties of GLT Beam

Fig.9(b): Defining Property RCC Column & Thickness of CLT slab

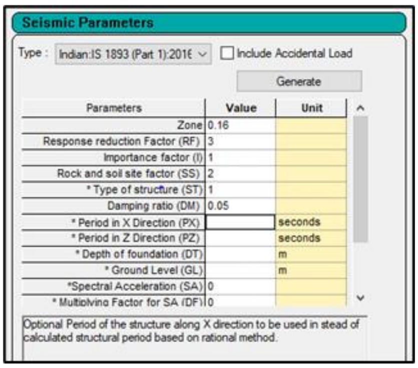
2.1.3.4 Load and Definition

The types of service loads and definitions are explained below-

- Seismic Load
- Wind Load
- Dead Load
- Live Load
- Floor Load
- Load Combination

I Seismic Loading

Specifying seismic load, and allocating it to the structure. Different criteria are necessary for definition, such as the zone factor, importance factor, structure type, soil type, footing depth, damping ratio, response reduction factor, and so on. These parameters are shown in Fig 10(a) and member (Beams) weight and Floor weight to be added as shown in the Fig 10(b).



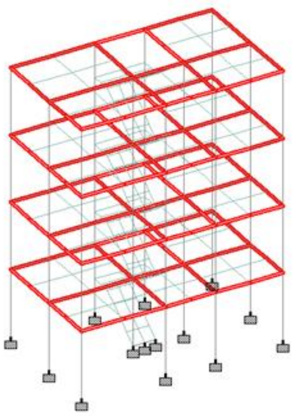


Fig.10(a): Defining Seismic Parameters as per IS 1893(Part 1)

Fig.10(b): Adding Member Weight and Floor Weight

To assign the Seismic Load in X & Z direction "Load Case Details" to be added. Adding new Load Case, by selecting loading type as "Seismic-H" & naming them as "EQX" & "EQZ", then selecting them one by one and adding Factors & Directions to the selected X & Z direction respectively and then to be added as shown in the Fig 10(c) and Fig 10(d).

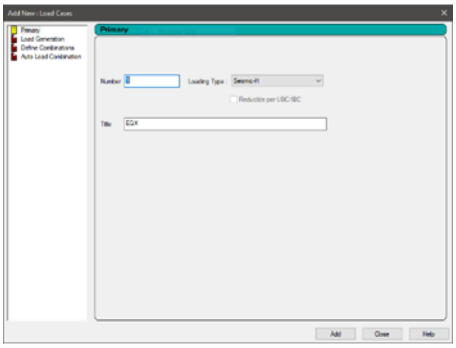


Fig.10(c): Adding New Load Cases

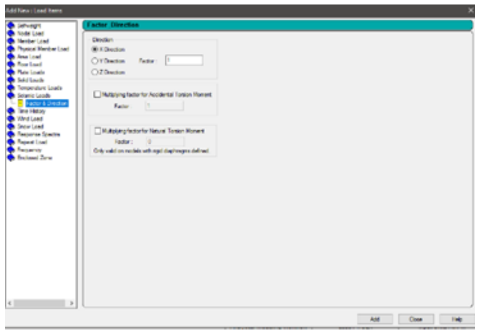


Fig.10(d): Adding Seismic Load Items (Factors & Direction)

II Wind Load

To assign Wind Load, "Wind Definition" must be defined and after adding "Wind Type Definitions", "Wind Intensity" to be calculated and added manually or letting the software generate it by selecting the suitable code for Wind Load and adding exposer also as shown in Fig 11(a).

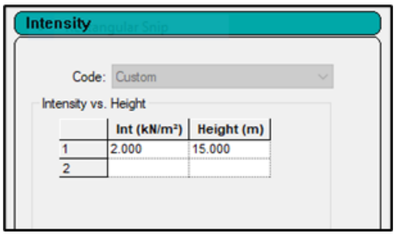


Fig.11(a): Defining Wind Intensity

After defining "Wind Definitions", new Load Cases to be added as "WX" & "WZ" for assigning wind load in X direction and Z direction respectively and then select both load case one by one and adding direction and range for each direction (+ve & -ve) as shown in the Fig 11(b) and Fig 11(c).

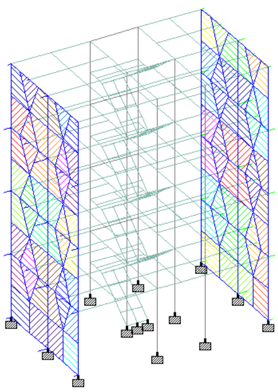


Fig.11(b): Wind Load in +ve X-direction

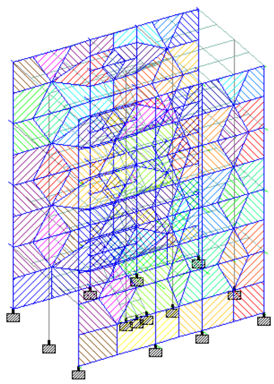


Fig.11(c): Wind Load in +ve Z-direction

III Dead Load

Dead Load is nothing but the Self-Weight of the Structure (the weight of any entity, such as Beams, Columns, Slabs etc.). It is the total load of all components. In STAAD PRO Dead Load is automatically assigned by giving the material property of the members as shown in Fig 12.

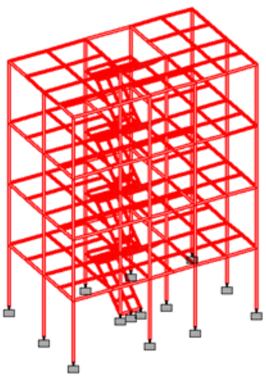


Fig. 12: Self-Weight of the Structure

IV Live Load

Live load is applied on the structure as per IS code. The unit of Live load is KN/m² and the load is in the form of Uniform Distributed Load which follows trapezoidal distribution. In the analysis we take 2.5 KN/m² floor pressure as Live load that is acting in the direction of “YRANGE”. To assign Live load we have to select “LL”- Load Case and add “Floor Pressure” as shown in the Fig 13(a)and Fig 13(b).

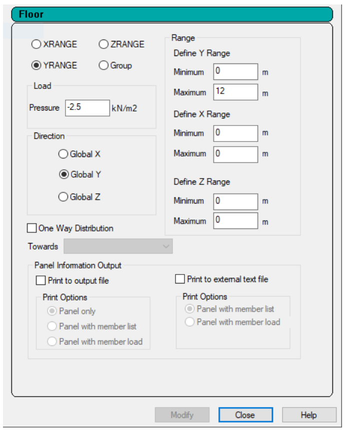


Fig.13 (a): Assigning Live Load

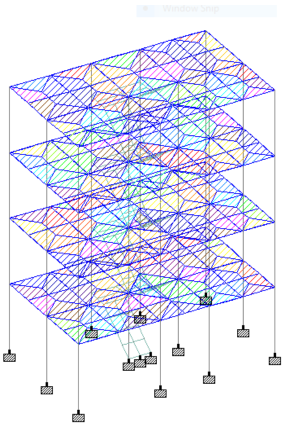


Fig.13 (b): Trapezoidal Load Distribution

V Floor Load

Floor Load of each floor is taken into consideration. Generally, it is acting same as Live load. In this analysis we take 1 KN/m² floor pressure as Floor load that is acting in the direction of “YRANGE” as shown in the Fig 14.

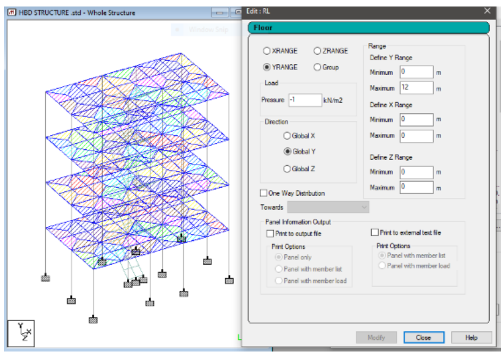


Fig.14: Assigning Floor Load

VI Load Combination

The Structure has been analysed for load combinations as per Indian Standard (IS 456 / IS 800). We let the software generate auto load combinations by selecting IS code as shown in Fig 15.

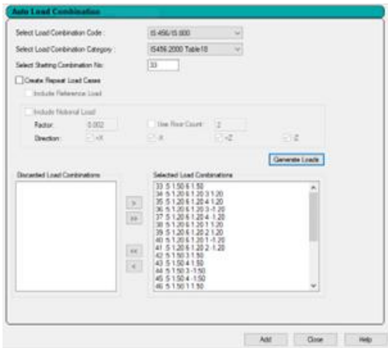


Fig.15: Generating Auto Load Combination as per IS Standards

2.1.3.5 Run Analysis

In the modelling mode, the instructions provided in the analyse menu were used to do the analysis. To proceed with Analysis/Design, select the Run Analysis option. The Analysis Status dialog box, seen below, displays. This dialog box shows the status of the analysis procedure. If an error happens during the analysis, the error message will be displayed in the above dialog box. In this dialog box, we are also given three alternatives, as seen in Fig 16..

- View Output file
- Go to post processing mode
- Stay in modelling mode

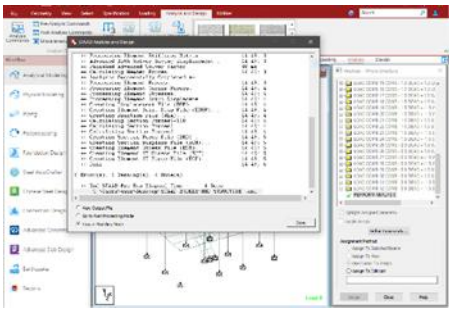


Fig.16: Run Analysis Window

2.1.3.6 Observation

The structural analysis report for ***Beam No. 80***, which is composed of glue- laminated timber, ***Column No. 24***, which is composed of reinforced concrete, and the support rection of the Column No. 24, is presented in this section under the structure's dead load. The geometry, section property, shear bending, and deflection result of these members, together with the appropriate figures, are displayed in this section. The post processing mode after the analysis is also displayed with the appropriate pictures of Structural Deflection, Structural Bending & Plate Stresses of the whole structure.

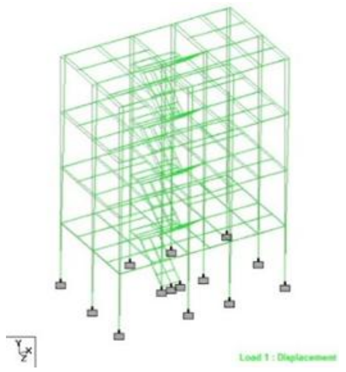


Fig.17 (a): Post-Processing mode – Structural Deflection

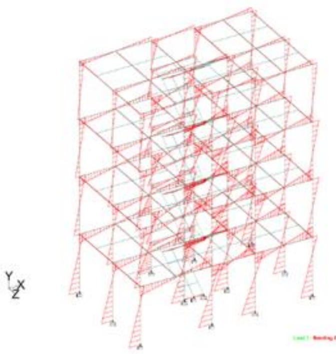


Fig.17 (b): Post-Processing mode - Structural Bending

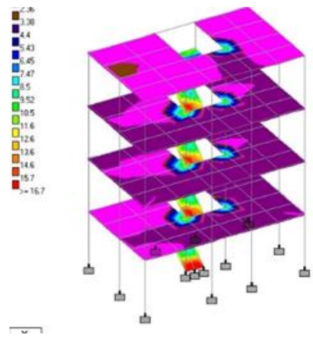
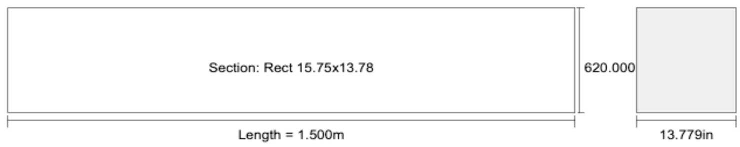


Fig.17 (c): Post-Processing Mode- Plate Stresses

2.1.3.7 Details of a Typical Beam (No. 80)

The material of the beam No 80 is taken as Glue Laminated Timber and its cross section is 350mm X 400mm

I Geometry and Property of Beam



Physical Properties

Ax	0.140	Ix	0.003
Ay	0.117	Iy	0.001
Az	0.117	Iz	0.002
Depth	0.400	Width	0.350

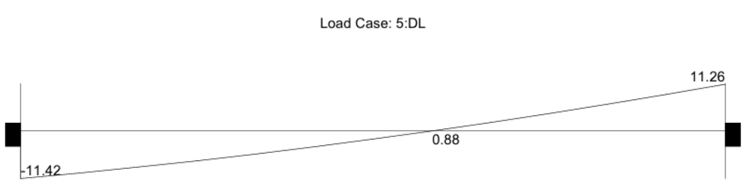
Material Properties

Elasticity(kip/in2)	1189.314	Density(kip/in3)	19.87 E-6
Poisson	0.250	Alpha	40 E-6

Node	X-Coord (m)	Y-Coord (m)	Z-Coord (m)
64	7.500	3.000	3.000
21	9.000	3.000	3.000

Fig.18: Geometry and material properties of a typical beam

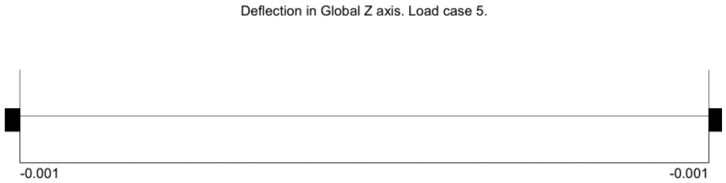
II Shear Bending about Z of the Beam



Dist.m	Fy(kN)	Mz(kip-in)
0.000000	-1.1416	-11.4180
0.125000	-1.2360	-10.1027
0.249999	-1.3304	-8.6831
0.374999	-1.4248	-7.1590
0.499999	-1.5192	-5.5305
0.624999	-1.6136	-3.7975
0.749998	-1.7080	-1.9601
0.874998	-1.8024	-0.0183
0.999998	-1.8968	2.0279
1.124998	-1.9912	4.1786
1.249997	-2.0856	6.4338
1.374997	-2.1799	8.7933
1.499997	-2.2743	11.2573

Fig.19: Shear bending of a typical beam

III Deflection about Z of the Beam



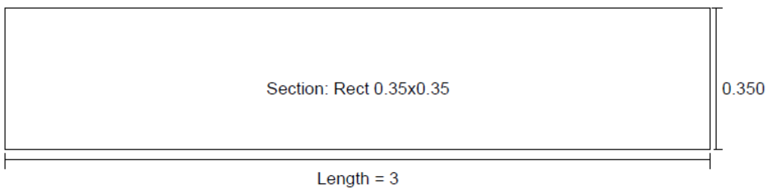
Dist.m	X(in)	Y(in)	Z(in)
0.000000	-0.0000	-0.0047	-0.0009
0.125000	-0.0000	-0.0046	-0.0009
0.249999	-0.0000	-0.0045	-0.0009
0.374999	-0.0000	-0.0044	-0.0009
0.499999	-0.0000	-0.0042	-0.0009
0.624999	-0.0000	-0.0040	-0.0009
0.749998	-0.0000	-0.0037	-0.0009
0.874998	-0.0000	-0.0035	-0.0009
0.999998	-0.0000	-0.0032	-0.0009
1.124998	-0.0000	-0.0030	-0.0009
1.249997	-0.0000	-0.0028	-0.0009
1.374997	-0.0000	-0.0026	-0.0009
1.499997	-0.0000	-0.0025	-0.0009

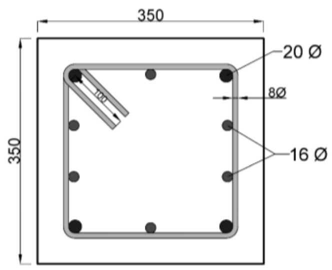
Fig.20: Deflection of a typical beam

2.1.3.9 Details of a Typical Column (No. 24)

The material of the column no. 24 is taken as Reinforced Cement Concrete and its cross-section is 350mm X 350mm & Height is 3000mm

I Geometry and Property of Column





Physical Properties

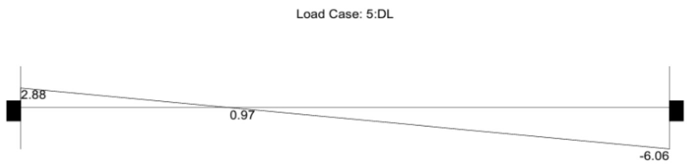
Ax	0.122	Ix	0.002
Ay	0.122	Iy	0.001
Az	0.122	Iz	0.001
Depth	0.350	Width	0.350

Material Properties

Elasticity(kN/mm2)	21.718	Density(kg/m3)	2402.615
Poisson	0.170	Alpha	10 E-6

Fig.21 Physical and material properties of a typical column

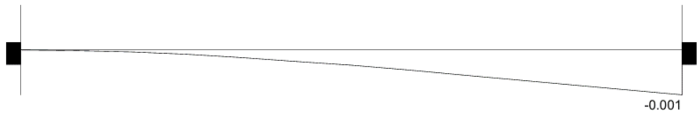
II Shear Bending about Z of the Column



Dist.m	Fy(kN)	Mz(kip-in)
0.000000	0.3369	2.8834
0.249999	0.3369	2.1378
0.499999	0.3369	1.3923
0.749998	0.3369	0.6467
0.999998	0.3369	-0.0988
1.249997	0.3369	-0.8444
1.499997	0.3369	-1.5899
1.749996	0.3369	-2.3355
1.999996	0.3369	-3.0810
2.249995	0.3369	-3.8266
2.499995	0.3369	-4.5721
2.749994	0.3369	-5.3177
2.999994	0.3369	-6.0632

Fig.22 Shear bending of a typical column

III Deflection about Z of Column



Dist.m	X(in)	Y(in)	Z(in)
0.000000	0.0000	0.0000	0.0000
0.249999	0.0000	-0.0002	-0.0000
0.499999	0.0001	-0.0004	-0.0000
0.749998	0.0001	-0.0006	-0.0001
0.999998	0.0002	-0.0008	-0.0002
1.249997	0.0002	-0.0010	-0.0002
1.499997	0.0003	-0.0012	-0.0003
1.749996	0.0003	-0.0014	-0.0004
1.999996	0.0003	-0.0017	-0.0005
2.249995	0.0003	-0.0019	-0.0006
2.499995	0.0002	-0.0021	-0.0007
2.749994	0.0001	-0.0023	-0.0008
2.999994	-0.0000	-0.0025	-0.0009

Fig.23 Deflection of a typical column

2.1.3.11 Column Design

The structure is designed in accordance with Indian and Canadian Codes. As this is a Hybrid Structure the Columns are made of Reinforced Cement Concrete and the Beams are made of Glue Laminated Timber and The Walls & Floors are made of Cross Laminated Timber. Basically, the Structure consists Mass Timber as well as RCC for better Load Bearing Capacity and better Environmental Impact and the statistics of design are given in Tab 2.

Table 2 : Statistics of the Design Results

Design Parameters	Numbers
Number of Joints	284
Number of Members	260
Number of plates	160
Number of Supports	14
Total Primary Load Cases	7
Total DOF	1620
Total Load Combination Cases	25

Using Indian Standards for designing, RCC columns are the only members that were designed using STAAD Pro CONNECT Edition (Version 22.09.00.115), proprietary program of Bentley Systems, Inc, and the columns were designed for concrete in accordance with IS 456 : 2000

==

Typical Design of Column No. 24

==

GRADE OF CONCRETE -**M25**

GRADE OF REINFORCEMENT- **FE415** (MAIN & SEC.)

LENGTH OF THE COLUMN- 3000.0 MM

CROSS SECTION- 350.0 MM X 350.0 MM

CLEAR COVER- 40.0 MM

GUIDING LOAD CASE: 2 END JOINT (8 TENSION COLUMN)

REQD. STEEL AREA- 980 SQ.MM.

REQD. CONCRETE AREA- 121520 SQ.MM.

MAIN REINFORCEMENT: PROVIDE 4-20MM Φ AND 6-16MM Φ (2.01%, 2463.009 SQ.MM.)

(DISTRIBUTED AS PER DIAGRAM)

TIE REINFORCEMENT- PROVIDE 8 MM DIA. TIES @ 150 MM C/C

SECTION CAPACITY BASED ON REINFORCEMENT REQUIRED (KNSMET)

P_UZ- 1672.13 M_UZ1- 49.61 M_UY1- 49.61

INTERACTION RATIO: 0.04 (AS PER CL. 39.6, IS456:2000)

SECTION CAPACITY BASED ON REINFORCEMENT PROVIDED (KNSMET)

WORST LOAD CASE- 2

END JOINT: 8 P_UZ- 1755.12 M_UZ- 61.30 M_UY- 61.30 IR- 0.03

2.2 Life Cycle Analysis

The carbon emissions of the above structural design that replaces certain components of a concrete building with mass timber are analysed in this article using the Life Cycle Analysis program Sima Pro 9.0. Life Cycle Assessment (LCA) is a methodology that evaluates the environmental impact of a product from its inception to its disposal. The life cycle of a product includes the following stages: extraction of raw materials, production and refining, usage, and disposal. The environmental impact of a manufacturing or service system is evaluated by analysing the materials and energy consumed at each stage of the product's life cycle for a specific unit of the product. The measurement of the specific function that a product performs is known as a functional unit. The investigation employed a functional unit of 1 cubic meter of Cross-Laminated Timber (CLT).

The material estimates used in this study were drawn from the computer based technological analysis done above using STAAD PRO software. It was assumed that the GLT and CLT are manufactured by small scale mill in Siliguri India using SYP or Douglas Fir species. All the material and energy estimates used in this study were drawn from the aforementioned computer based technological analysis, including the resin type, the resin volume estimates, and the energy estimates at various stages of the manufacturing process. Sima Pro LCA software incorporates different LCA databases and impact assessment methods. While timber and concrete input data were adapted from the above-mentioned technological analysis, data for processes such as electricity generation, lumber production, and fuel consumption were obtained from the coinvent v3.10 database, the new industry-specific Agri-footprint database and the ELCD database. Inventory data for resin production came from a combination of LCI databases and existing literature.

2.2.1 System Boundary

The CLT material was brought to the building site in Kolkata, and the system boundary began at the Siliguri plant, where the CLT and GLT were manufactured. Consequently, the following items and procedures were considered in this LCA study: raw materials, production, transportation, and the delivery of CLT panels to the construction site. The process consisted of three primary steps: acquiring resources, manufacturing lumber, and manufacturing CLTs. This study also accounts for impacts related to building construction, building use, demolition, or end-of-life. This analysis did not cover procedures like manufacturing capital equipment, facility maintenance, or labour costs.

2.2.2 Assumptions

1. For the baseline scenario for CLT production, 50% Douglas-fir and 50% Southern Yellow Pine, was considered.
2. The bone-dry lumber density for the aforementioned species mix was assumed to be 460 kg/m3, in the baseline scenario.
3. The technological analysis was used to collect data on the concrete nd CLT, GLT used for the building.
4. The moisture content of CLT panels was assumed to be 12% ± 3%.
5. The construction site where the CLT panels were delivered was assumed to be located in the city Of Kolkata.

2.2.3 Impact Assessment

To characterize the extent to which a process or system produced affects, we employed a number of indicators in the life cycle impact assessment. For this environmental impact model, we turned to the Trade-Related Assessment of Chemical and Other Impacts (TRACI) Tool. In order to quantify the effects of a particular process system, the

United States Environmental Protection Agency (EPA) created TRACI, a methodology that incorporates global, regional, and local impact indicators. This study primarily examines four impacts: eutrophication (N equivalent), acidification (SO_2), fresh water consumption, global warming potential (GWP) (CO_2 equivalent), and eutrophication. We used a 100-year timescale to determine the effect on climate change in our research. From Siliguri to Kolkata, the logistics were planned with the assumption that the CLT and GLT producer would make arrangements to purchase sliced and treated wood at its entrance. Imported timber will be utilized in India, the provenance of which is now a mystery. It is still difficult to model such distances.

2.2.4 Results & Observation

The results of the environmental assessment for the above-mentioned Ground + 3 floored hybrid mass timber building in comparison to a full concrete building from phase CLT manufacturing phase to Building manufacturing phase and to its end of life are presented in this section.

1.2.4.1 Building Material Comparison

Tab 3 shows the materials used in the Timber and Concrete Building The structural system consists of CLT floors and concrete slabs (monolithic with the interior walls) on horizontal CLT supporting elements; A typical floor is represented by a single layer CLT panel for the main part, supplemented in case of interior RNG units / gypsum concrete compacted in 50-55 mm thickness. The metal stud & rebar requirement is far-higher in concrete building compared to the timber building – say 141394 KG of Rebar required for foundation of Concrete Building and only 17500 kg of same for Timber Building. Both buildings need fiberglass insulation and gypsum boards in the walls, but only a maximum of 1/2 to 3/4 as much for each one.

Table 3 : Whole Building Material Analysis

Members	Material Name	Unit	Timber	Concrete
Columns and Beams	Concrete	m^3	0	17.64
	Glulam	m^3	19.4	0
	Rebar	Kg	0	51011.4737
Exterior Walls	Aluminium Studs	Kg	0	496.105263
	CLT	m^3	28052	0
	3-5/8" Fiberglass mat	m^2	0	1105.68421
	5/8" Gypsum board	m^2	1105.68421	1105.68421
	5" Mineral wool	m^2	1105.68421	0
	1-1/2" Polystyrene	m^2	0	1105.68421
Floors	3/8" Acoustic mat	m^2	4071.89474	0
	CLT	m^3	29.4	0
	Concrete	m^3	78.5263158	1034.10526
	Gypsum concrete	m^3	206.842105	161.789474
	3/8" PE vapor barrier	m^2	418.947368	257.157895
	Rebar	Kg	1141.57895	19315.0526
Foundation	Concrete	m^3	259.157895	354.315789
	Rebar	Kg	16359.1579	25504.7368
Interior Walls	CLT	m^3	20104	0
	Concrete	m^3	155.684211	304.842105
	3-5/8" Fiberglass mat	m^2	1858.42105	1923.68421
	5/8" Gypsum board	m^2	27591.4737	13232.3158
	5-1/2" Mineral wool	m^2	0	0
	Rebar	Kg	0	45562.7368
	Steel stud	Kg	8292.63158	8538.94737
	Exterior Brace Framing	Kg	5386.84211	0

1.2.4.2 Mass Assembly Comparison

The Mass Assembly comparison provides a broad sense of how mass is located across key components in mass timber and concrete buildings. This will in-turn help construction professionals and stakeholders gain an understanding of material use differences along with identifying areas where design can be responsible for increasing the efficiency in materials used especially when procuring. The following Tab 4 summarizes the mass distribution for key building assemblies in both mass timber and concrete buildings:

Table 4 : Whole Building Mass by Assembly, G+3 Building

Mass Timber		
Assembly	**Kg**	**% of overall building mass**
Columns	248994	10.4%
Exterior Wall	61557	2.6%
Floor	1214306.5	50.9%
Foundation	1119419	23.4%
Interior Wall	302439.5	12.7%
Concrete		
	Kg	**% of overall building mass**
Columns	140439	3.1%
Exterior Wall	26430	0.3%
Floor	2762956.5	61.0%
Foundation	816584.5	18.0%
Interior Wall	1592703	17.6%

The comparison reveals significant differences in mass distribution between mass timber and concrete buildings:

(i) **Weight Efficiency**
Comparatively, concrete structures weigh more than 4.34 million kg, while mass timber buildings weigh about 2.39 million kg, or roughly 45 percent less. This indicates that timber buildings may have lower material requirements in terms of weight, which could result in transportation and construction cost reductions.

(ii) **Floor Mass**
Floors make up the bulk of the structure in both kinds of buildings. On the other hand, mass timber flooring are lighter (50.9% weight) than concrete floors (61.0% weight), suggesting that concrete buildings require stronger structural support.

(iii) **Foundation Mass**
In comparison to the concrete structure, the mass timber construction has a heavier base (23.4% vs. 18.0%). This might be because timber constructions require more support at the top because their upper parts are lighter.

(iv) **Interior and Exterior Walls**
In contrast to the concrete structure, which devotes a disproportionately significant amount of mass to its inner walls (17.6%), the mass timber building displays a more even distribution of mass throughout its interior and external walls.

2.4.2.3Embodies Carbon

Over all regions and building heights the mass timber buildings had lower embodied carbon (emissions associated with the extraction, production, and transportation of materials) than the functionally equivalent concrete building. Tab 6 shows the Global Warming potential (GWP) of mass timber building compared the corresponding concrete building.

Table 6 : Global Warming potential (GWP) of mass timber building

LCIA Indicator	Global warming potential, fossil (GWP)	Acidification potential of soil and water sources (AP)	Eutrophication potential (EP)	Consumption of freshwater resources (FW)	Scenarios
Unit	**kg CO2e**	**kg SO2e**	**kg Ne**	**m3**	
CLT Building	56.72	0.78	0.17	0.40	A1- A3
Concrete Building	106.27	0.39	0.16	1.01	A1- A3
Diffrence %	-47%	99%	6%	-61%	A1- A3
CLT Building	5.80	0.03	5.00E-03	0.00E+00	A4
Concrete Building	2.77	0.02	1.65E-03	9.90E-04	A4
Diffrence %	109%	106%	203%	-100%	A4
CLT Building	2.02	0.03	2.00E-03	0	A5
Concrete Building	3.98	0.10	8.00E-03	4.77E-04	A5
Diffrence %	-49%	-74%	-75%	-100%	A5
CLT Building	64.55	0.85	0.20	0.40	Total
Concrete Building	113.00	0.45	0.30	1.01	Total
Diffrence %	-50%	-38%	-53%	-64%	Total

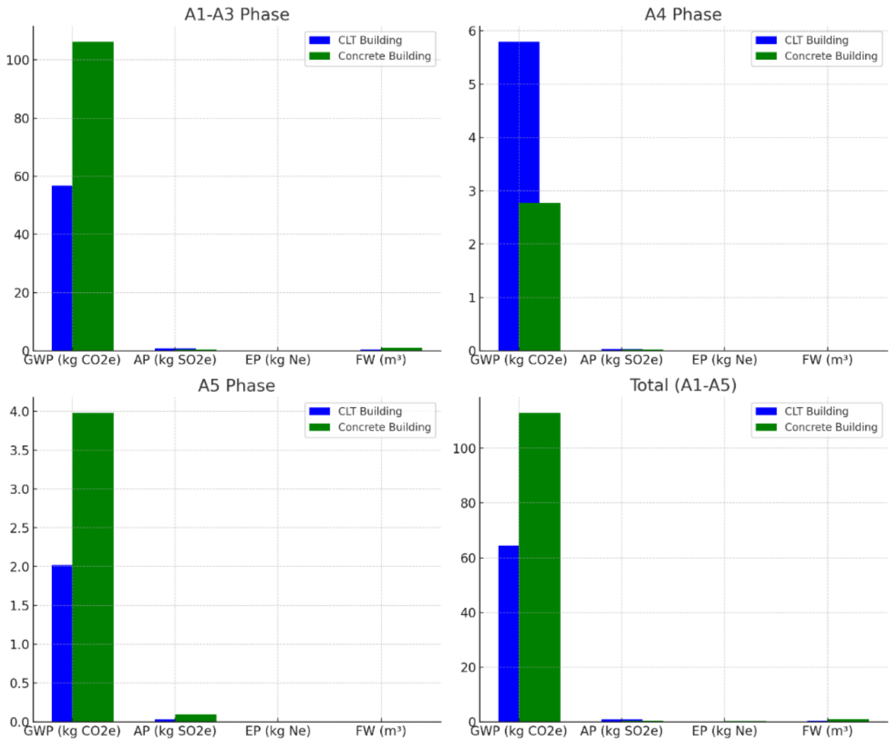


Fig 24 : Environmental implications of concrete and CLT buildings

The environmental implications of concrete and cross-laminated timber (CLT) buildings are compared in the bar graph given in Fig 24 using four important indicators from the Life Cycle Impact Assessment (LCIA):

Freshwater Consumption (FW), Global Warming Potential (GWP), Acidification Potential (AP), and Eutrophication Potential (EP). There are three parts to the analysis: A1–A3, A4–A5, and the overall impact (A1–A5).

A1-A3 Phase (Material production and transportation)

I **Global Warming Potential (GWP)**: CLT buildings demonstrate a significant reduction in CO2 emissions (56.72 kg CO2e) compared to Concrete buildings (106.27 kg CO2e), showing a 47% decrease.

II **Acidification Potential (AP)**: CLT's acidification impact is notably higher at 0.78 kg SO2e, almost twice that of concrete (0.39 kg SO2e).

III **Eutrophication Potential (EP)**: Both materials show similar levels, with CLT at 0.17 kg Ne and concrete at 0.16 kg Ne.

IV **Freshwater Consumption (FW)**: CLT uses 61% less freshwater (0.40 m^3) compared to concrete (1.01 m^3).

A4 Phase (Transport to construction site)

I **GWP**: CLT exhibits higher emissions (5.80 kg CO2e) compared to concrete (2.77 kg CO2e), with a 109% increase.

II **AP and EP**: Both acidification and eutrophication potentials are also higher for CLT, with a 106% increase in AP and a 203% increase in EP compared to concrete.

III **FW**: CLT does not consume freshwater, whereas concrete uses a small amount (0.00 m^3 vs. 9.90E-04 m^3).

A5 Phase (Construction process)

I **GWP**: CLT again shows a reduction in emissions (2.02 kg CO2e) compared to concrete (3.98 kg CO2e), with a 49% decrease.

II **AP and EP**: CLT significantly outperforms concrete in both categories, with reductions of 74% in AP and 75% in EP.

III **FW**: CLT has no freshwater consumption, while concrete has minimal use (4.77E-04 m^3).

Total Impact (A1-A5)

I **GWP**: CLT's total emissions (64.55 kg CO2e) are half that of concrete (113.00 kg CO2e).

II **AP**: Although CLT reduces overall emissions, its acidification potential remains higher (0.85 kg SO2e) than concrete (0.45 kg SO2e).

III **EP**: CLT performs better with 0.20 kg Ne, a 53% reduction compared to concrete (0.30 kg Ne).

IV **FW**: CLT consumes 64% less freshwater than concrete across the entire life cycle.

The results show that CLT buildings offer substantial environmental benefits, particularly in reducing global warming potential and freshwater consumption. However, CLT has a higher acidification impact, especially during material production (A1-A3). Therefore, while CLT is an eco-friendlier material in terms of climate change and resource use, efforts are needed to address its acidification and eutrophication impacts.

Conclusion

The investigation indicates that mass timber buildings are significantly less heavy than concrete buildings. The lightweight nature of timber makes it a desirable choice for minimizing material usage and potentially decreasing construction expenses. Nevertheless, mass timber designs necessitate more substantial foundations to provide stability. Concrete buildings require a greater amount of structural mass, especially in floors and inner walls, in order to meet the load-bearing requirements. The lesser weight of Mass Hybrid structure allows for construction in soils with relatively less bearing capacity, or in sites prone to seismic activities. This allows for cost saving in building Foundations. Wood is easier to obtain because it is widely available. It is an effective option for design-build companies that need to complete projects quickly and for construction sites where scheduling the supply and mixing of concrete is challenging. This can expedite the duration and effectiveness of building.

The mass timber building outperforms the concrete building in terms of Global Warming Potential (GWP) and freshwater consumption, with a 50% reduction in GWP and a 64% decrease in freshwater use. Nevertheless, the CLT construction has a greater acidification potential (AP), particularly during phases A1-A3 and A4, with respective increases of 99% and 106%. The eutrophication potential (EP) has a somewhat varied pattern, showing a modest rise during transportation (A4) for the CLT building. However, there is an overall decrease in the construction phase and the whole life cycle impact. Mass timber structures show great potential for sustainable construction, since they provide efficient use of materials and a less environmental impact in comparison to conventional concrete buildings. Additional research is needed to assess the extended lifespan and effectiveness of mass timber constructions in different weather conditions and architectural applications.

4 Credit authorship contribution statement

Amitava Sil – Writing, review and editing, supervision, original draft, conceptualization, resources & management. **Anindita Bhattacharyya** – Concept of life cycle analysis, resources, **Sourav Dandapat** – Writing, original draft, editing, visualization, software, formal analysis, data creation & methodology. **Supriya Pal** – Editing and Conceptualization.

5 Declaration of competing interest

The authors state that they have no known conflicting financial interests or personal ties that might have influenced the work presented in this study.

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