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An overview of the differences and comparisons between timber(CLT) and reinforced concrete structural houses

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Abstract: This paper presents an overview comparing the two types of building structures in terms of carbon emissions (sustainability issues), cost, structural characteristics, force mechanics analysis, effects of earthquakes on the structure and post-disaster reconstruction. In order to compare wood and reinforced concrete structures more intuitively, visual comparisons will be made through the actual existence and data of the building, and reasonably speculated how to solve the advantages and disadvantages of these two materials.

1. Introduction

The construction industry plays a pivotal role in global sustainable development efforts. In recent years, there has been a growing demand for environmentally friendly materials and energy-efficient buildings, which has renewed interest in traditional materials such as timber, while reinforced concrete continues to dominate the urban landscape. The contribution of wood, particularly cross-laminated timber (CLT), in reducing carbon emissions has been widely recognized due to its renewability and ability to store carbon throughout its life cycle. In contrast, reinforced concrete, although cost-effective and widely used, has attracted attention for its environmental impacts, especially the high energy consumption and CO2 emissions during production.

Sustainability is now at the forefront of construction innovation, driving the construction industry to explore alternative building materials that offer long-term environmental benefits without compromising structural integrity. Wood and reinforced concrete are two such materials that offer trade-offs between environmental performance, structural analysis, and cost. The purpose of this paper is to examine the advantages and challenges associated with wood and reinforced concrete, focusing on their sustainability, mechanical properties, and performance in the face of natural disasters such as earthquakes.

2. Timber structure in the world

Daramu House, by the architects TZANNES , is a largely timber-framed and completed in 2019 with the area of 11,700m^2 which locates in Australia.

Ascent, designed by Korb + Associates Architects, is a 25-storey high-rise condominium in Milwaukee, Wisconsin, USA. Completed on 1 July 2022, Ascent is 86.56m high, breaking the height limit for wood structures in the United States.It is by far the tallest wooden structure in the world.

Mjøstårnet flats are located in Brumunddal, Norway (about 85.m high), the project started in 2015 and opens in 2019.Mjøstårnet has 18 floors and more than 11,300 square metres of floor space.

Table 1: Comparison of three buildings in terms of location, structural type, etc

Name of the building	Daramu house	Ascent	Mjøstårnet
Location	Australia	U.S.A	Norway
Type of wood material	cross-laminated timber (CLT)	CLT (336,000 square foot)& glue laminated timber (80,000 square foot)	cross-laminated timber (CLT)
Structure type	Timber structure	Timber structure and concrete structure	Timber structure
cost	/	about $1.4 billion	$1.4 billion

The full name of the material is cross-laminated timber ,like the table 1, and unlike glued laminates, CLT is a composite material that utilises spruce and other woods that are arranged in a 90-degree crosswise arrangement. Due to its larger planar dimensions, the unique cross-laminated structure minimises the expansion and contraction of the object. Advantages such as lower air permeability, shorter site installation time , resistance can against the sheat in-plane [1] In addition to this, the material CLT has natural advantages in sustainability. Pressing C into the wood makes it stronger. [2] This is a perfect example of the benefits of the CLT.

However, the choice of CLT as a building material comes with a series of problems, such as low utilization of wood and the inability to build too high a building. The most obvious is the high cost of construction, such as the price of bare wood structure will be 10%-15% higher than the same series of steel structure and concrete structure.[3]In addition, CLTs face challenges in terms of resistance to lateral loads, fire safety issues and building performance.[4]

3. The background of the concrete

Concrete in the modern sense dates back to the 18th and 19th centuries. By far, China is the country that uses the most reinforced concrete structures in the world.There are many types of concrete, and most of the raw materials of concrete are cement, sand, stone and other materials mixed in proportion. Compared with steel structure, concrete structure will not become ribbon at high temperature. And because steel bars are surrounded by concrete, this means they are also more durable than steel structures. Compared with wood structural materials, reinforced concrete structures are cheaper and raw materials are more readily available.

However, concrete has the lower tensile strength and weak resistance to crack formation. At the same time, it is not environmentally sustainable because its manufacturing process accounts for 7% of the world's total emissions [5] . At the same time, after the end of its life, the recycling and treatment of reinforced concrete will also cause problems such as waste of resources, high cost and environmental pollution.

4. Compare the timber with the reinforced concrete

4.1 Compare the timber with the reinforced concrete in making proccessing

Comparison of the figurative differences between reinforced concrete structures and wood structures begins with the differences in the generation of raw materials and in the construction process in the *Fig1* and *Fig2*.

In the case of reinforced concrete structures, the reinforcement is first treated and then the concrete is combined with the reinforcement to form reinforced concrete through the static pile method, grouting method, etc.

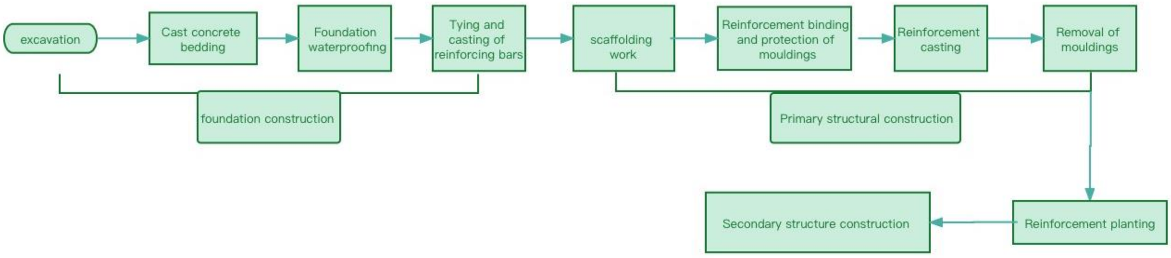

Figure 1: Construction flow chart for reinforced concrete

In order to become a CLT, materials such as spruce have to undergo a number of processes, starting with the selection of dry wood (e.g. with a moisture content of less than 15 per cent). Of course, lesser-known or diseased or hazardous wood can also be used as a raw material for better sustainability [8]. The CLTs are bonded together by crossing them at 90 degrees.

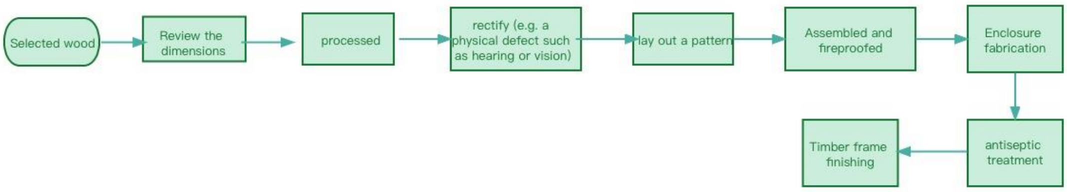

Figure 2: Timber construction flowchart

By comparing the two flow charts, it is clear that wood construction has fewer steps and is easier to install. This greatly reduces construction time and labor costs, thus reducing the budget.

4.2 Carbon footprint

Carbon emissions are the highest pollutant of the two building types

All the data are shown in the *Table 2*

The production of concrete, including reinforced concrete (RC) and plain concrete, is significantly higher, accounting for 57% of total product production. However, its carbon emissions from the production process are relatively low, with the production process accounting for 2.7% of total emissions. Despite this low percentage of emissions, concrete still accounts for a sizable share of overall carbon emissions, accounting for 9% of total emissions (B). The measured carbon footprint per gigatonne (GT) of concrete production is 0.16 ± 0.04, indicating relatively low variability in emissions.

On the other hand, wood accounts for a much smaller proportion of the total production, only 6% of the total production (A). However, the carbon emissions from wood in the production process are much higher than those from concrete, accounting for 5.4% of the total emissions. Wood's contribution to total carbon emissions is also much larger, at 18% of total emissions (B). Its carbon footprint per gigatonne of production is much larger, at 2.9 ± 1.5, with greater variability in emissions results than for concrete.

This comparison highlights the trade-off between production volume and environmental impact. Concrete is produced on a much larger scale and has relatively low emissions per unit of production, whereas wood, although produced on a smaller scale, has higher emissions relative to its production volume. Wood's larger carbon footprint is somewhat offset by its lower carbon emissions.

Table 2: Carbon emissions are the highest pollutant of the two building types

Material	Production/GT	As % of total product (A)	CO_2emitted during production/GT	As % of total CO_2 (B)	$I_p = B \div A$
Concrete (RC+plain)	19	57	2.7	9	0.16±0.04
Timber	2.1	6	5.4	18	2.9±1.5

4.3 Sutainable development

This year, environmental issues are at the forefront of everyone's mind. Therefore, while we focus on building performance, we should also minimize carbon emissions and other issues. Some related studies show that within the same unit (volume, duration, etc.) wood structures require 16% less energy than concrete structures, and global warming trend is reduced by 31%. [10]

And to minimize the ECf can use C50 concrete. [6] [7] Among them, wood products are considered to be the most sustainable material because wood is a good carbon sequestering material from an environmental point of view. In terms of the structure of the building, the thermal conductivity of concrete (1.4w/) is ten times that of wood. [9]

Meanwhile, studies have shown that timber structures have superior energy saving performance than reinforced concrete structures . [11] This means that timber insulation is more stable in the same situation. And the building is definitely insulated, which results in timber spending less on insulation and lower budget.

Meanwhile, comparing the data of *Fig.3* and *Fig.4*, it can be learned that the carbon emission of reinforced concrete structure is always higher than that of wood structure when comparing the carbon emission of different kinds of buildings and different cities. In summary, it can be concluded that wood structures are significantly better than reinforced concrete structures in terms of sustainability.

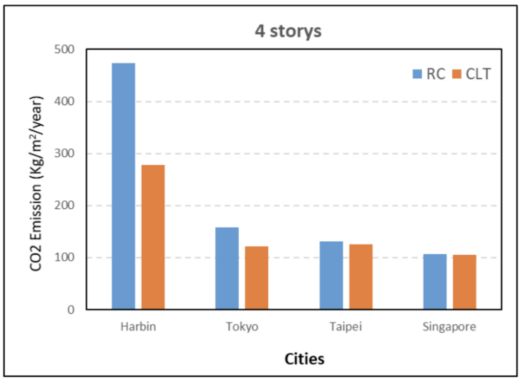

Figure 3: Carbon emissions between reinforced concrete and wood under 4 storys

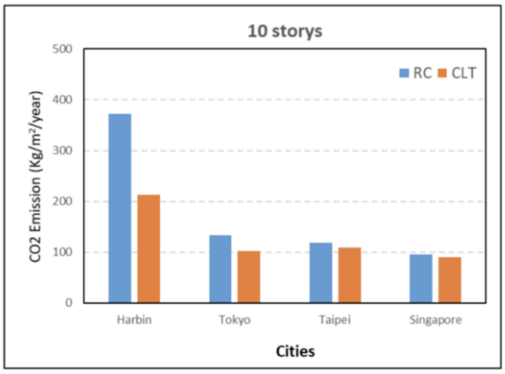

Figure 4: Carbon emissions between reinforced concrete and wood under 10 storys

The carbon footprint of reinforced concrete (no date) Advances in Cement Research. Available at: https://www.icevirtuallibrary.com/doi/epdf/10.1680/adcr.13.00013 (Accessed: 21 October 2023).

	EC Factor ($kgCO_2e/kg$)	Density (kg/m^3)
Concrete	0.22	2,500
Steel	1.55	7,800
Timber	0.437 (No carbon storage) Your choice which to use and justify	500
Timber	-1.2 (Including carbon storage) Your choice which to use and justify	500

Figure 5: The EC factor of different materials (From the univercity of Sheffield)

However, different materials of timber (like *Fig.5*) will produce different carbon emission, and wood which can store carbon dioxide is of course more environmentally friendly.

4.4 Performance of two types of buildings during an earthquake

For mechanical structural characteristics:

Mechanical characteristics of CLT: CLT beams are not easy to break because CLT is perpendicular to the beam axis and has high tensile strength. Moreover, the elasticity and strength of CLT is increased by about 30% compared to GLT.

Mechanical characteristics of RC: The compression strength of concrete is higher than its tensile strength.

The timber material is lighter and easier to build platforms, studies have shown that: using traditional connectors may cause a large collapse during earthquakes, but switching to the new material will reduce this situation. This means that we can prevent large scale damage caused by earthquake hazards through effective means. That is, the layers are stacked so that each layer is load bearing on the wall panels.

For reinforced concrete structures a hierarchy of strength development should be established to ensure that brittle damage does not occur in the event of a mega-earthquake whereas the expected annual economic loss for a group of RC-framed buildings in a high seismicity area in California is about 1.0% of the replacement cost of the building. The maintenance and cost of reinforced concrete structures is also highly dependent on their construction design.

While wood and reinforced concrete have their advantages and disadvantages when it comes to seismic resistance, recent research has shown that wood structures, particularly CLT structures, have significant advantages in earthquake-prone areas.CLT is lightweight and highly resilient, making it an ideal material for absorbing and dissipating seismic forces, which reduces the risk of structural failure during earthquakes.The material is also highly resilient, which makes it ideal for absorbing and dissipating seismic forces and reduces the risk of structural failure during earthquakes. Studies have shown that CLT structures suffer less damage in earthquakes than reinforced concrete buildings, largely due to the material's elasticity and ability to distribute loads evenly throughout the structure. Modern building techniques, such as the use of innovative connectors that reduce the risk of collapse, further enhance the inherent seismic capacity of wood in earthquakes.

In contrast, reinforced concrete buildings, while strong, are more prone to brittle damage under extreme seismic loads. Concrete's high weight and low tensile strength make it less able to withstand the forces generated by earthquakes. While reinforced concrete buildings are designed to withstand earthquakes, the costs associated with reinforcing these structures can be prohibitively high, especially in areas of high seismic activity. Therefore, wood construction offers a more cost-effective and earthquake-resistant alternative for buildings in earthquake-prone areas.

5. Conclusion

In summary, this analysis provides a comprehensive comparison of wood (CLT) and reinforced concrete structures, considering all aspects of environmental sustainability, thermal insulation, mechanical properties, and seismic performance. It is clear that both materials have unique advantages and disadvantages that suit different types of projects and structural requirements.

From a sustainability perspective, timber structures are clearly superior to reinforced concrete structures because of their ability to sequester carbon and significantly reduce greenhouse gas emissions. Timber also requires less energy to produce than concrete, making it a more environmentally friendly option. However, cross-laminated timber (CLT) remains a challenge due to the complexity of production, limited availability and high initial costs. Over time, technological advances and economies of scale can reduce these costs, making cross-laminated timber a more viable option in the future.

On the other hand, reinforced concrete structures are widely used for their availability, cost-effectiveness, and ability to withstand extreme forces such as earthquakes. Despite its widespread use, the environmental impact of concrete production - accounting for 7% of global carbon emissions - highlights its significant disadvantage in terms of long-term sustainability. In addition, recycling and disposal of concrete at the end of its life cycle further contributes to environmental pollution.. With the development of technology in the future, if the production cost of CLT can be reduced, I believe that most of the buildings in the future will adopt CLT structure.

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