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EXPLORING THE POTENTIAL OF GLUED AND CROSS-LAMINATED TIMBER IN SUSTAINABLE CONSTRUCTION

Matheus Barreto de Góes
Universidade Federal de Minas Gerais (UFMG)

Edgar Vladimiro Mantilla Carrasco
Universidade Federal de Minas Gerais (UFMG)

10.37885/231115032

ABSTRACT

This article presents an analysis of the properties of glued laminated timber (GLT) and cross-laminated timber (CLT), solutions developed for the structural use of wood. The aim of this work is to evaluate the sustainability, cost-effectiveness, and resilience of these materials in construction. For this purpose, a literature review of studies and research in the field was conducted. The results indicate that the use of wood in its laminated form has advantages over other conventional materials, especially regarding sustainability and resilience. Wood is a renewable resource with a positive carbon footprint, and its use in construction can contribute to reducing environmental impact. In addition, GLT and CLT have high mechanical strength and durability, making them a viable alternative to the use of concrete and steel in some situations. Regarding costs, the results found are equivalent between wood and concrete in some buildings up to five stories. However, laminated timber may have higher prices compared to other materials, but construction time is usually faster due to the use of prefabricated systems, which can result in significant savings in total project costs. The main challenge identified for the growth and implementation of these materials is the short development time and the need for greater dissemination of research and practical results in the field. It is important that government agencies, universities, and industries work together to promote research and development of new materials and construction technologies that can help drive the adoption of laminated timber as a sustainable and cost-effective building material.In summary, the analysis carried out in this work indicates that the use of glued laminated timber (GLT) and cross-laminated timber (CLT) in constructions can be a sustainable option with equivalent results in terms of cost compared to other conventional materials. However, more investment in research and dissemination is needed to drive the adoption of these materials in construction.

Keywords: Laminated Timber, Sustainability, Wood Construction.

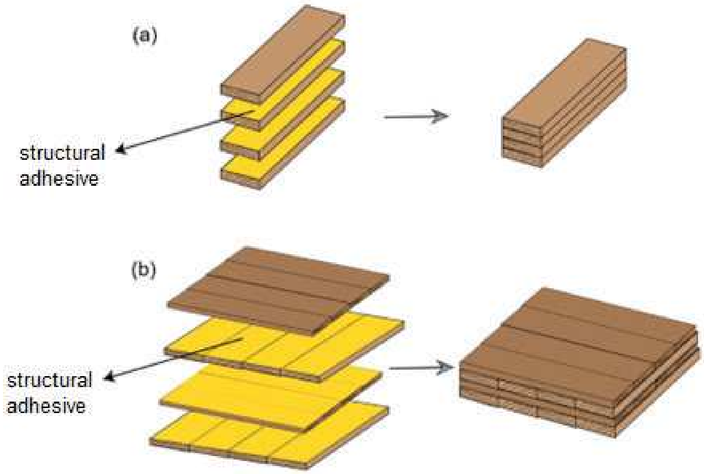
INTRODUCTION

Wood is a material widely used in construction due to its favorable physical characteristics for structural applications, such as high strength-to-weight ratio, low energy consumption for production, and its intrinsic quality of being a natural and renewable material. However, its hygroscopic and anisotropic nature can limit its use in buildings where structural height poses a challenge. Recently, engineered wood alternatives have emerged in the market, specifically developed to overcome the limitations of natural wood, such as dimensional instability, variabilities, and growth defects [1].

One available model that has experienced significant growth in the construction industry is Glue Laminated Timber (Glulam), a system in which boards, typically made from reforested wood like Pine or Eucalyptus, with a maximum thickness of 5 cm, are arranged in parallel and bonded with structural adhesives to form larger pieces capable of withstanding higher loads than wood in its original state (Figure 1A). Glulam pieces are commonly used in construction as beams and columns [2].

Another variety is Cross Laminated Timber (CLT), also based on bonding wood boards, but arranged orthogonally (crosswise), resulting in the creation of larger and thicker panels that can be used as walls and slabs (Figure 1B). CLT panels have gained popularity in Europe since the late 1990s due to their structural advantages, aesthetic qualities, and the increasing environmental movement at that time. Currently, pre-fabricated CLT panels serve as the foundation for many wooden construction projects. Europe remains the main hub for manufacturing and utilization, accounting for 90% of global production in 2015, with a projected increase to over three million cubic meters by 2025 [3].

Figure 1. Example of MLC and CLT assembly.



While Europe has seen significant growth in the use of these new wood technologies, the countries in the Americas have not experienced the same level of adoption. There is believed to be a substantial market in the Americas, but the adoption in these countries has been relatively slower. The industry in these countries tends to be conservative and methodical in implementing new technologies. In the United States, for instance, it is estimated that new construction techniques or products take around 17 years to become widely adopted and popular [4].

In a survey conducted by Germain *et al.* (2022), it is pointed out that the delay in the dissemination of this technique in the United States is largely due to a lack of knowledge about its attributes, capabilities, and costs. A considerable number of architects in the country were not even aware of CLT, indicating that a necessary step for product adoption is awareness, which in turn sparks interest among professionals.

In addition to raising awareness and adopting glued laminated timber (GLT) and cross-laminated timber (CLT) technologies in new constructions, another crucial aspect of sustainable development in the construction industry is building refurbishment or the renovation of existing buildings. Building refurbishment is an essential practice to improve energy efficiency, extend the lifespan of structures, and reduce the environmental impact of the construction sector.

Older buildings often have wooden structures that may be deteriorated or suffering from natural wear and tear over time. In such cases, the use of GLT and CLT can be an excellent alternative to revitalize and strengthen the structures, providing greater resistance and durability.

Glued laminated timber and cross-laminated timber are ideal materials for building refurbishment, as they can be custom-made to meet the specific needs of the project while offering a sustainable solution for the renovation of older buildings. Moreover, the lightweight nature of these materials reduces the additional load on existing foundations, minimizing the costs of structural reinforcement.

When considering building refurbishment, it is essential to consider not only the replacement of structural elements but also the improvement of energy efficiency, the incorporation of sustainable technologies, and the optimization of natural resource utilization. The use of GLT and CLT can contribute to these objectives, providing benefits both from an environmental and economic perspective.

Therefore, building refurbishment, combined with the use of innovative technologies such as glued laminated timber and cross-laminated timber, can represent an efficient and sustainable approach to the construction industry, allowing the environmentally responsible and cost-effective revitalization of old buildings. Awareness and knowledge of these technologies are vital to drive their adoption and promote a more sustainable future for the construction sector.

This work focuses on investigating characteristics related to cost-effectiveness, sustainability, and resilience capacity of glued laminated timber and cross-laminated timber constructions.

METHODOLOGY

The research method used for this study involved a thematic approach with available data from various online databases. Recent bibliographic sources (between 2017 and 2022) addressing the topic of wooden constructions were included, as well as older bibliographic sources (before 2017) that deal with wooden constructions in general and serve as references for this area of study.

The study is divided into three main stages, providing information on sustainability, taking into account aspects such as greenhouse gas emissions, sustainable forest management, and end-of-life cycle considerations; cost-effectiveness; and resilience of wooden constructions. Afterward, discussions on the presented topic are conducted, followed by final considerations on the subject.

Sustainability

Sustainable development is a concept becoming increasingly prevalent in today's society. The construction industry is no exception, as this concept seeks to strike a balance between social, economic, and environmental development, aiming for long-term human well-being. Within this context, building construction has a significant impact on economic and environmental sectors [5].

A sustainable built environment should always strive to optimize the relationship between economic and environmental consequences in design concepts. The choice of the most suitable building material can help improve the sustainable performance of buildings. In this regard, wood presents itself as a material with sustainable characteristics that can be compared to other widely used construction materials in Brazil.

Greenhouse Gas Emissions

Wood is one of the few natural and renewable construction materials. While materials like concrete and steel emit CO2 into the atmosphere during their production, trees naturally absorb CO2 during their growth. As products containing wood are used in constructions, the CO2 absorbed during tree growth remains stored throughout the material's lifespan. Consequently, the use of wood instead of concrete and steel components reduces the amount of carbon incorporated into buildings [6].

In addition to reducing embodied emissions in materials, prefabricated wood can considerably reduce carbon emissions from heavy vehicles. Glued laminated timber and cross-laminated timber are produced off-site and assembled with fewer machines, resulting in up to 20% cost savings compared to traditional methods [7].

The high air-tightness and low thermal conductivity of wood can also contribute to improved energy efficiency in buildings using this component. A study conducted in China by Guo *et al.* (2017) compared the life cycle emissions profile of a seven-story concrete building with its hypothetical wood equivalent, concluding that the wooden building can reduce energy consumption by up to 30% and CO2 emissions by over 40% when compared to concrete and steel buildings [6].

This approach regarding greenhouse gas emissions demonstrates that wood-based products have the potential to enhance the energy efficiency of buildings and offer an opportunity for the construction industry to contribute to achieving a significant reduction in net carbon emissions.

Sustainable Forest Management

Considering the expanded use and adoption of GLT, CLT, and wood in general in construction, questions may arise about the consumption of wood for their production. The renewable nature of wood is due to its abundance in nature. Specifically, GLT and CLT pieces are products developed from reforested trees, which do not pose a risk to native forests in the manufacturing regions [8].

While the wood used comes from reforested forests, long-term sustainable forest planning is necessary to ensure environmental, economic, and social benefits in the future. As the demand for wood for GLT and CLT production increases, it is expected that areas allocated for reforestation will also increase, providing an alternative market outlet for these species and encouraging sustainable management over time [6].

End-of-Life Cycle Considerations

The sustainability of materials should encompass the entire lifecycle, including manufacturing, transportation, use, and disposal. Concerning the final disposal of wood, a crucial aspect for sustainability, it is essential to be mindful that burning or decomposing the material will release the stored CO2 back into the atmosphere. Therefore, reusing wood components is essential to maximize the environmental benefits of GLT and CLT.

In this context, three possible destinations for discarded pieces are suggested. The most suitable option is reuse, as removed pieces can be utilized in other constructions under the same conditions or adapted for non-structural purposes, such as facades and decorations. Reuse extends the material's lifespan, increasing the carbon sequestration time and avoiding the need for new wood production and subsequent emissions [6].

When reuse is not feasible, the discarded wood can be used for biomass production, which reduces the consumption of fossil fuels. The last, less desirable alternative, is landfill disposal, as it indirectly releases CO_2 and does not recover energy from wood products [6].

In general, when designing with GLT and CLT, a comprehensive analysis of all construction stages, including end-of-life destinations for all components, is essential to establish wood as a truly sustainable material.

Cost-Effectiveness

One of the main obstacles to the widespread use of GLT, CLT, and wood in construction is the fear among professionals that this method may lead to higher project costs compared to traditional methods. The construction industry tends to avoid risks, making it unlikely for revolutionary technologies to be adopted without clear evidence of significant cost savings. Innovations that reduce construction time or project expenses often drive advantages in the construction market. The costs related to GLT and CLT constructions are not well understood due to their relatively new status, and there is not a considerable number of constructed projects that can confirm their cost-effectiveness. However, several comparative studies exist on the costs between wooden constructions and other conventional methods [6].

Material Costs

A significant portion of the total building cost is related to the cost of materials used. For GLT and CLT to be more widely adopted, their prices must be competitive with other established materials like concrete and steel. While comparing directly may be challenging due to regional availability, market demand, and offers, some comparative studies have been conducted [16].

For example, a study in the UK evaluated the construction of a nine-story Murray Grove Cross Laminated Timber (CLT) building and found that the use of a wooden structural system increased material costs by 30% compared to reinforced concrete. Another analysis in the US compared the costs of a hypothetical ten-story CLT building with an equivalent cast-in-place concrete structure, resulting in wood being between 16% and 29% more expensive than concrete [6].

However, other studies demonstrate that wood can lead to cost savings in construction. A detailed analysis of a seven-story hypothetical project in Sydney, Australia, showed a 13.6% reduction in material costs compared to a reinforced concrete building, with all areas presenting savings, except for Glulam columns [18]. Green (2017) found favorable results for using structural walls, with savings of up to 26%, while wooden floor, column, and beam solutions would cost 43% more than concrete. The origin of the purchased material also plays a role in calculating material costs. Byle (2012) stated that material cost savings could double if materials were locally produced instead of imported from Europe.

Overall, it is not definitively clear whether GLT and CLT use is more economical than concrete or steel. However, even considering that current costs may be higher, it is expected that costs will decrease as projects using this material become more widespread and the production and distribution chain becomes more established in the market. Additionally, considering only material costs ignores potential gains in other areas of construction projects.

Reduction in Construction Time

A frequently highlighted advantage of GLT and CLT construction is the speed at which buildings can be erected. Prefabrication of components allows for their delivery to the construction site and installation by a small team of workers. This speeds up the construction process and enables structural components and foundation elements to be built simultaneously. As a result, the common delays in masonry projects, where foundation stages must be completed before starting wall construction or where concrete needs 28 days to cure before constructing a new floor, are minimized [16].

By appropriately coordinating design, fabrication, and construction stages, GLT and CLT projects significantly reduce the time spent on-site, benefiting worker safety, minimizing disruptions to the neighborhood, and reducing material waste. Some studies indicate that wooden constructions can be erected in approximately 3 to 4 days per floor, whereas reinforced concrete requires 28 days for each floor [6],[16].

For example, a study by Smith *et al.* (2018) compared the execution schedule of a series of seven wood-structure buildings with conventional concrete structures. The results showed an average 20% reduction in execution time for wood projects, with an average duration of 12.7 months compared to 15.4 months for concrete projects.

While it is already proven that wooden construction reduces the project duration compared to concrete structures, as with material costs, experience gained through increased adoption of this technology is expected to further decrease construction timelines.

Resilience of Wooden Constructions

The study of structural performance is essential to ensure building safety. In the context of sustainable design, constructions must be designed to withstand various critical events. With the effects of climate change, the need to anticipate adverse situations, such as earthquakes, hurricanes, and other natural disasters, is crucial to ensuring structure resilience and avoiding material or human losses. A concept of sustainability cannot exist in a structure that may need to be rebuilt before its intended lifespan due to unforeseen failures [9].

In 2014, the National Institute of Building Sciences (NIBS) of the United States, along with other organizations representing approximately 750,000 professionals, issued a joint statement defining resilience as: “The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events” [9].

While research related to the resilience of buildings made from conventional materials such as concrete and steel has been studied by professionals for a longer time, studies on the behavior of wooden buildings subjected to seismic events are more recent, with significant growth only since the early 2000s. Consequently, there is a limited number of responses regarding the behavior of wooden buildings in such situations, but the studies available have shown positive responses to these occasions. Particularly, studies have been conducted by researchers in regions more prone to earthquakes, such as East Asia (Japan, China), the Americas (Chile, Canada, USA), and Europe [6].

In a study conducted by Ceccotti *et al.* (2013) in Japan, a full-scale seven-story CLT building was constructed according to the European standard Eurocode 8. The building was placed on a 3D shaking table and subjected to simulated earthquake loads. After receiving a series of earthquake loads, the building did not experience any residual displacements, and no critical damage was observed.

Another study conducted in Canada by Shahnewaz *et al.* (2017) aimed to analyze the seismic behavior of a hypothetical six-story CLT building using Incremental Dynamic Analysis. With this technique, researchers examined the structural response of the building under simulated earthquake excitations. The objective was to verify if the construction could withstand a MCE (Maximum Considered Earthquake) - an extremely high-intensity earthquake with high ground motions, predicted to occur once every 2,500 years. The results indicated that no significant damage would occur during a MCE, and the possibility of collapse was less than 0.1%.

Timmers and Jacobs (2017) conducted another study using computational and numerical analyses, comparing a 20-story reinforced concrete building with an equivalent one built with wood. The wooden building had glued laminated timber (GLT) columns and cross-laminated timber (CLT) floor and wall panels. At the end of the study, the wooden project had half the mass and half the stiffness of the reinforced concrete, which is desirable for building resilience.

All these conducted studies demonstrate that not only does wood have satisfactory performance during critical seismic events, but it can also outperform concrete. This superior performance is attributed to the considerably lighter weight of wooden constructions, minimizing the inertia forces generated during earthquakes and reducing the risk of collapse. Additionally, the high rigidity of CLT panels allows structures to resist lateral distortion, and ductile connections can yield without compromising the overall structural integrity [6].

Although research has already confirmed the viability of using GLT and CLT under critical seismic conditions, further investigative studies are needed to confirm their applicability for more complex buildings, particularly those with more than 20 stories.

Building Refurbishment

The link between cost-effectiveness, sustainability, and resilience of glued laminated timber (GLT) buildings in the context of building refurbishment is essential for promoting a holistic and sustainable approach to the renovation of existing structures. The use of glued laminated timber as an alternative construction material enables the revitalization of old structures with a more economical approach, due to the possibility of custom fabrication, which reduces waste and streamlines the construction process. Furthermore, glued laminated timber is a sustainable choice as it is derived from renewable sources, aids in carbon sequestration, and reduces the environmental impact of the construction sector. In addition to offering economic and environmental advantages, the resilience of glued laminated timber is a critical feature in building refurbishment, as these structures can outperform concrete in critical situations, minimizing collapse risks during adverse events such as earthquakes and other extreme weather conditions. Thus, considering building refurbishment with glued laminated timber allows for efficient, sustainable, and resilient renovation, contributing to a more conscious and responsible future in the construction industry.

Moreover, the selection of glued laminated timber in the building refurbishment process also contributes to the preservation of architectural and cultural heritage, especially in historical and traditional buildings. The ability to adapt and strengthen existing structures with sustainable materials like GLT enables these buildings to be revitalized without compromising their authenticity and historical value. Therefore, glued laminated timber not only offers technical benefits but also preserves the identity and memory of a location, adding value not only to the occupants but to the entire community.

In addition to its technical and cultural advantages, glued laminated timber in building refurbishment can also play a significant role in reducing carbon emissions and mitigating climate change. By choosing renewable construction materials such as wood instead of more carbon-intensive options like concrete and steel, it is possible to substantially decrease the carbon footprint of the construction industry. This is crucial for achieving sustainability goals and environmental resilience, contributing to a healthier and more sustainable environment for future generations. Therefore, the integration of glued laminated timber in building refurbishment not only promotes efficient solutions for existing buildings but also contributes to a construction sector that is more environmentally conscious and aligned with the environmental and social challenges of the 21st century.

RESULTS AND DISCUSSIONS

This article explored glued laminated timber (GLT) and cross-laminated timber (CLT) as alternative construction materials to traditional options like concrete and steel, with a particular focus on their role in building refurbishment. Building refurbishment, the renovation of existing buildings, is essential for improving energy efficiency, extending the lifespan of structures, and reducing the environmental impact of the construction industry.

In terms of sustainability, using GLT and CLT in building refurbishment offers significant advantages. Wood is readily available in nature and renewable, emitting no greenhouse gases during its growth process. Moreover, it acts as a carbon sink throughout its life cycle, unlike concrete production, which contributes substantially to pollution. The encouragement of sustainable forest management and reforestation further emphasizes the importance of using wood, as it helps protect native forests from deforestation and creates a market for forest producers. The life cycle of wood-derived materials offers environmental benefits, as wood can be reused in various forms before being discarded, extending its lifespan and delaying the release of carbon into the atmosphere.

When considering the cost-effectiveness aspect, GLT and CLT show promise in building refurbishment projects. Wood, as a construction material, can be manufactured to precise measurements, reducing waste and expediting the construction process. Additionally, the data presented in this study demonstrate a significant reduction in the duration of construction for GLT and CLT structures, indirectly leading to cost savings. As these innovative wood technologies gain wider market acceptance and experience in their use increases, the cost-effectiveness is expected to further improve, making them more competitive with traditional materials like concrete and steel.

The resilience of GLT and CLT structures in building refurbishment scenarios is another critical factor. The superior performance of wood in critical situations, such as earthquakes, can minimize the risk of collapse during adverse events. Wood's lighter weight reduces the load on existing foundations, reducing the moment of inertia generated during seismic events. Furthermore, the flexible connections and joints in wood constructions facilitate repairs after tremors, a feature not found in rigid concrete structures.

In addition to their technical advantages, the use of GLT and CLT in building refurbishment can play a significant role in reducing carbon emissions and mitigating climate change. Opting for renewable construction materials like wood, instead of more carbon-intensive options like concrete and steel, substantially reduces the carbon footprint of the construction industry. This is crucial in achieving sustainability goals and environmental resilience, contributing to a healthier and more sustainable environment for future generations. Therefore, integrating GLT and CLT in building refurbishment not only promotes efficient solutions for existing buildings but also contributes to a construction sector that is more environmentally conscious and aligned with the challenges of the 21st century.

Moreover, the use of GLT and CLT in building refurbishment also contributes to the preservation of architectural and cultural heritage, particularly in historic and traditional buildings. By adapting and strengthening existing structures with sustainable materials like GLT, the authenticity and historical value of these buildings can be maintained. This preservation not only benefits the occupants but also adds value to the community as a whole.

In conclusion, the discussion of GLT and CLT in building refurbishment reveals that these engineered wood products offer a holistic and sustainable approach to renovating existing buildings. They provide economic, environmental, and technical advantages, including cost-effectiveness, reduced carbon emissions, and improved resilience. Incorporating GLT and CLT in building refurbishment projects not only leads to efficient renovations but also promotes a more environmentally conscious and socially responsible construction industry.

CONCLUSIONS

As our society experiences economic, environmental, and social development, the need for alternative and sustainable solutions becomes increasingly evident. Glued laminated timber (GLT) and cross-laminated timber (CLT) emerge in this context with the purpose of preserving the environment, reducing costs, and providing greater safety in critical situations for users. The findings presented in this study suggest that wood surpasses or at least matches traditional methods in all these aspects. While more studies and constructions with these materials will lead to more favorable conclusions, it is already evident that the implementation of GLT and CLT has been embraced by builders and users seeking to combine economy, sustainability, and safety – with successful outcomes.

To increase the utilization of these efficient materials, it is essential to foster a positive feedback loop. By promoting the dissemination of research results and practical applications by builders, raising user interest and generating market demand, we can stimulate the growth of manufacturing facilities and derivative products. This, in turn, will lead to financial investments in further advancements and research within the sector.

In conclusion, the integration of GLT and CLT in building refurbishment and new constructions offers a promising path towards a more sustainable and resilient construction industry. From their sustainable sourcing to their cost-effectiveness and superior performance in critical situations, GLT and CLT demonstrate their potential as a key solution for modern construction challenges. As the industry moves towards a more environmentally conscious and socially responsible future, the adoption of these innovative wood technologies will play a pivotal role in shaping a greener and more sustainable built environment for generations to come.

Figures and tables must be integrated into the file, in their corresponding place within the text.

PUBLISHING AGREEMENT

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001

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