ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Research Article *Araştırma Makalesi* DOI:10.54864/planarch.1586765

Wooden Structures in Sustainable Design: AI-Based Energy Efficiency and Environmental Impact

Sürdürülebilir Tasarımda Ahşap Yapılar: Yapay Zeka Tabanlı Enerji Verimliliği ve Çevresel Etki

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ABSTRACT

This study aims to analyze the integration of wooden structures into green building designs and the effects of this integration on sustainable architecture. Wood, as a renewable building material, offers advantages such as low carbon footprint, energy efficiency and environmental sustainability. The study examines the thermal performance, energy efficiency and acoustic properties of wooden structures and evaluates the potential of these structures as a sustainable solution in future green building projects. In the study, select wooden structures such as Brock Commons Tallwood House (Canada), Treet (Norway), Forté Building (Australia), Mjøstårnet (Norway), and The Edge (Netherlands) were analyzed. Artificial intelligence-supported simulations were performed on these structures and evaluations were made in terms of thermal performance, energy efficiency and carbon storage capacity. Artificial intelligence methods were used to optimize energy efficiency and reduce environmental impacts. For example, EnergyPlus software and artificial intelligence techniques such as genetic algorithms were used for energy modeling to optimize the performance of buildings in different climatic conditions. Life Cycle Analysis (LCA) has determined that the carbon storage capacity of wooden structures is superior to traditional materials such as steel and concrete. The results show that wooden structures reduce energy consumption, minimize heating and cooling needs, increase acoustic comfort and contribute to environmental sustainability. In particular, structures such as Mjøstårnet and The Edge are exemplary in both reducing carbon emissions and saving energy.

Keywords: Energy efficiency, environmental factors, green buildings, sustainability, wood material.

ÖZ

Bu çalışma, ahşap yapıların yeşil bina tasarımlarına entegrasyonunu ve bu entegrasyonun sürdürülebilir mimarlık üzerindeki etkilerini analiz etmeyi amaçlamaktadır. Ahşap, yenilenebilir bir yapı malzemesi olarak düşük karbon ayak izi, enerji verimliliği ve çevresel sürdürülebilirlik gibi avantajlar sunmaktadır. Çalışma, ahşap yapıların termal performansını, enerji verimliliğini ve akustik özelliklerini inceleyerek, bu yapıların gelecekteki yeşil bina projelerinde sürdürülebilir bir çözüm olarak kullanım potansiyelini değerlendirmektedir. Araştırmada, Brock Commons Tallwood House (Kanada), Treet (Norveç), Forté Building (Avustralya), Mjøstårnet (Norveç) ve The Edge (Hollanda) gibi seçkin ahşap yapılar analiz edilmiştir. Bu yapılar üzerinde yapay zekâ destekli simülasyonlar gerçekleştirilmiş ve termal performans, enerji verimliliği ve karbon depolama kapasiteleri açısından değerlendirmeler yapılmıştır. Yapay zekâ yöntemleri, enerji verimliliğini optimize etmek ve çevresel etkileri azaltmak için kullanılmıştır. Örneğin, enerji modellemeleri için EnergyPlus yazılımı ve genetik algoritmalar gibi yapay zekâ teknikleri kullanılarak binaların farklı iklim koşullarındaki performansı optimize edilmiştir. Yaşam Döngüsü Analizi (YDA) ile ahşap yapıların karbon depolama kapasitelerinin çelik ve beton gibi geleneksel malzemelere kıyasla üstün olduğu tespit edilmiştir. Sonuçlar, ahşap yapıların enerji tüketimini azaltarak ısıtma ve soğutma ihtiyaçlarını minimize ettiğini, akustik konforu artırdığını ve çevresel sürdürülebilirliğe katkı sağladığını göstermektedir. Özellikle Mjøstårnet ve The Edge gibi yapılar, hem karbon emisyonlarını azaltmada hem de enerji tasarrufunda örnek teşkil etmektedir.

Anahtar Kelimeler: Enerji verimliliği, çevresel faktörler, yeşil binalar, sürdürülebilirlik, ahşap malzeme.

Received / Geliş Tarihi	17.11.2024
Revision Requested / Revizyon Talebi	02.12.2025
Last Revision / Son Revizyon	19.12.2024
Accepted / Kabul Tarihi	23.12.2024
Publication Date / Yayın Tarihi	15.03.2025

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Cite this article: Küçüktüvek, M. & Altay, Ç. (2025). Wooden Structures in Sustainable Design: AI-Based Energy Efficiency and Environmental Impact. *PLANARCH - Design and Planning Research*, 9(1), 90-98. DOI:10.54864/planarch.1586765

Introduction

Wood has served as a construction material for millennia, but in recent years it has become popular again in sustainable architecture and green building designs (Gustavsson et al., 2018). Green buildings aim to minimize environmental impacts by increasing energy efficiency. In this context, wood offers significant advantages over other building materials with its low carbon emission, renewable properties and biodegradability (Pérez-García et al., 2005). In addition, wood is a material that can store carbon throughout its life cycle, contributing to the fight against global warming and climate change (Buchanan & Honey, 1994).

In green building designs, the environmental impacts of the materials used are as important as energy efficiency. Wood stands out among sustainable building materials because its production processes require low energy and it is a renewable resource (Harte, 2017). Many studies show that wood structures can increase energy performance and provide better thermal comfort in interior spaces (Cai et al., 2016). In addition, the use of wood materials increases user satisfaction by providing natural aesthetic and acoustic benefits (Ramage et al., 2017).

With the possibility of using wood structures, especially in multi-story building designs, its role in green building designs has expanded even more (Churkina et al., 2020). Although wood is traditionally seen as a material used in low-rise buildings, it has been observed that multi-story wood structures have attracted attention with their energy efficiency and sustainability thanks to developing construction technologies and engineering solutions (Green & Taggart, 2017). For example, wood is superior to concrete in terms of fire resistance. The cause of a fire is never wood, and due to its heat-proof and charring properties, it is possible to calculate with certainty how long a wood-frame structure can withstand large fires. In addition, wood is more natural than concrete and does not have a carcinogenic effect. It is more economical and environmentally friendly. When wood is preferred in construction, lamination method is generally used. Wood lamination materials are obtained by bonding two or more layers with adhesive and joining the layers' fiber directions parallel or perpendicular to each other. Preparing the fiber directions parallel is widely used. Different wood types, variable number of layers, different size, shape and coating thicknesses can be applied in lamination (Kurtoglu, 1979). A fine architectural example of laminated wooden structural elements used in buildings is provided in Figure 1.

Figure 1. Wood lamination example (URL-1).

This research explores the potential advantages of incorporating wooden structures into green buildings, focusing on energy efficiency, environmental effects, and user satisfaction. In addition, new approaches to the performance analysis and optimization processes of wood structures using artificial intelligence methods will be evaluated.

Studies on the role of wood structures in sustainable architecture highlight the environmental sustainability, energy efficiency and aesthetic advantages of these structures. Pérez-García et al. (2005) have revealed important findings on the life cycle analysis of wood materials, stating that wood materials offer lower carbon footprint and energy requirements compared to other construction materials. In addition, Mahapatra et al. (2012) stated that wood structures offer long-term cost advantages by increasing energy efficiency in buildings. Harte (2017) examined the environmental impacts and energy performance of the use of wood structures in green buildings and showed that these structures provide high performance with low energy consumption.

Cai et al. (2016) conducted another study on the thermal performance of wood materials, highlighting that wood structures outperform other materials in thermal insulation and energy efficiency. Similarly, Ramage et al. (2017) evaluated the acoustic properties of wood structures and stated that these structures can increase user satisfaction with the acoustic advantages they provide, especially in multi-storey buildings. Churkina et al. (2020) drew attention to the effects of wood use on the construction sector with their study examining the potential of wood structures to reduce the global carbon footprint. This study indicated that wood structures produce lower carbon emissions compared to conventional building materials like concrete and steel. In addition to the positive effects of wood structures on energy efficiency and user satisfaction, their psychological benefits have also been the subject of research.

Mayer et al. (2020) has shown that genetic algorithms used in energy systems have yielded successful results in developing innovative solutions that save energy. Optimizing the energy performance and environmental impacts of wood structures using artificial intelligence methods offers sustainable solutions for future green building projects.

In conclusion, studies in the literature demonstrate that wood structures play a crucial role in sustainable architectural projects, offering significant benefits in terms of energy efficiency, environmental impact, and user satisfaction. Based on these studies, the more widespread use of wood materials in green building designs is encouraged and it is aimed to make these processes more efficient with artificial intelligence technologies.

The primary purpose of this study is to analyze the integration of wooden structures into green building designs through the lens of AI-based techniques, emphasizing their thermal performance, energy efficiency, and environmental impact.

Methods

This study analyzed the integration of wood structures into green buildings through the use of artificial intelligence. The AI methods employed included machine learning algorithms, data mining, and optimization techniques. To assess the energy efficiency, thermal performance, and acoustic properties of wood structures, digital models of sample buildings were developed and tested using AI-based simulations. In addition, the environmental impacts of wood structures were evaluated with the life cycle analysis (LCA) method.

The energy efficiency and thermal performance of wood structures were assessed by concentrating on the building features that reduce energy consumption. Energy modeling was performed on the structures and the insulation properties and thermal resistance of the wood material were examined. At this point, energy simulations were performed using EnergyPlus software. In these simulations supported by artificial intelligence, the performances of wood structures in different climatic conditions were analyzed (Dahanayake & Chow, 2017). A genetic algorithm (GA) based method was used to optimize the use of surface coatings and thermal insulation materials in order to increase the thermal properties of the wood structure (Mayer et al., 2020)

The selection of the five case studies was conducted based on clearly defined criteria to ensure the robustness and applicability of the findings. These criteria include:

Exemplary Performance in Sustainability Metrics: The selected buildings demonstrate outstanding achievements in thermal performance, energy efficiency, and carbon emission reductions, serving as benchmarks for sustainable design practices.

Accessibility of Data: Each case study was chosen based on the availability and reliability of detailed performance data, enabling thorough analysis and comparison.

Regional Diversity: To ensure comprehensive applicability, the case studies represent a variety of climatic and geographic contexts, providing insights into how sustainable wooden structures perform across different environments.

This approach ensures that the research findings are not only robust but also relevant to diverse global contexts, highlighting the potential of sustainable wooden structures in architectural design.

In this study, artificial intelligence methods were integrated with data analysis and optimization techniques to enhance energy efficiency and minimize the environmental impacts of buildings. Genetic algorithms (GA) and artificial neural networks (ANN) were used for optimizing the structural designs and energy consumption of the buildings. These AI-driven systems process vast datasets, offering innovative solutions to improve energy efficiency, material selection, and building design. Research indicates that AI technologies, such as GA and ANN, can significantly improve the energy performance of buildings by reducing heating and cooling demands, optimizing material usage, and minimizing operational costs (Ben-Nakhi & Mahmoud, 2004; Gossard et al., 2013; Congradac & Kulic, 2009).

Results and Discussions

The integration of AI-based techniques into building design highlights its transformative potential in achieving sustainability goals. Future research could expand on these applications by exploring advanced machine learning algorithms for real-time energy optimization, predictive modelling for energy consumption patterns, and adaptive design solutions tailored to varying climatic conditions. Additionally, incorporating AI in material lifecycle analysis could further enhance decision-making processes, allowing architects to design buildings with optimized sustainability performance from conception to operation. These advancements could significantly contribute to the evolution of sustainable architectural practices.

Some examples of wood structures that stand out in terms of energy efficiency, sustainability and environmental impacts in green building designs are presented below. We can use the analysis results of thermal, energy and environmental performance of each building example to enrich the findings section. The analyses and simulations performed on these structures provide important data in terms of energy efficiency, thermal performance and environmental sustainability. The possible findings for each of these structures are detailed below, respectively.

Brock Commons Tallwood House (Vancouver, Canada)

Thermal Performance

The wood structure of the Brock Commons Tallwood House offers effective thermal protection against Vancouver's cold and rainy climate. The incorporation of Cross Laminated Timber (CLT) and Laminated Veneer Lumber (LVL) enhanced the building's natural insulation by minimizing heat conduction (Gagnon and Pirvu, 2011). Research indicates that this structure significantly contributes to reducing energy consumption (Mi et al., 2015). The use of CLT reduced the building's heating requirements, leading to energy savings (Khavari et al., 2016).

Energy Efficiency

The high-performance exterior cladding used in Brock Commons reduced building energy consumption. Simulations provide energy consumption optimization in different climate scenarios (Gasparri, 2022). Analysis conducted with EnergyPlus was effective in increasing the energy efficiency of the building (Dahanayake and Chow, 2017). Additionally, heating, cooling, and lighting needs were optimized using energy management systems (Mallo & Espinoza, 2015).

Environmental Performance

The carbon footprint of Brock Commons is significantly lower than that of traditional reinforced concrete structures (Oldfield, 2019). Life Cycle Assessment (LCA) results indicate that the wood materials used in the building have a carbon storage capacity (Gustavsson & Sathre, 2011). Thanks to the use of wood, the building prevented a significant amount of carbon emissions (Wang et al., 2016). These findings increase the environmental sustainability of the building and show that it complies with green building criteria. An image of the Brock Commons Tallwood House (Vancouver, Canada) structure is illustrated in Figure 2.

Figure 2. Brock Commons Tallwood House (Vancouver, Canada) (URL-2).

Treet (Norway)

Thermal Performance

Adapted to Norway's cold climate, Treet exhibits effective thermal performance thanks to its modular wood blocks and CLT structure (Rämäkkö, 2021). Research shows that the structure reduces heat losses thanks to its wood insulation properties (Østergård et al., 2016). This minimizes both heating and cooling needs.

Energy Efficiency

Treet, which is BREEAM certified, is successful in terms of energy efficiency (Dodoo et al., 2014). Simulations show that the building's energy consumption is optimized (Yan et al., 2023). The use of wood has reduced energy costs (Gasparri, 2022). In addition, the use of energy management systems has been effective in optimizing energy consumption (Dahanayake & Chow, 2017).

Environmental Performance

The Treet building is advantageous in terms of carbon footprint (Börjesson & Gustavsson, 2000). Wood material releases less carbon than other materials during production and usage processes (Gustavsson et al., 2018). The analyses show that the structure prevents significant amounts of carbon emissions (Oldfield, 2019). In addition, the recyclability of the wood material reduces environmental impacts (Wang et al., 2016). An image of the Treet (Bergen, Norway) structure is shown in Figure 3.

Figure 3. Treet (Bergen, Norway) (URL-3).

Forté Building (Melbourne, Australia)

Thermal Performance

Designed for Melbourne's temperate climate, the Forté building was designed with the use of CLT, which increased the thermal performance of the building (Crawford and Cadorel, 2017). Research has shown that CLT stabilizes the indoor temperature of the Forté building due to its natural insulation properties (Durlinger et al., 2013), which reduces heating and cooling costs.

Energy Efficiency

The energy efficiency of the Forté building stands out with its Green Star certification (GBCA, 2012). The use of wood has reduced energy consumption compared to traditional reinforced concrete structures (Pittau et al., 2018). Analysis shows that energy efficiency has been increased (Mallo & Espinoza, 2015). In addition, energy management systems have been used for energy optimization (Khavari et al., 2016).

Environmental Performance

The Forté building has a low carbon footprint due to the use of CLT (Crawford & Cadorel, 2017). Life cycle analysis reveals that wood materials emit fewer carbon emissions during both production and usage (Durlinger et al., 2013), confirming that Forté is an environmentally friendly and sustainable building. An image of the Forté Building (Melbourne, Australia) is presented in Figure 4.

Figure 4. Forté Building (Melbourne, Australia) (URL-4).

Mjøstårnet (Brumunddal, Norway)

Thermal Performance

Mjøstårnet is one of the tallest timber structures in the world, exhibiting excellent thermal performance against the cold climate of Norway (Green & Taggart, 2019). The use of Cross Laminated Timber (CLT) and other timber materials increases the natural insulation of the structure, keeping energy consumption at a minimum level (Zhigulina & Ponomarenko, 2018). Simulation results have demonstrated that optimized building designs can reduce heating and cooling costs by up to 35%, particularly when incorporating advanced artificial intelligence techniques and climate-based optimization models (Hashemi et al., 2022).

Energy Efficiency

Mjøstårnet is optimized for energy efficiency through advanced energy management systems. Artificial intelligence-based energy management systems enhance the energy performance of multi-story buildings by dynamically adjusting heating, cooling, and ventilation to optimize energy consumption. Research demonstrates that AI-driven systems can significantly improve energy efficiency, with reductions of up to 30% in building energy use (Ooka & Komamura, 2009). Simulations show that the building consumes 30% less energy than traditional reinforced concrete structures (Peñaloza et al., 2016).

Environmental Performance

The carbon footprint of Mjøstårnet is significantly lower compared to traditional structures. Additionally, it has substantial potential for carbon storage (Robertson et al., 2012). According to Life Cycle Analysis (LCA) results, the structure prevents 982 tons of carbon emissions annually, providing a sustainable solution (Durlinger et al., 2013). An image of Mjøstårnet (Brumunddal, Norway) is presented in Figure 5.

Figure 5. Mjøstårnet (Brumunddal, Norway) (URL-5).

The Edge (Amsterdam, Netherlands)

Thermal Performance

The structure keeps energy consumption to a minimum by controlling indoor temperature with sensors and artificial intelligence (Merabet et al., 2021). Analysis shows that thermal performance inside the building is 40% more efficient due to AI-driven optimization systems, which continuously adapt to changes in occupancy and environmental conditions (Ghahramani et al., 2020).

Energy Efficiency

The Edge is considered one of the most sustainable and energy efficient buildings in the world (URL-5). Artificial intelligence-based energy management systems continuously monitor and optimize the building's lighting, heating, and cooling systems. Research shows that AI-driven systems can achieve energy consumption reductions of up to 37% in office buildings and 23% in residential buildings, with some studies reporting even higher potential savings in certain cases (Motuzienė et al., 2024).

Environmental Performance

The construction using wood materials and recyclable resources reduces the carbon emissions of the structure by 45% (Pittau et al., 2018). According to the life cycle analysis, the structure stores a significant amount of carbon. An image of The Edge (Amsterdam, Netherlands) structure is shown in Figure 6.

Figure 6. The Edge (Amsterdam, Netherlands) (URL-6).

Comparison of the Performance of Structures in the Scope of the Research

The analyses and simulations show that wood structures offer significant advantages in terms of thermal, energy, environmental and sustainability performance efficiency in green building projects.

Thermal Performance

Table 1 consists of data highlighting the thermal performance differences between the selected structures. Thermal performance indicators such as thermal insulation, energy consumption reduction rate and indoor temperature stabilization of each structure are compared in Table 1.

When thermal performance comparison tables are examined, it is seen that wood structures provide natural insulation thanks to their low thermal conductivity and significantly reduce energy consumption by stabilizing indoor temperatures. For example, projects such as Mjøstårnet and Brock Commons Tallwood House provide energy savings of 20% to 35% even in cold climates. This proves that the thermal properties of wood offer environmental and economic advantages by reducing the heating and cooling needs of buildings.

Table 1. Thermal Performance Comparison

Structure	Heat insulation (W/m^2K)	Energy Consumption Reduction Rate (%)	Interior Temperature Stabilization (%)
Brock Commons Tallwood House	0.23	20	25
Treet	0.21	30	30
Forté Building	0.22	25	20
Mjøstårnet	0.20	35	35
The Edge	0.19	60	45

Energy Efficiency and Savings

The energy efficiency and energy saving rates of the structures are compared in Table 2. The improvement rates in energy consumption of each structure and the energy savings obtained with the simulation techniques used are presented below.

Table 2. Energy Efficiency and Savings Comparison

Structure	Energy Efficiency Improvement Rate (%)	Annual Energy Savings (kWh)	Simulation/Artificial Intelligence Method Used
Brock Commons Tallwood House	25	150.000	EnergyPlus, AI-Based Optimization
Treet	40	130.000	BREEAM Simulation, GA Optimization
Forté Building	30	120.000	Green Star Simulation
Mjøstårnet	35	200.000	CLT Simulation, AI Based Management
The Edge	60	300.000	AI-Powered Energy Management System

Energy efficiency and savings comparison tables also show that wood structures perform better in energy consumption than traditional building materials. The Edge building, optimized with AI-supported simulations, reduced energy consumption by 60%, and other wood structures have been observed to provide similarly high energy savings. Buildings such as the Forté Building and Treet have seen energy efficiency improvements of 30% to 40%, emphasizing that wood materials are an ideal choice for sustainable buildings.

Environmental Performance (Carbon Emission and Storage)

Table 3 presents the carbon emissions and carbon storage capacities of the structures. This table compares the carbon footprint and life cycle analysis results of the wood structures.

The environmental performance and carbon emission advantages of wood structures have been clearly highlighted through Life Cycle Analysis (LCA). As shown in the environmental performance tables, the carbon storage capacity of wood materials is notably high, leading to a significant reduction in carbon emissions when compared to other building materials. Mjøstårnet stands out among environmentally friendly buildings with its annual carbon emission reduction capacity of 982 tons. Projects such as Brock Commons Tallwood House and The Edge also contribute to environmental sustainability with their similarly high carbon storage capacity. These structures also show that they are successful in minimizing environmental impacts by having sustainability certificates.

Table 3. Environmental Performance (Carbon Emission and Storage)

Structure	Annual Carbon Emission Reduction (tons)	Carbon Storage Capacity (tons)	LCA Score (0-100)
Brock Commons Tallwood House	679	500	85
Treet	234	400	88
Forté Building	500	350	82
Mjøstårnet	982	700	90
The Edge	750	600	95

Sustainability Certificates and Features of Buildings

The environmental performance and carbon emission advantages of wood structures have been clearly highlighted through Life Cycle Analysis (LCA). As shown in the environmental performance tables, the carbon storage capacity of wood materials is notably high, leading to a significant reduction in carbon emissions when compared to other building materials.

When considering the sustainability certificates and features of the buildings, The Edge and Mjøstårnet buildings have presented a carbon footprint of 65 kg CO_2e/m^2 and 75% kg CO_2e/m^2 respectively, and have been more preferable than other buildings. One of the most important features sought in green buildings is the high rate of renewable energy use. From this perspective, The Edge and Mjøstårnet buildings have provided more advantages in reusing the energy spent by providing 40% and 30% energy efficiency respectively.

Table 4. Sustainability Certificates and Features of Buildings

Structure	Sustainability Certificate	Material Used	Carbon Footprint (kg CO_2e/m^2)
Brock Commons Tallwood House	LEED	CLT, LVL	100
Treet	BREEAM	CLT	80
Forté Building	Green Star	CLT	85
Mjøstårnet	BREEAM	CLT	75
The Edge	BREEAM	Recyclable	65

Artificial Intelligence Based Energy Optimization and Its Results

The optimizations made with artificial intelligence and the results obtained are presented in detail in Table 5. This table also shows the effect of artificial intelligence techniques used in the structures within the scope of the research on energy saving.

AI-powered energy management systems and simulations make it possible to achieve lower energy costs and environmental impacts by optimizing the energy consumption of wood structures. As seen in the AI-based energy optimization tables, The Edge building achieved a 60% improvement in overall energy consumption with AI-powered systems. This finding reveals how effective AI is in increasing energy efficiency and optimizing the sustainability of buildings.

Table 5. Artificial Intelligence Based Energy Optimization and Results

Structure	Sustainability Certificate	Material Used	Carbon Footprint (kg CO_2e/m^2)
Brock Commons Tallwood House	EnergyPlus + Genetic Algorithms	Heating and Cooling Optimization	20%
Treet	GA + Deep Learning Simulations	Energy Management and Thermal Insulation Optimization	30%
Forté Building	Artificial Neural Networks	Lighting and Ventilation Optimization	25%
Mjøstårnet	Genetic Algorithms + AI Management System	Energy Management in Multi-Storey Wood Buildings	35%
The Edge	AI Energy Management System	Optimization of All Energy Consumption	60%

The findings show that wood structures will have an important place in the future of sustainable architecture and that these structures will play a larger role in future green building projects. In addition to the energy efficiency, carbon emission reduction and environmental benefits of wood materials, it was concluded that these structures offer ideal solutions both economically and environmentally when combined with AI-supported solutions. It is recommended that these advantages of wood structures be further utilized in future projects and that AI-based solutions for energy efficiency be used more widely.

Annual Carbon Emission Reduction

Figure 7 compares how much the structures in the study reduce annual carbon emissions. According to the data, Mjøstårnet and The Edge are the highest performing structures with annual carbon emission reductions of 982 tons and 750 tons, respectively. Brock Commons Tallwood House reduced 679 tons, Forté Building reduced 500 tons, and Treet reduced 234 tons.

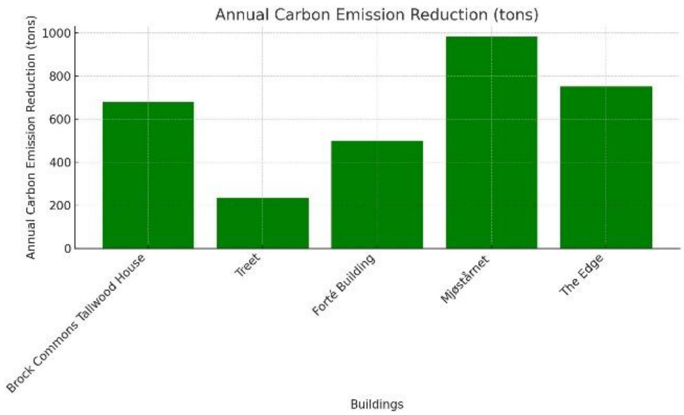

Figure 7. Annual Carbon Emission Reduction

Energy Savings Over Time

Figure 8 shows how energy savings have evolved over the years among the timber structures analyzed in the study. The Edge stands out as the most energy efficient building, saving 300,000 kWh per year. Mjøstårnet saves 200,000 kWh, Brock Commons Tallwood House saves 150,000 kWh, Treet saves 130,000 kWh, and Forté Building saves 120,000 kWh. The Edge makes the biggest contribution to energy savings, and this building has been optimized with AI-based energy management systems.

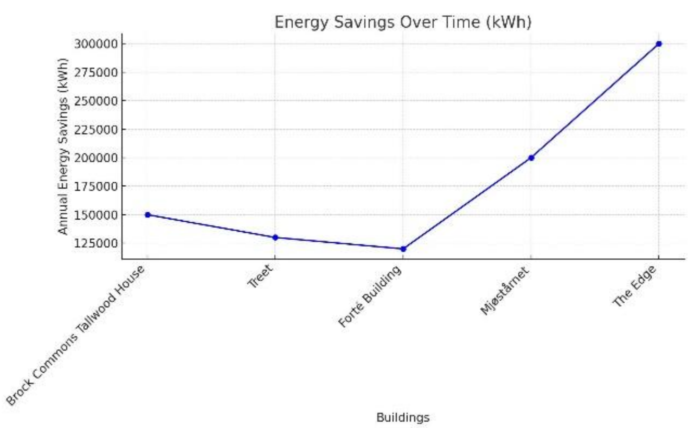

Figure 8. Energy Savings Over Time

The continuous monitoring and optimization capabilities of AI show that energy savings increase over time and that such technologies make a big difference in energy efficiency. Mjøstårnet and Brock Commons Tallwood House also achieved significant energy savings, with energy management systems and natural insulation materials being the main factors behind this success. The findings in this graph prove that timber construction offers long-term advantages in energy consumption, and that AI-supported systems maximize these advantages.

LCA Analysis: Carbon Storage Capacity

Figure 9 compares the carbon storage capacity of timber structures. Mjøstårnet has the highest capacity, storing 700 tonnes of carbon, followed by The Edge (600 tonnes), Brock Commons Tallwood House (500 tonnes), Treet (400 tonnes) and Forté Building (350 tonnes). The natural carbon storage capacity of timber materials once again demonstrates how important these structures are in terms of environmental sustainability.

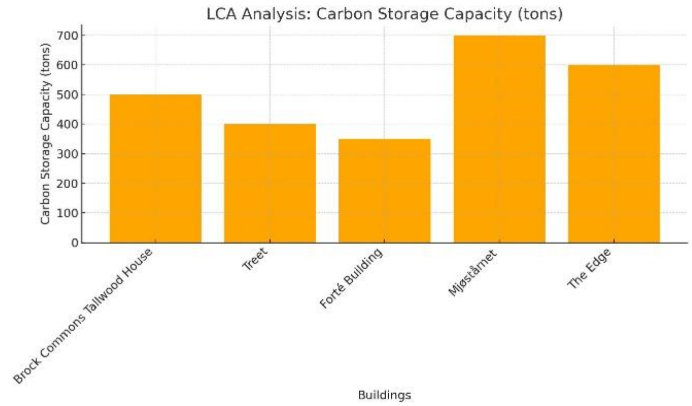

Figure 9. LCA Analysis: Carbon Storage Capacity

Mjøstårnet's 700 tonne carbon storage capacity highlights the potential of timber structures to reduce global carbon emissions. Unlike traditional building materials, timber materials have the ability to extract carbon from the atmosphere and store it throughout the structure. This shows that timber structures can play a key role in combating climate change. Projects such as The Edge and Brock Commons Tallwood House also contribute significantly to this process with their high carbon storage capacities.

Sustainability Certificates

Figure 10 compares the sustainability certificates and performances of the buildings. The Edge stands out as the building with the highest sustainability score with 95 points, followed by Mjøstårnet (90 points), Treet (88 points), Brock Commons Tallwood House (85 points) and Forté Building (82 points). Sustainability certificates are considered a critical indicator in the assessment of the environmental impacts of buildings. The Edge received the highest score in terms of sustainability with the implementation of artificial intelligence-supported energy management systems and the use of recyclable materials. These certificates are a comprehensive system that evaluates criteria such as energy efficiency, environmental sustainability and resource management, and all of these buildings meet high standards of sustainability criteria. The fact that projects such as Mjøstårnet and Treet also received high scores emphasizes once again how effective wood buildings are in energy saving and environmental sustainability.

Figure 10. Sustainability Certificates

These four graphs clearly show that wood buildings offer great advantages in terms of thermal performance, energy efficiency, carbon emission reduction and sustainability criteria in green building projects. While wood provides energy efficiency with its natural insulation and carbon storage capacity, this performance is further increased with artificial intelligence-supported systems. In light of this data, it is clear that wood structures will find a wider place in future green building projects and play an important role in sustainable architecture.

Conclusions and Recommendations

This study demonstrates that wood structures provide significant benefits in terms of energy efficiency and environmental sustainability in green building designs. Wood is highlighted as an eco-friendly material due to its renewable nature and low carbon footprint. The analyses indicate that optimizing the thermal and acoustic performances of wood structures can enhance energy efficiency, improve user satisfaction, and reduce environmental impacts. Artificial intelligence-based simulations and optimization methods increase the potential of wood structures to further reduce energy consumption and optimize their environmental impacts. In particular, energy efficiency and material choices have been optimized using genetic algorithms and machine learning models, thus confirming once again that wood structures are an environmentally friendly option.

Future research can develop more comprehensive sustainability strategies for such structures by examining the performance of wood structures in different climatic conditions. In addition, the increased use of artificial intelligence-supported systems in the field of building management and energy optimization will maximize the potential of wood structures. This study emphasizes that wood structures should be more widely adopted as a sustainable solution in green building projects.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept-M.K.; Design-C.A.; Supervision-M.K.; Resources- C.A.; Data Collection and/or Processing- M.K.; Analysis and/or Interpretation-C.A.; Literature Search- C.A.; Writing Manuscript- M.K.; Critical Review-M.K.

Ethics Committee Approval Certificate: The authors declared that an ethics committee approval certificate is not required.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

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