doi.org/10.62683/SINARG2025.200

Review paper

ENVIRONMENTAL AND ARCHITECTURAL ASPECTS OF TIMBER CONSTRUCTION IN LONG-SPAN STRUCTURES: A REVIEW OF SELECTED EVALUATION CRITERIA

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Abstract

The article presents an interdisciplinary view of long-span timber structures, combining architectural and environmental approaches. The authors, working in the field of architectural design, analyze wood not only as a structural material, but also as a means of spatial, aesthetic and cultural expression. Particular attention was paid to such aspects as expression of form, quality of detail, user comfort and integration of the structure with function and environment. In parallel, an environmental analysis was conducted, including material life cycle (LCA), carbon footprint, energy efficiency, and the potential of wood for reuse and recycling in the context of a circular economy. The results of the 2021-2025 literature review indicate that engineered wood (CLT, glulam, LVL) allows combining sustainability goals with high quality architectural space. The article emphasizes the importance of integrating environmental and design criteria in the creative process and the need for further research into the sustainability, adaptability and regulatory aspects of wood construction. Wood appears as a material of the future, both in terms of aesthetics and climate responsibility.

Key words: *Timber Architecture, Long-span Timber Structures, CLT Buildings, Sustainability, LCA, Carbon Footprint, Circular Timber, Architectural Expression*

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1. INTRODUCTION

Contemporary long-span wooden structures represent one of the most dynamic fields of architectural and environmental exploration. Their significance goes beyond the engineering understanding of structure; they are also a manifestation of new design values: sustainability, material expression, user comfort and integration into the local spatial context. In this context, engineered wood [CLT (Cross-Laminated Timber) – multilayer wooden panels in which each layer of boards is glued crosswise, providing high strength in two directions; Glulam (Glued Laminated Timber) – structural beams or components made from thin layers of wood glued parallel to the grain, used to carry heavy loads; LVL (Laminated Veneer Lumber) – an engineered wood product made from thin wood veneers glued together lengthwise, known for its high strength and uniform properties] becomes not only a structural material, but also a carrier of architectural identity and ideas [1, 2].

The purpose of this review is to identify and organize the key criteria for evaluating long-span timber structures, with an emphasis on their architectural and environmental dimensions. The authors, working in the field of architecture and design, focus on those issues that allow us to understand the role of the material in shaping public space, the aesthetics of the structure and the quality of the indoor environment, while also analyzing its impact on climate and resources [3, 4].

In order to organize the review, a two-part division of criteria was proposed: (i) environmental criteria and (ii) architectural criteria.

Environmental criteria – refer to the environmental impact of wood structures over the full life cycle of a building. They include both quantitative indicators, such as greenhouse gas emissions (carbon footprint), primary energy consumption or the results of LCA analyses, as well as qualitative considerations related to the comfort of the indoor environment [5, 6, 7, 8, 9]. A special place in the analysis is given to the potential of wood material in the context of a circular economy: the possibility of disassembly, reuse of components, recyclability of structural components and locality of supply chains [10, 11]. As a material that is separable and recyclable with relatively low energy input, wood fits into the GOZ concept, which in recent years has become a key paradigm in sustainable design [3, 12].

Architectural criteria – describe how wood influences the form of a space, the expression of a structure, the quality of a detail and the user experience. Issues such as wood's ability to create spanning spatial structures, the visibility of the structure as an aesthetic element, the integration of the structural system into the building's functional program, as well as the acoustic, thermal and visual qualities of the material in the indoor environment are included [13, 14].

Structuring the review in this way makes it possible not only to organize existing knowledge, but also to identify areas of data deficiency and research that can be the subject of further exploration, especially within interdisciplinary teams combining architecture, environment and materials engineering.

2. METHODOLOGY AND MATERIALS

The purpose of this paper was to conduct a review of the scientific literature on the environmental and architectural aspects of wood construction in long-span structures, from the perspective of architecture as a design and cultural discipline. A qualitative approach was adopted, focusing on the identification and classification of key evaluation criteria that appear both in the scientific literature and in design practice.

A full systematic model was abandoned in favor of a problem-thematic analysis, typical of architectural research. This method allows not only the compilation of quantitative indicators, but also the interpretation of qualitative spatial, aesthetic and functional phenomena.

2.1. Assumptions and objectives of the review

The purpose of the analysis was to identify (i) key directions for environmental and architectural research on large-scale wood buildings, (ii) the most frequently addressed research problems and gaps in the literature, (iii) examples of best practices and innovative design solutions.

2.2. Literature selection criteria and data sources

Only publications meeting the following criteria were included in the analysis: peer-reviewed articles published in scientific journals indexed in the Scopus or Web of Science database; published between 2020 and 2025; bearing a DOI number and available in full text. Topics - environmental issues (e.g., carbon footprint, energy efficiency, LCA) and architectural issues (e.g., aesthetics, user comfort, structural form). The following databases were used for the literature search: Scopus (Elsevier), Web of Science Core Collection (Clarivate), supplementary: ScienceDirect, MDPI, SpringerLink and Taylor & Francis - provided that articles were simultaneously indexed in Scopus. Searches were supported by manual selection by reviewing references from papers with high citation counts. The search process was conducted in English and Polish using a combination of keywords, such as timber architecture, long-span timber structures, CLT buildings, sustainability, LCA, carbon footprint, circular timber, architectural expression. In addition, a back-reference analysis was performed on publications considered key to identify complementary and contextual works.

2.3. Analysis process

The analysis was conducted in three stages: (i) Categorization - division of articles into two main thematic groups: environmental and architectural, (ii) Comparative analysis - review of research approaches, types of construction, materials and case studies, (iii) Synthesis and classification of research problems - identification of challenges, recurring methodological limitations and niche topics. Ultimately, the results of the analysis allowed the formulation of research problems and cognitive gaps, which are discussed in the following sections of the article in the context of both engineering practice and further scientific research.

3. ANALYSIS OF ENVIRONMENTAL AND ARCHITECTURAL ASPECTS

An analysis of selected publications reveals a clear diversity of research approaches to timber construction in long-span structures, with environmental and architectural aspects being particularly emphasized. While many studies to date have focused on structural-engineering aspects, one can now see an intensification of research covering a broader spatial, aesthetic and environmental context.

The following section provides a detailed overview of environmental (3.1) and architectural (3.2) approaches, taking into account both research-developed areas and those in need of further exploration. A key goal is to identify current trends and cognitive gaps that can provide a starting point for further research and design work in the area.

3.1. Environmental aspects

In the environmental stream, special attention is paid to the analysis of the life cycle of wood materials, their carbon storage capacity, as well as the potential environmental advantages of wood over conventional building materials in terms of emissions, energy efficiency and reusability. Importantly, not only quantitative data are considered, but also geographic, climatic and socioeconomic conditions affecting the environmental performance of wood technology [9, 15].

In recent years, there has been growing interest in the use of engineered wood in long-span structures due to its potential in reducing greenhouse gas emissions and its ability to sequester carbon. Life cycle analyses (LCA) show that wood, as a renewable material, can significantly reduce the carbon footprint of buildings compared to traditional materials such as steel or concrete [16].

Comparative studies indicate that structures made of cross-laminated timber (CLT) have a lower environmental impact throughout the building life cycle. Analyses show that CLT-based buildings have a smaller carbon footprint than their concrete or steel counterparts, especially in the context of long-span structures [1, 5, 17, 18].

Additionally, engineered wood exhibits favorable thermal properties, resulting in better energy efficiency of buildings. Thanks to the natural insulating properties of wood, these structures can provide better thermal comfort with lower energy consumption for heating or cooling. Studies confirm that solid wood buildings have lower energy consumption compared to traditional structures [19, 20, 21].

It is also worth noting that the use of wood in construction contributes to reducing the consumption of non-renewable resources and emissions associated with the production of building materials. As a natural material, wood requires less energy to process compared to steel or concrete, further reducing the overall environmental impact of a building.

In summary, the use of engineered wood in long-span structures offers significant environmental benefits, including reduced greenhouse gas emissions, improved energy efficiency and reduced consumption of non-renewable resources. These properties make wood an attractive material in the context of sustainable construction and the fight against climate change.

3.2. Architectural aspects

The architectural approach, on the other hand, considers wood not only as a structural material, but as a carrier of spatial, aesthetic and cultural values. In the literature analyzed, there is a strong tendency to combine structural expression with functional and symbolic requirements, which is particularly important in the design of large-scale public buildings. Some studies also point to the importance of wood for improving the quality of the indoor environment, including thermal, acoustic and visual comfort of users. The growing role of digital design tools that enable generative shaping of wood forms and their integration with prefabrication is also not without significance.

As a structural material, wood offers architects a wide range of possibilities for shaping the form and aesthetics of long-span buildings. Its natural texture, warmth of color and ability to create complex geometries make it a frequent choice for projects requiring both functionality and distinctive visual character [22]. An example is the use of glulam in long-span roof structures, where the material allows for the creation of lightweight yet strong structures that give spaces a unique character [23].

The visibility of wood structural elements in a building's interior space not only emphasizes aesthetics, but also influences users' perception of the space. Exposing a wooden structure can reinforce a sense of security and stability, as well as introduce elements of rhythm and order into the interior design [12, 24]. In projects such as the Cochrane Transit Hub, the use of visible glulam beams not only serves a structural function, but is also a key aesthetic element, integrating the building with its surroundings and emphasizing its identity [25].

The precision of detailing in wood structures is crucial to the durability and aesthetics of a building. Modern woodworking technologies, such as CNC, make it possible to create intricate joints and details that are both functional and aesthetically refined [3]. High-quality detailing also influences the perception of users, increasing their comfort and satisfaction with the space [26].

Wood has natural acoustic and thermal properties that affect user comfort. Studies show that the presence of wood in a space can improve the acoustic quality of rooms, reducing noise and reverberation [27]. In addition, wood has good thermal insulation, which contributes to maintaining a stable temperature inside the building and increases the thermal comfort of users [28]. In addition, the presence of wood in a space can have a positive impact on the well-being of users, reducing stress and improving the overall experience of the environment [29].

The flexibility of wood as a construction material allows spaces to be easily adapted to different functions. Prefabrication of wood elements allows for quick and efficient implementation of projects, which is particularly important in buildings with a variable functional program [30]. An example is the Carbon12 building, where the use of wood allowed the creation of living spaces of a high standard, while integrating a variety of functions in a single structure [31].

In light of the above reflections, it is worth highlighting several European examples that illustrate the architectural and cultural potential of long-span timber construction. In Poland, the Education and Culture Center in Kozienice demonstrates how glulam roof structures can create both functional and inviting interior spaces. In Serbia, the exhibition pavilion in Novi Sad stands out as a project where locally sourced timber forms an open, rhythmic spatial experience that resonates with the regional architectural identity.

In Germany, the Hallenbad Pforzheim sports hall uses curved glulam beams to emphasize both the rhythm and lightness of the interior. The port terminal in Bergen, Norway, shows how cross-laminated timber (CLT) can serve as both a structural and expressive element, strengthening the building’s identity while echoing the surrounding landscape and local building culture. In Austria, the Bildungscampus Seestadt Aspern exemplifies how timber construction can support the integration of learning and communal spaces while creating interiors with high acoustic and visual comfort.

These cases show that timber, when used in large-scale architecture, goes far beyond technical requirements. It enriches spaces with symbolic, emotional, and cultural meaning. Referring to realized European projects deepens the understanding of timber’s potential to bring together function and architectural expression, helping create environments that are both coherent and inspiring for users.

4. DISCUSSION

Long-span timber construction is increasingly being presented as an alternative to concrete- and steel-based technologies, for both environmental and architectural reasons. Based on previous analyses, it can be seen that wood structures not only reduce the carbon footprint, but also offer spatial and performance values difficult to achieve with other technologies.

Environmentally, engineered wood structures, especially CLT and glulam, show significantly lower CO_2 emissions than their concrete and steel counterparts. Studies indicate that the use of wood in place of conventional materials can lead to up to a 50% reduction in emissions over the life cycle of a building [31]. Additionally, wood not only generates fewer emissions during production, but also sequesters carbon, acting as a “carbon store” [32].

In contrast, concrete and steel production involves very high primary energy consumption and emissions, mainly due to the energy-intensive nature of the clinkerization and metallurgical processes [33]. Moreover, concrete and steel do not offer comparable benefits in the context of a circular economy, unlike wood, which can be more easily dismantled, recycled and reused [34].

At the utilitarian level, wood is characterized by its natural thermal and acoustic properties, which positively affect the comfort of indoor spaces. The material exhibits low thermal conductivity and the ability to stabilize the microclimate inside buildings [28]. Moreover, wooden interiors, especially when exposed, are perceived by occupants as more welcoming, warm and less stressful than their steel or concrete counterparts [12].

In architectural terms, wood offers a unique material and structural expression. The visibility of beams and structural frames often becomes an important compositional element, while allowing for the integration of form and spatial function [15]. In many cases, wood serves a narrative function, highlighting the identity of a place and connecting the design to the local cultural context [29].

The prefabrication and digital precision of the material allow for faster construction and greater programmatic flexibility, important for public or multi-use facilities. Wood allows for subsequent changes in functional layout without disturbing the main load-bearing structure, which is more difficult to achieve in concrete structures [35].

Despite these advantages, it should be noted that wood construction is not without its limitations. The most commonly cited challenges are fire resistance, biological durability and the availability of certified raw material in adequate quantities. However, advances in engineering and materials technology are effectively mitigating these risks, including through the use of protective coatings, waterproofing, multi-layer CLT assemblies and advanced fire detection systems [36].

5. SUMMARY AND CONCLUSIONS

Long-span wood construction offers a number of significant advantages over conventional technologies in both environmental and design terms. Wood's ability to store carbon, the high quality of its indoor environment, its expressive aesthetics, and its potential for prefabrication and space adaptation make it one of the most relevant materials for future sustainable construction. Its wider use, however, requires overcoming regulatory and logistical barriers. Nevertheless, with the current emphasis on decarbonizing construction, wood appears as a key material in the sustainable development strategies of the architectural and engineering sector.

The purpose of this article was to review the environmental and architectural aspects of wood construction in long-span structures. The analysis was based on scientific publications from 2020-2025, indexed in Scopus and Web of Science databases, oriented to modern structural and design solutions using engineered wood (CLT, Glulam, LVL). The article was prepared from the perspective of architects, and the research approach adopted made it possible to extract a set of key evaluation criteria from the field of environmental impact and architectural values.

Among the environmental criteria were carbon footprint, energy efficiency, life cycle (LCA), recycling potential and the material's ability to fit into the principles of a circular economy. The analysis showed that wood significantly reduces CO_2 emissions compared to concrete and steel, and promotes the implementation of decarbonization strategies in the construction sector.

Architectural aspects were referred to such categories as form and aesthetics, structural expression, quality of detailing, integration with the functional program, and comfort of the indoor environment - especially acoustic and thermal. In light of current research and realizations, wood appears as a material that enables the creation of coherent, aesthetic and welcoming functional environments, while at the same time fostering prefabrication, adaptability and integration of structural and spatial design.

A comparative discussion with other technologies, mainly concrete and steel, unequivocally demonstrated the advantage of wood in terms of environmental impact and potential for creating quality space. At the same time, limitations such as fire resistance or local availability of certified raw material were pointed out, which require further research and technological optimization.

Conclusions:

1. Long-span timber construction is a viable, sustainable alternative to conventional technologies, offering environmental and architectural benefits important in public, sports and mixed-use facilities.
2. An integrated design approach, combining life cycle analysis (LCA) with spatial design, should be standard in the evaluation and planning of engineered wood projects.
3. Exposure of wood structure can be not only an aesthetic expression, but also a factor supporting user comfort and place identity.
4. Further interdisciplinary research is needed, especially on durability, fire resistance and adaptation systems of wooden structures in the context of changing functional programs.
5. Increasing availability of materials data and environmental assessment tools will promote further development of responsible wooden architecture.

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