detritus | Multidisciplinary Journal for Circular Economy and Sustainable Management of Residues

CIRCULARITY OF TIMBER CONSTRUCTION ACCORDING TO THE LIFE-CYCLE POTENTIAL OF WOOD BY-PRODUCTS

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Article Info:
Received:
13 June 2025
Revised:
24 October 2025
Accepted:
3 November 2025
Available online:
17 November 2025

Keywords:
Architecture industry
Circularity
Durability
Life-cycle assessment
Wood by-products

ABSTRACT

This scoping review examines the integration of life-cycle assessment (LCA) and circular economy principles - specifically practices such as recycling, reuse, reclamation, and upcycling - within wood-based architectural design, building, and construction industry. The aim is to provide a detailed evaluation of the environmental impacts associated with wood and timber materials in the context of sustainable building practices. By analyzing recent studies, this review focuses on how these materials perform environmentally across various life-cycle stages (A1: raw material supply, A3: manufacturing, C1: deconstruction, and C3: waste processing). Each selected study's materials were assessed mainly for Global Warming potential (GWP) and, where data was available, for other environmental impact indicators based on established LCA frameworks. In addition to environmental assessments, the review documents relevant metadata, including material origin, year of publication, and study sources, to construct a comprehensive dataset. The findings underscore that reclaimed and recycled wood materials offer significant potential for reducing greenhouse gas emissions, aligning with the goals of a circular economy by minimizing resource extraction and waste generation. However, several challenges impede widespread adoption. These include concerns regarding the durability and long-term performance of recycled or reclaimed wood, the economic feasibility of implementing circular practices at scale, and regulatory or policy barriers that can limit the reuse and upcycling of wood materials. Despite these challenges, the study emphasizes the untapped potential of upcycled wood products and the need for further research into their environmental benefits and structural performance in architectural applications. This review provides critical insights for advancing a sustainable and resource-efficient construction industry, laying the groundwork for future investigations into innovative wood material practices within the framework of a circular economy.

1. INTRODUCTION

The construction industry, one of the largest contributors to global carbon emissions and resource consumption, faces mounting pressure to adopt sustainable practices to mitigate environmental impacts. A growing body of research emphasizes the need for sustainable materials and building methods, especially through the integration of renewable resources such as wood and timber (FAO, 2018; EC, 2019; Gresham, 2020; Galluccio et al. 2024). Wood, as a renewable and carbon-sequestering material, has gained significant interest in sustainable architecture, particularly when combined with circular economy principles like recycling, reuse, reclamation, and upcycling (Beyer et al., 2011; Braungart & McDonough, 2013; Campbell et al. 2020). These approaches aim to extend material life cycles, reduce waste, and lower emissions throughout a building's life span. IPCC (2022) highlights that the building and construction sector accounts for a significant share of global greenhouse gas emissions, especially through energy use and material production.

UNEP (2020) reports that buildings and construction are responsible for nearly 40% of global energy-related carbon dioxide emissions and resource consumption, underscoring the urgency for sustainable practices.

EN 15804 provides the framework for Environmental Product Declarations (EPDs) in construction, defining the different stages of a product's life cycle (A1-A3 for product stage, B1-B7 for use stage, C1-C4 for end-of-life stage, and D for benefits beyond system boundary). However, this work focuses on A1 (raw material supply), A3 (manufacturing), C1 (deconstruction), and C3 (waste processing) as these stages are often emphasized because they repre-

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https://doi.org/10.31025/2611-4135/2025.19543

sent the most significant contributions to global warming potential (GWP) and other environmental impacts for wood-based materials, while also aligning with current literature on timber life-cycle assessments. Since Life-cycle assessment (LCA) has become a critical methodology for evaluating the environmental impacts of wood and timber across their full life cycle, from raw material extraction to disposal or reuse (El-Haggar, 2007; Hauschild et al., 2018; Yu & Fingrut, 2022), this review focuses on assessing recent applications of LCA in wood-based architectural and construction projects to better understand the global warming potential (GWP) and environmental impacts of wood materials across specific life-cycle stages, including A1 (raw material supply), A3 (manufacturing), C1 (deconstruction), and C3 (waste processing). Furthermore, the review compiles data on various wood materials identified in relevant literature, emphasizing GWP, life-cycle stage impacts, location, year, and source, thereby providing a robust database framework. GWP is an index that quantifies the relative climate impact of different greenhouse gases over a specified time horizon (typically 100 years), expressed in terms of carbon dioxide equivalents (CO_2e). This makes it a widely adopted and comparable metric across LCA studies. Justifying the focus on GWP would enhance methodological transparency, as it highlights that GWP captures the most critical environmental impact category linked to construction materials, while also acknowledging that other impact categories (e.g., acidification, eutrophication, resource depletion) could provide complementary insights.

Specifically, this review contributes critical research on environmental data essential for building a first "prototype" of a comprehensive database to support LCA-type evaluations within digital design and manufacturing processes. By emphasizing innovative and circular materials, this research aims to support sustainable digital design practices that leverage LCA insights to guide material selection and resource-efficient construction. As such, this review attempts at forming the foundation for future environmental databases in digital design, thereby advancing circular design practices in architecture and construction. We also discuss ongoing challenges to implement these practices, such as economic viability, material durability, and regulatory compliance, and identify research needs for optimizing wood's role in sustainable architecture. Specifically, this review contributes critical research on environmental data essential for building a first "prototype" of a comprehensive database to support LCA-type evaluations within digital design and manufacturing processes. In this context, "digital design" refers to emerging practices such as BIM-based modeling, parametric workflows, and fabrication-oriented approaches, which increasingly shape architectural production both technically and culturally (Perriccioli & Ruggiero, 2024). By emphasizing innovative and circular materials, this research aims to support sustainable digital design practices that leverage LCA insights to guide material selection and resource-efficient construction.

This paper is organized in 5 paragraphs: "Introduction", "Research and Methodology", "Results", "Discussion", "Conclusion". In "Research and Methodology", we conduct a systematic literature review, analyzing studies on LCA and circular wood materials from 2010 onward. Key environmental metrics, such as GWP and life-cycle stages, are extracted to compare the impact of reclaimed, recycled, and new wood. A database is developed to support sustainable material selection in digital design and manufacturing. In "Results", we highlight that wood-based materials have a lower environmental impact than concrete and steel, with circular strategies (reuse, recycling, upcycling) reducing emissions. However, material durability, recyclability issues, and regulatory barriers limit adoption. In "Discussion", we analyze LCA data across life-cycle stages, highlighting the benefits of circular practices and carbon sequestration. Challenges include regional processing differences and logistical constraints, requiring regulatory support and standardized LCA methodologies. In "Conclusions" we emphasize that circular economy practices in wood construction can significantly lower emissions. Future efforts should focus on LCA standardization, digital databases, and optimized reuse strategies to advance sustainable, low-carbon construction.

2. RESEARCH METHODOLOGY

2.1 Literature search and selection criteria

The initial step involves a systematic search of peer-reviewed journals, conference proceedings, and industry reports related to the keywords: "life-cycle assessment" (LCA), "recycle," "reuse," "reclaim," "upcycle," "architectural design," "building," "construction," "wood," and "timber." Key academic databases, including Web of Science, Scopus, Google Scholar, and ScienceDirect, are searched to ensure a comprehensive selection. The search focuses on studies published from 2010 onward to capture recent advancements in LCA and circular material practices, while priority is given to publications from regions where sustainable construction is highly regulated, such as Europe, North America, and parts of Asia (EC, 2003; ISO, 2006a;b; Rigillo et al., 2023) (Figures 1-3). Key academic databases, including Scopus, were searched to ensure a comprehensive selection. The review focuses on studies published from 2010 onward, a starting point chosen to capture the period following the introduction of influential policy and conceptual frameworks such as the EU Roadmap to a Resource Efficient Europe (EC, 2011) and the wider diffusion of circular economy paradigms through the Ellen MacArthur Foundation (2012) (Figure 4). These milestones mark a shift toward sustainability-driven construction research and provide a strong rationale for this temporal boundary (Figure 5). Priority is given to publications from regions where sustainable construction is highly regulated, such as Europe.

2.2 Data collection

From each selected study, specific data points are extracted to evaluate the environmental impact of wood-based materials across different life-cycle stages, as follows:

1. Global Warming Potential (GWP) - Among the indicators used in LCA, global warming potential (GWP) is particularly critical because it quantifies greenhouse

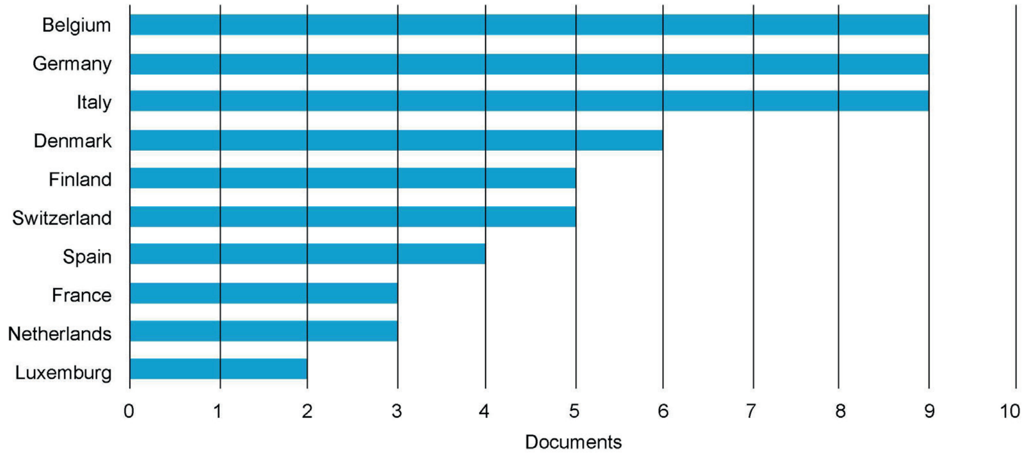

FIGURE 1: Data on the number of documents categorized by countries or territories.

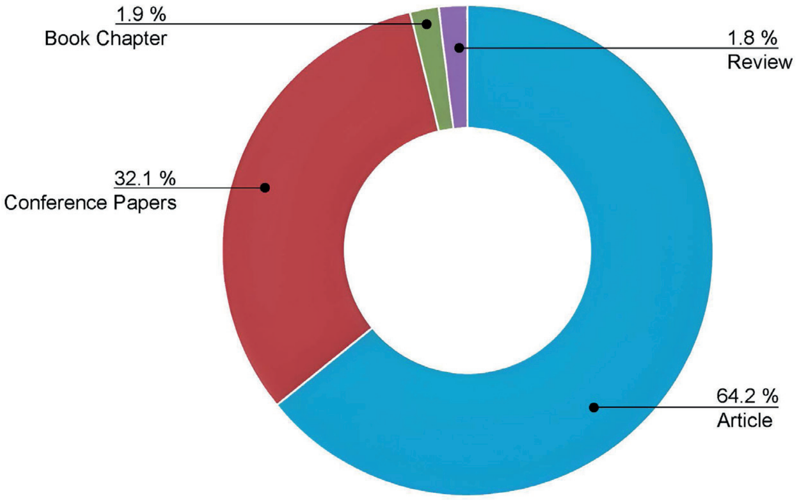

FIGURE 2: Data on the percentage distribution of documents by type.

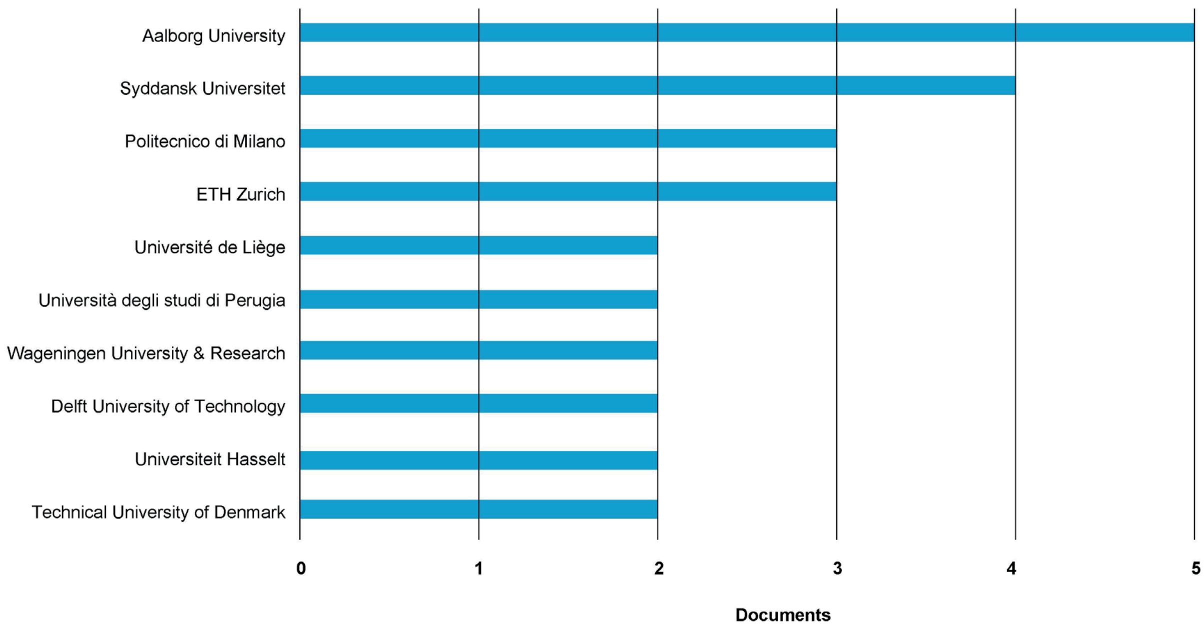

FIGURE 3: Data on the percentage of documents categorized by affiliation.

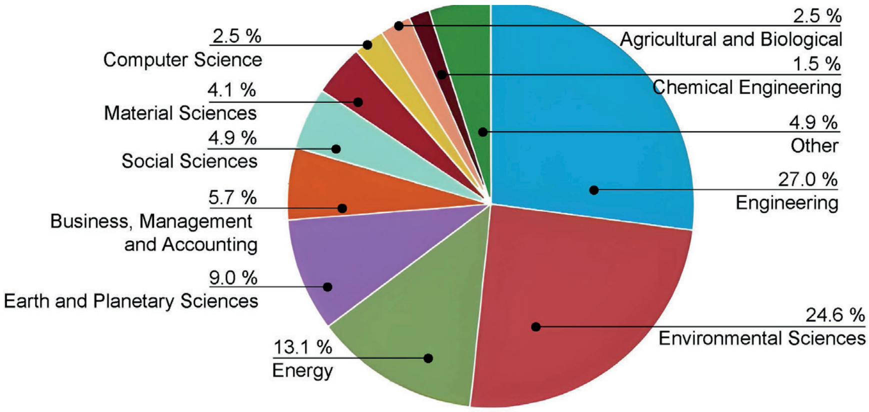

FIGURE 4: Data depicting the percentage distribution of documents across various subject areas.

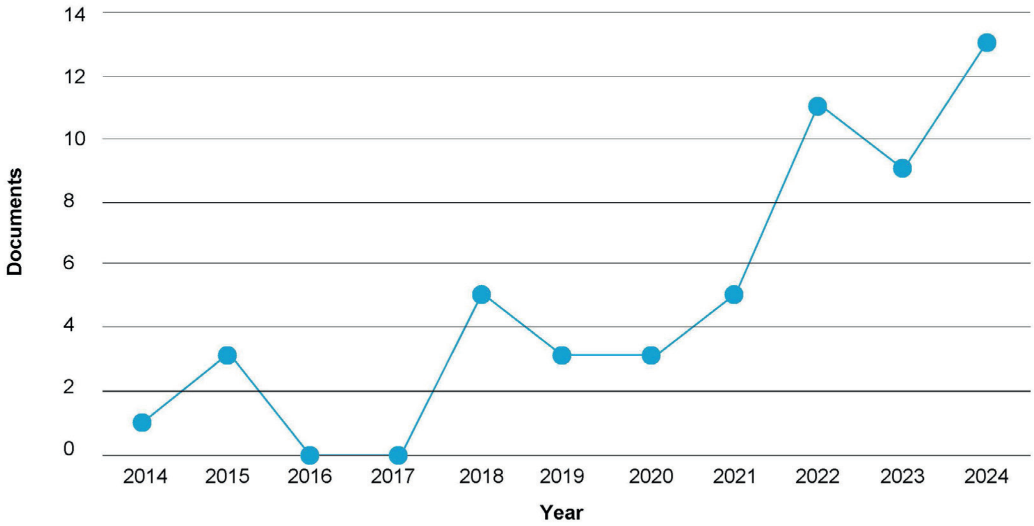

FIGURE 5: Number of documents (Papers) produced annually from 2014 to 2024.

gas emissions across different life-cycle stages in terms of their contribution to climate change. Beyond serving as an environmental indicator, GWP has direct design implications: it enables architects and engineers to compare the carbon intensity of alternative materials (e.g., timber versus concrete), evaluate the impact of design strategies such as modularity, prefabrication, or reuse, and align construction practices with broader climate targets and net-zero pathways (IPCC, 2022; UNEP, 2020). In this way, GWP functions as both a scientific measure and a decision-making tool that informs sustainable material selection and resource-efficient architectural design. A key metric that quantifies the greenhouse gas emissions associated with the material over its life cycle, measure in kg of CO_2 equivalent;

2. Life-Cycle Stages - Impacts were evaluated specifically at stages A1 (raw material supply), A3 (manufacturing), C1 (deconstruction), and C3 (waste processing) to assess the material's environmental footprint;
3. Material Source, Year, and Location - Information on the origin of each material (region or country), year of study, and publication source was documented to allow for comparisons across different contexts.

This data is organized into a structured datasheet, allowing for easy reference and future use in creating databases for LCA-type evaluations within digital design and manufacturing processes. The goal is to define a foundation that could support the growing demand for open LCA-driven tools in digital construction, facilitating the selection of materials with lower environmental impacts (Augustì-Juan et al., 2016;2017; EC, 2021; Ke Yin Lee et al., 2023; Galluccio et al., 2025).

2.3 Evaluation criteria and analysis

The extracted data are analyzed using a comparative approach, focusing on the environmental benefits and drawbacks of circular practices with wood materials in construction. Comparative analyses are conducted across GWP values and life-cycle impacts for different wood materials (e.g., reclaimed versus virgin wood) to understand how recycled and reused wood fares against new timber in sustainable design contexts. Each study is also evaluated according to its methodology to assess the reliability of reported LCA values, considering factors such as the inclusion of end-of-life stages, completeness of system boundaries, and geographic relevance. Further, each study's methodology is scrutinized to identify common gaps, such as the lack of comprehensive end-of-life data for reclaimed wood, that could inform future LCA research. The methodological workflow could be summarized in the following steps:

1. Literature Review. A systematic search was conducted across major academic databases, including Scopus, Web of Science, Google Scholar, and ScienceDirect. The search employed targeted keywords such as "life-cycle assessment," "wood," "timber," "reuse," "recycle," and "upcycle." Inclusion criteria required publications from 2010 onward, peer-reviewed status, and direct relevance to life-cycle assessment (LCA) and circular wood applications. Studies not meeting these criteria were excluded.
2. Data Extraction - Selected studies were analyzed to extract key variables, including:
   - Material types (e.g., virgin wood, reclaimed wood, engineered timber);
   - Life-cycle stages addressed (A1, A3, C1, C3);
   - Reported environmental impacts (e.g., global warming potential [GWP], other impact categories);
   - Geographic origin and publication year;
   - Methodological parameters (e.g., system boundaries, end-of-life scenarios, underlying assumptions).
3. Database Construction. Extracted data were organized into a structured comparative framework. Units of measurement, impact categories, and life-cycle modules were standardized to ensure consistency and facilitate cross-study comparison.
4. Comparative Evaluation and Synthesis. The compiled dataset was used to:
   - Compare GWP values across different wood material types (e.g., virgin vs. reclaimed);
   - Evaluate the methodological rigor of each study, focusing on system boundaries, end-of-life modeling, and regional specificity;
   - Identify recurring patterns, inconsistencies, and gaps in reported outcomes.

This synthesis enabled the identification of environmental advantages and limitations associated with circular wood practices. It also revealed common methodological shortcomings — such as incomplete end-of-life data — and informed recommendations for future research, including the development of sector-specific LCA guidelines and improved integration of circularity metrics in sustainable wood construction.

2.4 Database development for digital design and manufacturing

The synthesized data will be instrumental in developing a database to support digital design and manufacturing processes with circular wood materials. This database will enable architects and designers to evaluate materials based on LCA metrics, facilitating sustainable material selection. The data compilation also considers scalability for use in digital tools like Building Information Modeling (BIM) software, which integrates LCA data for holistic environmental assessments during the design phase (Cays, 2017). The synthesized data will be instrumental in developing a prototype database to support digital design and manufacturing processes with circular wood materials.

The database is structured as a relational framework, organized around key parameters including material type (virgin, reclaimed, engineered timber), life-cycle stages covered (A1, A3, C1, C3), reported GWP values and other LCA indicators, geographic location, year of study, and methodological characteristics such as system boundaries and treatment of end-of-life scenarios. To ensure comparability, data were standardized in terms of units, functional units, and impact categories before being organized into the database.

While currently developed as a conceptual prototype, the structure has been designed with scalability in mind, allowing future integration into digital tools such as Building Information Modeling (BIM) software. This integration would enable architects and designers to query material options based on environmental metrics, facilitating evidence-based material selection and more holistic environmental assessments during the design phase (Cays, 2017).

3. RESULTS

This data highlights the significant environmental benefits and challenges of integrating various wood materials into sustainable construction practices. Many wood-based materials, like Cross-Laminated Timber (CLT) and Glulam, exhibit lower global warming potential (GWP) compared to conventional materials like concrete and steel, with some even demonstrating carbon sequestration capabilities. Reclaimed, recycled, and upcycled wood products show strong potential for reducing emissions and supporting circular economy principles through reuse and energy recovery. However, factors such as limited recyclability (e.g., due to adhesives), high emissions in certain life-cycle stages, and regulatory or logistical barriers can complicate widespread adoption. Despite these challenges, the data underscores the opportunity to optimize wood use across life-cycle stages, driving a more sustainable, resource-efficient construction industry while reducing overall carbon footprints. The study finds that integrating life-cycle assessment (LCA) with circular economy principles in wood-based architectural design and construction offers significant environmental benefits.

Key results include:

1. Global Warming Potential (GWP) Reduction. Reclaimed and recycled wood significantly reduces greenhouse gas emissions compared to virgin timber, especially in life-cycle stages A1 (raw material supply) and A3 (manufacturing);
2. Enhanced Sustainability Metrics. Circular economy practices, such as reuse, recycling, and upcycling, extend material life cycles, decreasing overall environmental footprints in construction;
3. Challenges Identified. Issues such as material durability, regional processing differences, and regulatory barriers persist, limiting the widespread adoption of circular practices.

3.1 Evidence from Reviewed Literature

The reviewed studies highlight both the environmental benefits and challenges of integrating various wood materials into sustainable construction practices. Materials such as Cross-Laminated Timber (CLT) and Glulam consistently demonstrate lower global warming potential (GWP) compared to conventional construction materials like concrete and steel, with some studies even documenting carbon sequestration capacities. Literature on reclaimed, recycled, and upcycled wood products further underscores their potential to reduce emissions while supporting circular economy principles through reuse and energy recovery. A concentration of studies in 2023 emerges from the analysis and could be interpreted as a signal of a rising trend of research on the topics of LCA and forest-based materials in architecture and design. Since international, European and even local regulations are pushing industries to adopt environmental impact metrics to assess their processes and products and a significative emphasis is being placed on the widespread use of bio-based renewable resources such as timber, it is expectable that the number of studies will even grow in the future.

3.2 Dataset Composition and Structure

The dataset (Table 1) compiled from the reviewed sources incorporates variables including material type (virgin, reclaimed, engineered timber), life-cycle stages analyzed (A1, A3, C1, C3), reported GWP values, geographic location, year of publication, and methodological features such as system boundary definitions and end-of-life treatments. This structure enables systematic comparison across case studies and facilitates the evaluation of both environmental performance and methodological robustness.

3.3 Environmental Performance Comparison

Comparative analysis reveals that reclaimed and recycled wood significantly reduce greenhouse gas emissions compared to virgin timber, particularly in the A1 (raw material supply) and A3 (manufacturing) stages. Circular practices, including reuse, recycling, and upcycling, extend material lifecycles and reduce the overall environmental footprint of construction projects. Engineered timber products (e.g., CLT, Glulam) consistently show lower GWP than conventional alternatives, positioning them as effective strategies for lowering emissions in sustainable design.

3.4 Critical Factors Limiting Circular Adoption

Despite these environmental benefits, several challenges persist. Issues such as limited recyclability due to adhesives, high emissions in specific life-cycle stages, and regional differences in wood processing methods introduce variability into results. Moreover, regulatory and logistical barriers restrict the widespread adoption of circular wood practices. These recurring limitations highlight the need for standardized LCA methodologies and improved end-of-life data for reclaimed wood to advance the integration of circular design in construction.

4. DISCUSSION

The findings of this review emphasize the pivotal role of integrating life-cycle assessment (LCA) and circular economy principles in advancing sustainable wood-based architectural design and construction. The data collected from recent studies reveal substantial environmental benefits associated with wood materials, particularly in their capacity to reduce global warming potential (GWP) compared to conventional materials such as concrete and steel. Materials like Cross-Laminated Timber (CLT), Mass Timber, and Glulam not only demonstrate significantly lower GWP values but also possess carbon sequestration capabilities, contributing to net-negative carbon impacts in certain scenarios (Abdolmaleki et al., 2025).

Key insights from this review underscore the transformative potential of integrating life-cycle assessment (LCA) and circular economy principles into wood-based architectural design, revealing significant environmental advantages over conventional materials. Engineered wood products such as CLT, Mass Timber, and Glulam not only exhibit lower global warming potential (GWP) but also contribute to carbon sequestration, offering net-negative carbon outcomes in certain applications. However, the path to widespread adoption is impeded by technical, economic, and regulatory challenges. Adhesive use, regional processing disparities, and high costs associated with reclaiming wood limit recyclability and scalability. Moreover, the absence of standardized certification and quality assurance frameworks hinders market development for recycled wood. Despite these barriers, circular strategies — particularly reuse and upcycling — demonstrate substantial emission reductions, with some materials achieving negative GWP values. The findings highlight the urgent need for harmonized LCA methodologies, improved end-of-life data, and supportive policy reforms to unlock the full potential of circular wood practices in sustainable construction. In the following four sub-paragraphs the insights and learnings from the review are examined.

4.1 Critical Factors Limiting Circular Adoption

Despite these environmental benefits, several challenges persist. Issues such as limited recyclability due to adhesives, high emissions in specific life-cycle stages, and regional differences in wood processing methods introduce variability into results. Moreover, regulatory and logistical barriers restrict the widespread adoption of circular wood practices.

To provide a more complete picture of these challenges, it is essential to acknowledge the significant economic and market barriers that hinder the scalability of circular wood practices. For instance, the costs associated with processing, sorting, cleaning, and re-engineering reclaimed wood often make it less competitive than new, virgin materials. The difficulty of establishing a stable, structured market for recycled wood is another major hurdle, exacerbated by the lack of standardized certification and quality assurance protocols that are necessary for its reliable integration into large-scale construction projects. These recurring limitations highlight the need for standardized LCA

TABLE 1: Summary table of all the wood materials mentioned in the papers and their Impact Global Warming Potential, A-1, A-3, C-1, C-3, Location, year and source. Notes: "Included" = stage explicitly modeled; "Limited" = partial coverage; "Not reported" = no data available; "Reuse potential" refers to end-of-life recovery options.

Wood product or by-product	A1 Raw Material Supply	A3 Mnfct.	C1 Dem./Decn.	C3 Waste Processes	GWP Impact (A1+A3+C1+C3)	Location	Year	Source
Cross-Laminated Timber (CLT)	Included	Included	Energy recovery considered	Some reuse potential	0.314kg CO_2e/kg	Europe, Denmark, USA, Japan	2021-2024	Discover Applied Sciences, IOP Conf. Series
Oriented Strand Board (OSB)	Limited reuse potential	Moderate emission	High reuse potential if not incinerated	Inciner. possible	Between 600 and 680 CO_2e/kg per m³.	Europe, Global	2023-2024	Discover Applied Sciences, Sugahara et al.
Plywood (PaB)	Adhesive limit to recycl.	Moderate emission	Inciner. provides energy offsets	Inciner. modeled	Approximately 1.07 kg CO_2e per kg, lower GWP impact through pulpwood substitution	Europe	2024	Discover Applied Sciences
Light Wood Framing	Included	Included	High impact if not reused	Recycling debated	0.46 kg CO_2e per kg, Varies based on end-of-life scenario	Southern USA	2020-2024	Passarell, IOP Conf. Series
Engineered Wood (LVL, Glulam, OSB)	Included	Included	High impact if landfilled	Recycling & reuse exist	338 kg CO_2e per cubic meter, Positive CO_2 sequestration but supply chain emissions	Europe, USA	2024	IOP Conf. Series
Mass Timber	Included	Included	High reuse potential	2.5x lower than concrete	582 kg CO_2 per cubic meter	Multiple locations	2023	Kanyilmaz et al.
Timber-Concrete Composite (TCC) Floors	30-50% lower emissions than RC	Low primary energy demand	Higher environ. benefits in reuse	Full reuse recomm.	0.159 kg CO_2e per kilogram, One-third of reinforced concrete (RC) emissions	Europe	2023	Research Journal
Deconstructed Timber Buildings	Carbon sequestr.	Embodi. carbon storage offsets emissions	Can be reintrod. into cycle	Circular approach ensures negative CO_2 balance	General Timber (excluding sequestration): 0.46 kg CO_2e per kg Glue-Laminated Timber: Approximately 0.87 kg CO_2e per kg	Europe	2023	Research Journal
Kraft Lignin	Biogenic carbon storage	Moder. emiss.	Reuse in bio-based applic.	Inciner. or reuse possible	Not reported	Latvia	2024	Constr. and Building Materials
Wood Fly Ash (WFA)	Utilized in asphalt filler	Moder. emiss.	No reuse	Reduces cement demand	Not reported	Latvia	2024	Constr. and Building Materials
Softwood (38x200mm)	Included	Included	Not explicitly stated	Not explicitly stated	0.46 kg CO_2e per kg	Belgium	2022	E3S Web of Conf.
CLT Timber Structure	Included	Included	Not specified	Not specified	0.43 kg CO2e/kg	Belgium	2022	Sustainab. Journal
Pine Timber (Structure)	Included	Included	Can be dismantled and reused	Reuse or inciner.	-382,101 kg CO_2 stored	Belgium	2021	Obaidy et al.
Timber Flooring	Included	Included	High reuse potential	Reuse or inciner.	73.5% of total structure weight	Belgium	2021	Obaidy et al.
Timber-Based Façade (Staples)	Included	Included	98% longer duration than best option	75% reusability, rest disposed	Highest among options due to waste	Italy	2022	Juaristi et al.
Timber-Based Façade (Screws)	Included	Included	35% longer duration than best option	100% reusability	Lower than staples, easier disassembly	Italy	2022	Juaristi et al.
Timber-Based Façade (Geometrical Assembly)	Included	Included	Best option, fastest disassembly	100% reusability	Very low GWP, best for reusability	Italy	2022	Juaristi et al.
Glulam (Glued Laminated Timber)	Included	Included	Included	Included	-656 kg CO_2e with biogenic uptake	Sweden	2016	Buildings Journal
Structural Timber (Glulam Beams)	Included	Included	Reused with minor processing	Energy recovery by incineration	30% lower impact than virgin production	Finland	2021	Niu et al.
Recycled Wood Fiber (CDW)	Included	Included	Moderate reuse potential	Incineration or recycling	-1.79 to -2.25 kg CO_2e (avoided impact)	Finland	2021	Sormunen et al.
Wood Waste Panel	Included	Included	Included	Included	-656 kg CO_2e (Glulam with biogenic carbon uptake)	Sweden	2021	Sustainab.
Cross-Laminated Timber	Included	Included	0.16 kg CO_2e/kg	Incineration or reuse	-1.78 kg CO_2e/kg	Belgium	2022	Binderholz EPD

methodologies and improved end-of-life data for reclaimed wood to advance the integration of circular design in construction.

4.2 Environmental performance across life-cycle stages

The LCA analysis of wood materials across life-cycle stages (A1: raw material supply, A3: manufacturing, C1: demolition, and C3: waste processing) illustrates distinct environmental trade-offs. While raw material supply and manufacturing processes can generate emissions, these are often offset by carbon sequestration during growth and energy recovery at the end of life. For example, Timber-Concrete Composite (TCC) floors exhibit a GWP impact of only 0.159 kg CO_2eq./kg, significantly lower than reinforced concrete, while reclaimed and recycled materials further extend the environmental benefits through waste reduction and reuse potential (Ivanica et al., 2022).

4.3 Potential for circular economy practices

Circular practices such as reuse, recycling, reclamation, and upcycling emerge as crucial strategies for enhancing the sustainability of wood-based materials. The data show that reclaimed timber and recycled wood fiber can drastically reduce emissions, with some materials even achieving negative GWP values. For instance, recycled wood fiber can avoid emissions ranging from -1.79 to -2.25 kg CO_2eq., illustrating the environmental savings possible through circularity (Abdolmaleki et al., 2025).

However, the feasibility of circular practices depends on several factors. Adhesives and treatments, commonly used in plywood and engineered wood, can limit recyclability, while the logistics of deconstruction and transportation may add emissions and costs. Yet, when circular economy principles are properly implemented, materials such as deconstructed timber buildings and geometrically assembled timber facades can achieve nearly 100% reusability, promoting material longevity and reducing waste (Xie et al., 2024).

4.4 Challenges and barriers to implementation

Despite the promising potential of wood materials in sustainable construction, several challenges hinder widespread adoption. Material durability and long-term performance are persistent concerns, especially for reclaimed wood. Additionally, regional variations in wood processing techniques and supply chain emissions introduce variability in environmental impacts, complicating the standardization of LCA practices. Furthermore, regulatory and policy limitations in some regions may restrict the reuse and upcycling of wood materials, emphasizing the need for updated legislation that encourages circular design. Beyond these issues, the economic feasibility and market maturity of circular practices present significant barriers. The high costs and labor involved in deconstruction, as well as the need for specialized equipment to process, sort, and clean reclaimed wood, often make these practices economically unviable when compared to using new timber. Additionally, the construction industry lacks a stable market with structured demand for recycled wood, which is further complicated by the absence of widely accepted certification and quality assurance standards. Without these systems, architects and engineers face difficulties in verifying the quality and reliability of reclaimed materials, limiting their use to smaller, non-structural, or niche applications.

5. CONCLUSIONS

The study concludes that adopting circular economic practices in wood-based construction can significantly reduce the environmental impact of the industry. Reclaimed and recycled wood demonstrate measurable benefits in reducing GWP and resource consumption. However, economic, regulatory, and methodological challenges must be addressed to fully realize their potential.

Future efforts should focus on standardizing LCA methodologies and expanding digital databases to support sustainable design and construction practices. However, challenges remain in fully adopting circular economy practices at scale, including issues related to material durability, inconsistent regional processing methods, and regulatory barriers that hinder widespread reuse and upcycling. The findings emphasize the need for continued research into the environmental benefits and structural performance of upcycled wood products, as well as the development of standardized LCA frameworks to better assess and compare materials across life-cycle stages. The creation of comprehensive LCA databases will be crucial in supporting sustainable, resource-efficient construction practices, enabling designers to make informed material choices that align with circular economy goals. In conclusion, while barriers to implementation persist, the ongoing integration of LCA and circular economy principles offers a transformative path forward for the construction industry, fostering more sustainable building practices and contributing to the global effort to reduce carbon emissions. Future research and technological advancements will be pivotal in overcoming current limitations, optimizing the use of wood in architecture, and advancing the transition to a circular, low-carbon construction sector.

Several limitations were encountered, including data variability due to regional differences in wood processing methods, and a limited number of studies covering comprehensive LCA stages for reclaimed wood. Future research is recommended to close these gaps, with emphasis on creating standardized LCA practices for circular wood materials in construction. This review also highlights the need for advanced LCA databases capable of supporting digital and circular design processes to optimize wood's role in sustainable architecture and construction.

ACKNOWLEDGEMENTS

This research was funded by FoRWARD - Furniture Waste for Circular Design research project, funded by MADE IN ITALY CIRCOLARE E SOSTENIBILE – MICS, C.F. 97931690156, NextGenEU, Extended Partnership 11, Project number PE_00000004.

Author Contributions: Conceptualization, S.F., R.H., G.G.; methodology, S.F., R.H., G.G; writing—original draft

preparation, S.F., R.H.; writing—review and editing, S.F., R.H., G.G; supervision, G.G.

In particular, Paragraphs 1, 2 and 5 should be attributed to S.F.; Paragraphs 3 and 4 should be attributed to R.H.

All authors have read and agreed to the published version of the manuscript.

The authors wish to thank the FoRWARD project coordinators Prof. Massimo Perriccioli and Prof. Marina Rigillo for their kind support.

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