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A Conceptual Framework for the Upcycling Supply Chain in the Wood Sector

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Abstract: This paper highlights the importance of sustainable practices in supply chain management, focusing on upcycling as a key approach to transforming discarded materials into valuable products. It proposes a conceptual framework based on state-of-art and action research, which integrates traditional wood upcycling with secondary material recovery, addressing gaps in the existing literature and promoting collaboration among manufacturers, waste managers, and designers. The framework emphasizes circular economy practices in the wood sector, aiming to enhance resource efficiency, reduce waste, foster innovation, and support job creation. Key aspects of the conceptual framework for the upcycling supply chain in the wood sector include supply chain restructuring, valorizing secondary wood, developing digital tools, and aligning global stakeholders to advance sustainability goals.

Keywords: upcycling; industry; wood sector; supply chain; circular economy; reverse supply chain

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1. Introduction

Sustainable practices have become fundamental to supply chain management in the context of environmental degradation, resource scarcity, and climate change [1]. Among these practices, the reverse supply chain plays a crucial role, as it encompasses the recovery of used products from consumers for purposes such as recycling, remanufacturing, or disposal [2]. Such practices aim to minimize waste and improve resource efficiency, serving as a critical component of a circular economy [3]. Upcycling practices emerge as a specific practice within the reverse supply chain, transforming discarded materials into highly valued products for the consumer [4]. While reverse practices focus on the recovery and reuse of materials, upcycling engages in innovative design processes and interactions with consumers, creating value from waste that transcends mere recycling [5].

In this regard, the European Union [6] has recognized the importance of both the reverse supply chain and upcycling to promote the efficient use of resources and sustainability in its three dimensions (social, environmental, and economic). Upcycling is acknowledged as a strategy to improve product lifecycle value while minimizing environmental impact, and it aligns with EU goals to promote a circular economy and reduce waste [7]. By reimagining discarded materials as valuable resources, upcycling contributes to environmental goals and opens new economic directions, addressing waste management challenges while enhancing supply chain resilience [7]. In the wood sector, processing wood by-products into high-quality furniture, decorative items, or building materials can

significantly reduce dependence on new wood resources while fostering local economies and sustainable practices [8].

However, despite being a key element in improving sustainability, the current literature often treats the reverse supply chain, in general, and upcycling, in particular, as isolated phenomena (analyzing their components and optimization, such as logistics, material acquisitions, or remanufacturing separately), neglecting the integrated framework necessary for their effective implementation along the entire supply chain [9,10].

This paper aims to present a conceptual framework that integrates the traditional supply chain for the wood sector with upcycling strategies and secondary material recovery. The necessity of this framework arises from the fragmented approach observed in the literature, which often analyzes supply chain components in isolation. This proposal promotes collaboration among stakeholders, including manufacturers, waste management companies, and design innovators. This holistic approach highlights the potential of secondary materials and encourages incorporating circular economy-based practices in the wood sector, promoting resource efficiency and waste reduction.

To explore the implications of this conceptual framework, the study addresses the following research questions aimed at improving sustainable practices based on upcycling in the wood sector: (1) What strategies can be implemented to enhance collaboration between stakeholders within the upcycling supply chain? (2) How can the wood sector optimize its processes to increase the value of secondary products while minimizing the environmental impact of its practices? (3) What innovative design and marketing strategies can be employed to improve the acceptance of recycled wood products?

The organization of the paper is as follows. Section 2 depicts the fundamental concepts of the upcycling supply chain, focusing on the wood supply chain and the difference between the reverse and upcycling supply chains. Section 3 presents the methodology conceptual research and action research. Section 4 presents the analysis of the results derived from the conceptual research while Section 5 presents the conclusions of the of action research. Section 6 establishes the conceptual framework for the proposed wood upcycling supply chain. The practical and theoretical implications are included in Section 7. Finally, the conclusions and further lines of research are described in Section 8.

2. Key Concepts of Upcycling Supply Chain

2.1. Wood Supply Chain Characteristics

The wood-based industries within the European Union encompass a variety of downstream sectors, including woodworking, significant segments of the furniture industry, pulp and paper production, and the printing sector. In 2020, around 393,000 businesses operated in these industries across the EU, representing 19% of all manufacturing enterprises. This indicates that apart from the pulp and paper industry—which benefits from economies of scale, most wood-based industries consist largely of small and medium-sized enterprises (SMEs) [11].

An industry's economic impact is often assessed by its contribution to gross value added (GVA). In 2020, the EU's wood-based industries contributed €136 billion in GVA, accounting for 7.2% of the total manufacturing sector. Pulp, paper, and paper product manufacturing generated the highest share at 34% (€46 billion). Printing and related services contributed 16%, while the production of furniture and wood products each comprised between 23% and 27% of the sector's total GVA [12].

The wood supply chain refers to the entire process of sourcing, processing, and distributing wood and wood-based products from the forest to the end consumer. It involves a set of connected stages, from the initial harvesting of trees to the final delivery of wood products to industries or retail markets. Each stage involves stakeholders, including [12]:

- Forest Management: This stage involves sustainable forest management practices and the harvesting of trees. Forest managers decide which trees to cut based on species, age, and environmental factors, ensuring the long-term health of the forest.
- Harvesting: Harvesting methods include logging, clear-cutting, and selective cutting.
- Transportation: Once harvested, trees are transported to processing facilities. This can be performed via trucks, rail, or water, depending on the location of the forest and processing plants. The wood may be transported as logs or sometimes as wood chips if intended for specific uses, like paper production.
- Processing (Sawmills and Other Facilities): At sawmills or other wood processing facilities, logs are transformed into usable products such as lumber, plywood, veneer, or chips. The logs may be cut, sawn, dried, treated, or otherwise processed depending on the desired final product.
- Secondary Manufacturing: Processed wood may undergo further refinement or transformation into products like furniture, construction materials, flooring, paper, or packaging. This stage adds value and prepares the wood for various end uses.
- Distribution: Finished or semi-finished wood products are distributed to wholesalers, retailers, or directly to manufacturers who use wood in products like furniture, paper, and construction materials.

The literature outlines three main categories of supply chains within the wood industry: the forest supply chain, the wood supply chain, and the wood-based supply chain. The forest supply chain involves the processes that convert standing trees into finished forest-derived products for consumers. This transformation includes producing logs, round wood, sawn timber, panels, construction timber, biomass, pulp, and bioenergy used for electricity and heating. A critical aspect of this supply chain is managing the balance between meeting industrial demand and maintaining environmental sustainability.

The wood supply chain centers on managing round wood for biomass and industrial use. In contrast, the wood-based supply chain involves networks of products made from wood by-products, such as sawdust and wood chips, which are used to manufacture items such as laminated boards, chipboard, and worktops. This is an option because these by-products are often sent directly for recycling and do not go through a process such as upcycling. The efficiency of the wood-based supply chain is demonstrated by global production companies that emphasize optimized supply and distribution networks [7].

The wood supply chain is inherently complex, requiring a balance between economic efficiency and environmental responsibility. It involves various actors and stages, each presenting unique challenges and opportunities for innovation [7]. Many scholars suggest that by integrating sustainable forestry practices, green chemistry, and innovative solutions, the wood industry can address current challenges and thrive in the future [13].

Another significant opportunity for long-term sustainability in the wood industry lies in waste management. Effective waste management practices are crucial for minimizing environmental impact and promoting sustainable operations [9]. Two key concepts in this area are upcycling and the reverse supply chain. Though distinct, these concepts complement each other by maximizing raw material usage, reducing deforestation, and minimizing the chemical processes needed for wood treatment, thus contributing to environmental sustainability.

While research and publications in the wood industry have increased over the last decade, focusing mainly on sustainability in forestry management, CO_2 compensation, and technological advances in supply chain automation [8], waste management, recycling, and the wider supply chain have received less attention. Most studies in this area have focused on biomass and bioenergy derived from wood.

Although China is the world's largest center of wood processing and wood product manufacturing, it is also a significant exporter of wood products. However, the utilization of wood and its waste in China is unsatisfactory, as only 50% to 60% of it is used, compared to 80% to 90% in developed countries. This is a global concern, as a significant portion of the wood used in household products and furniture is neither reused nor recycled [14]. Global demand for roundwood is projected to rise by up to 49% from 2020 to 2050 [15,16]. Table 1 shows the growing global demand for wood, highlighting the urgent need for worldwide sustainability in the wood supply chain.

Table 1. Trend projections for global roundwood demand (based on trends for 2012–2022).

Years	Billion m^3
2022	4
2030	4.35
2050	5

According to [17], Europe's rising demand for wood in buildings and products could lead to a shortage by 2030. Multiple factors drive this trend, including the growing focus on sustainable construction and renewable materials. As industries and governments strive to reduce their carbon footprint, wood is increasingly considered a favorable alternative to more carbon-intensive materials like steel and concrete. However, this rising demand places pressure on the continent's forest resources, which could lead to supply limitations if not managed sustainably.

To deal with this shortage exacerbated by waste management, practices must prioritize landfill and energy recovery over material recycling. Additionally, recycling contaminated wood waste poses challenges. The European Union has launched a set of laws, strategies, and policies to address the wood supply chain casuistic, including, amongst others, the Nature Restoration Law [18], the New EU Forest Strategy for 2030 [19], the EU Forest Strategy [20], and the European Green Deal [21].

2.2. Upcycling and Reverse Supply Chain

The shift from waste management to resource and recycling management, driven by rising price pressures and resource scarcity, requires enhancements in the quality and efficiency of logistics systems [22].

A reverse supply chain refers to moving goods from their destination back to the manufacturer or retailer to obtain value or proper disposal. Principal activities include the following: (1) Returns management (handling defective or unwanted products), (2) Re-manufacturing (restoring used products to a like-new condition), (3) Recycling (processing material to create new products). This involves effective management of raw materials, finished products, and in-process inventory from production back to consumption [23], aiming to recover value from disposed of goods. Also, this process involves services for handling returns from the field, including diagnosing, evaluating, repairing, or disposing of returned units, products, parts, in general, materials, some of these products may be redirected to the forward supply chain, sold in secondary markets, or fully disposed of.

In a reverse supply chain, collection centers are used to analyze and determine whether products can enter a second cycle as the same product or if they have the potential to be converted into something else. The reverse supply chain has specific characteristics, including processes for treating and transforming products that will undergo a second cycle. Some research has aimed to generate an aggregate production plan to forecast demand from end consumers of second-hand products, allowing for a more organized and efficient production plan [24].

Tools such as mathematical models allow us to calculate recovered wood's environmental and social parameters after its reuse using known variables. A computer-based model for the mathematical reverse logistics (RL) process is called Cascade Treatment of WOOD (CATWOOD) with Microsoft Excel. The CATWOOD model is deterministic and assumes all external constraints are known. The model provides a detailed representation of natural phenomena in the wood cascade process, which is the wood's reverse supply chain [24].

Conversely, the concept of "upcycling" plays a crucial role in a profitable and sustainable business strategy. Upcycling aims to enhance or maintain a product's functionality while using minimal raw materials and energy. It is also a method of extending a product's life that would otherwise be discarded, giving it a renewed purpose [5].

Upcycling also involves transforming waste materials or unwanted products into new products of higher quality or value. The principal activities are the creative reuse of material and design for upcycling (creating products that cannot be easily repurposed). Table 2 presents the key differences and relationships between upcycling concepts and the reverse supply chain [25].

Table 2. Upcycling and the reverse supply chain, key aspects comparison.

Aspect	Reverse Supply Chain	Upcycling Supply Chain
Purpose	Recover value and reduce waste	Create new high-value products from waste
Process	Involves returns, recycling, and remanufacturing	Involves creative reuse and reimagining materials
Benefits	Focused on efficiency and cost recovery	Focused on creativity and sustainability
End Goal	Minimize environmental impact and maximize recovery	Transform waste into valuable new products

To extract the trend publications on upcycling in the wood industry, Scopus and Web of Science databases were used according to the following search strategy TITLE-ABS-KEY (upcycling AND industry AND wood). Figure 1 depicts the trend publications on upcycling in the wood industry. As can be seen from the graph shown in Figure 1, the upcycling concept has been addressed in a median of two papers per year from 2018 to 2022. Nevertheless, starting in 2023, there is an increase in papers published, detecting a research trend on upcycling in the wood industry. Despite this, research on upcycling in the wood supply chain is limited. However, this presents an opportunity to delve deeper into the subject and develop tools that can optimize the upcycling process.

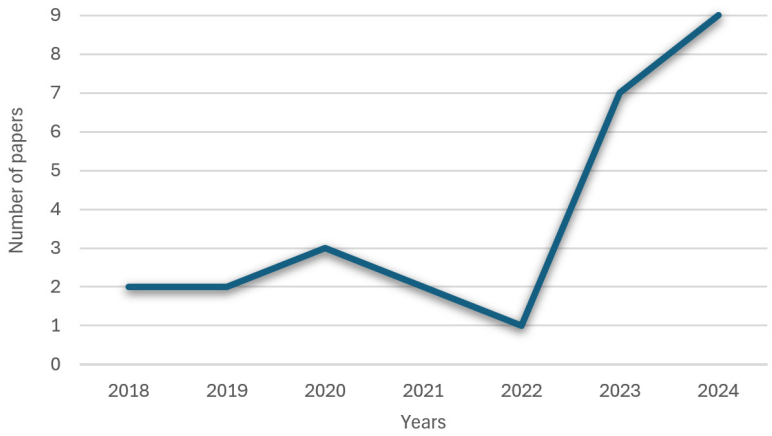

Figure 1. Trend publications on upcycling in the wood industry.

Although reverse logistics has been studied more extensively than upcycling, both concepts are complementary and can effectively coexist. However, they are independent, and their activities can provide significant mutual benefits. The potential for a second use of a product depends on its condition. In this context, an analysis of the product is necessary to assess whether it can undergo an upcycling process. Its quality must be carefully evaluated to determine if it can be transformed into a new, higher-value product [26].

2.3. Upcycling Supply Chain in the Wood Sector

At the end of their first life, most wood-based products still retain material qualities suitable for reuse or recycling in various forms. However, much of this recovered wood is incinerated rather than being reused, even though it is at its highest possible quality. The potential for efficient material cascading—reusing and recycling wood through multiple stages—remains underdeveloped in the wood product sector. Recent and ongoing projects are now working to create solutions and technologies that will enable more efficient reuse and recycling of reclaimed wood [27].

At the end of their service life, used wooden products will increasingly be treated and recycled to produce raw materials, which will compete with newly harvested forest products. This shift presents an opportunity for new and established businesses to offer products, services, and materials to companies in the forest product industry.

Likewise, upcycling focuses on inventive and creative methods such as repair, refurbishment, redesign, upgrading, and remanufacturing. This process plays a vital role in the circular economy by minimizing waste generation. By reducing solid waste, enhancing resource efficiency, and limiting the demand for new raw materials, upcycling aids in decreasing industrial energy use and greenhouse gas emissions. This contribution supports sustainability efforts and advances the pursuit of net-zero emissions [28].

Although the importance of upcycling practices is growing, the academic literature on the topic remains fragmented, especially in the wood sector. This presents an opportunity to delve deeper into research on upcycling, particularly in the wood sector. In this context, the furniture industry stands out, where upcycling practices primarily focus on repainting, repurposing, and refurbishing. However, in other areas of the wood industry, research is scarce or even non-existent, such as in the sectors of household utensils or wooden boards used for constructing various objects [14].

Indeed, upcycling in the wood sector is a powerful strategy for reducing waste, conserving resources, and promoting sustainability. By turning discarded or low-value wood into high-quality, functional products, the industry can extend the life of wood materials while contributing to environmental goals. With growing awareness and demand for sustainable products, upcycling is set to play an even more significant role in the future of the wood industry [5].

The upcycling supply chain in the wood sector contributes positively to three key dimensions: economic, social, and environmental well-being, beyond simply supporting sustainable resource management [4].

- Economic impact: it encourages entrepreneurship and innovation, enabling small businesses to thrive through sustainable practices.
- Social dimensions: upcycling promotes a sustainable consumption culture, raising consumer awareness about waste reduction and resource conservation.
- Environmental impact: Upcycling minimizes waste, reduces the need for virgin wood, and extends the lifecycle of wood products, helping to preserve forests and biodiversity.

In addition, it is essential to mention that several factors can increase the success of upcycling. According to [29], these factors include consumer attitudes toward upcycled products and business recognition of upcycling's role in transitioning toward a sustain-

able society. After conducting several tests, it was observed that fine arts and design professionals aged 30 and older have shown a particular interest in upcycling.

On the other hand, several challenges upcycling faces today can be identified, according to [4], particularly for the stakeholders involved (see Table 3).

Table 3. Challenges and success factors within the upcycling supply chain.

Stakeholders	Challenges	Success Factors
Material suppliers	• Material available to source • Lack of funding • Market perception for upcycled products • Complex legislation depending on the country	• Outreach for material donation for upcycling • Legislative support • Financial contribution
Upcycling designers and manufactures	• Costly item for marketing • Lack of affordable resources (space, time, equipment, skills, and materials) • Insufficient availability of materials that meet the necessary quality and quantity standards	• Critical resources available (human, financial, materials, infrastructure, tools) • Marketing for upcycled product • Skills development in human resources
Retailers	• Good quality upcycled products available • Financial constraints	• Effective marketing • Quality of products • Consumer awareness
Consumers	• Good quality products available • Promotion of upcycled products	• Promotion of upcycled products • Lower price of upcycled products • Affordable prices for upcycling products

3. Methodology

The research of this paper is structured into two complementary strategies, each one corresponding to a phase of the methodology, the conceptual research strategy (phase 1 of the methodology) and the action research strategy (phase 2). Both of them helped to build phase 3: in which the conceptual framework with a holistic understanding of the concept of wood upcycling supply chain is proposed (Figure 2).

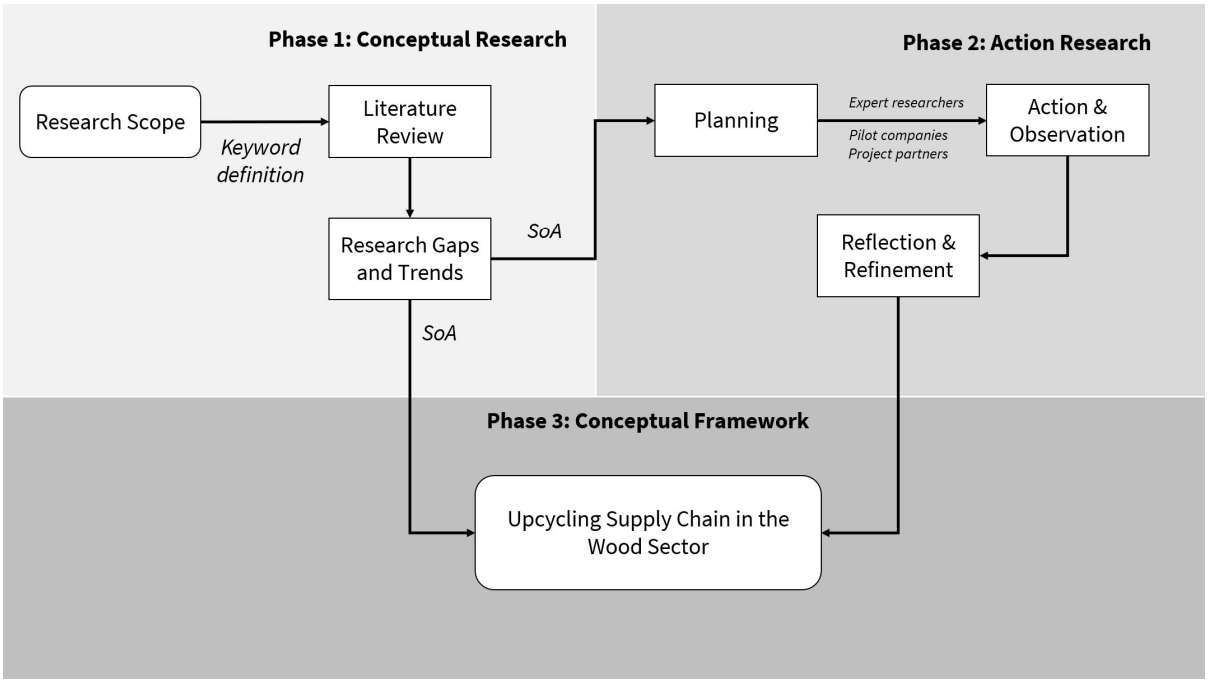

Figure 2. Methodology complementary phases.

Phase 1, Conceptual Research: aims to carries out a state-of-the-art review by identifying research gaps and trends based on the analysis of keywords and the scope of the research.

Phase 2, Action Research: evaluates the theory of the gaps and trends identified in the state-of-the-art. This evaluation was carried out through interviews with expert researchers, pilot companies collaborating in partnership, and project partners actively involved in the research. The first step was to plan the process, followed by contacting the participants and proceeding with the action and observation process. With the guidance of expert researchers, the final reflection and refinement of information and knowledge was achieved. Together with both research approaches (conceptual and action), this enabled the development of the conceptual framework presented in the corresponding section of this paper.

3.1. Conceptual Reearch Strategy

Conceptual research strategy is based on the academic approach, in wich a state-of-the-art (SoA) is carried out, as a comprehensive and structured review of the current knowledge, research, and advancements in a specific field of study or research area. Its primary purpose is to summarize, analyze, and evaluate the existing literature, theories, methodologies, trends, and gaps to provide a clear and updated understanding of the topic.

This subsection outlines the approach used to conduct the state-of-the-art(SoA) analysis for wood upcycling supply chain. The keywords are: (TITLE-ABSTRACT-KEY ("upcycling") AND TITLE-ABSTRACT-KEY ("wood" OR "wood sector") AND TITLE-ABSTRACT-KEY ("supply chain")). Scopus was the database used for a range of years, from 2015 to 2024. Figure 3 explains the search strategy, which involved an initial screening of the 45 articles identified.

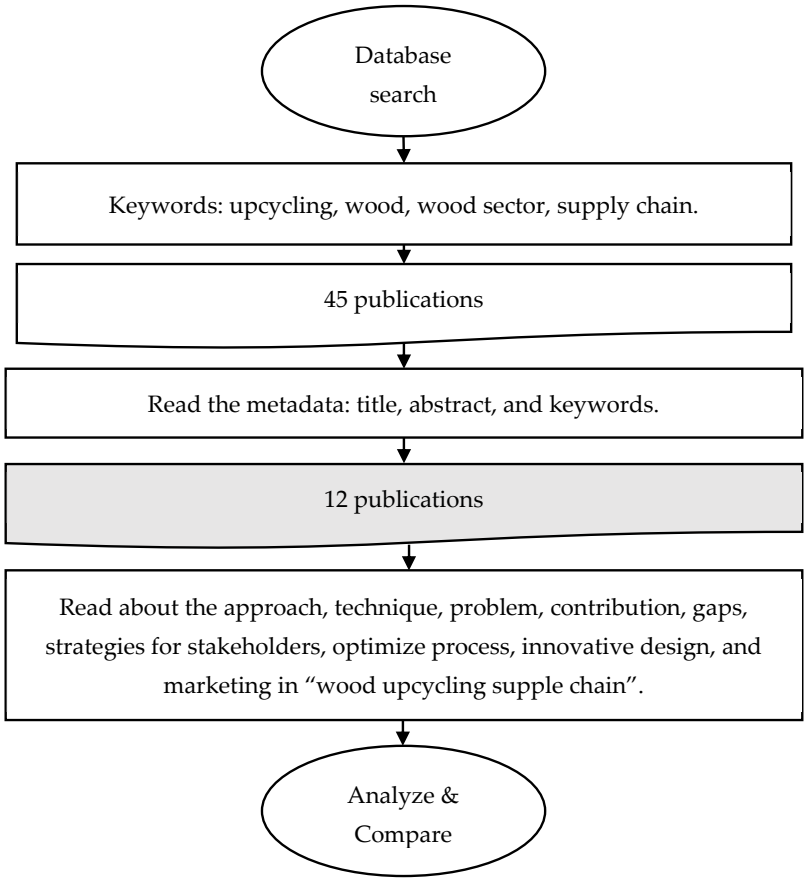

Figure 3. Research Method for SoA.

After reading the article and identifying key information such as the title, authors, year of publication, journal, and keywords, 12 articles were chosen and a summary is created for each of them. This summary includes the problem addressed, the approach taken, the technique used, and the gaps identified; each of these points has been identified as important for understanding the literature in its full context, including the most common problems and the number of studies that focus on addressing theory-related issues. These studies often use a qualitative approach, while case study methods with a quantitative approach are occasionally employed to test specific theories. The contributions were summarized to gather information not only about the contributions of each study but also about the gaps they identified in their research. This approach helps in creating a comprehensive summary of the reviewed works. It also examines whether the article discusses aspects of stakeholder collaboration, process optimization to enhance the value of second-use products, and efforts to minimize environmental impact. Additionally, it considers whether the study proposes any innovative designs or marketing strategies to improve the acceptance of upcycled products, particularly in the context of the wood upcycling supply chain.

3.2. Action Research Strategy

Action research strategy emphasizes active participation in processes, moving beyond passive observation. This method not only generates new knowledge but also solves practical problems. It uses a critical and reflective approach to understand theories by analyzing actions that lead to specific outcomes, even if those outcomes were not the original goals. The process involves continuous interaction between action and reflection, where actions inform the reflective process, making it a learning-driven methodology.

The participants were stakeholders such as pilot companies with whom contact was established to gather information, project partners who contributed valuable knowledge based on their experience in the field of study, and expert researchers who guided the entire process to ensure that each stage was completed.

This action research method can sometimes lack rigor; therefore, according to certain experts, it is essential to address any disagreements and clarify all perspectives to ensure that the knowledge obtained is as thoughtful, refined, reliable, and valuable as possible in providing solutions to the identified problem or topic. Thus, different angles for the same questions were required. Below is the proposed strategy for the action research (Table 4):

Table 4. Action Research process.

Planning	Description of the problem or challenges: No comprehensive proposal fully integrates the upcycling process into the reverse supply chain and circular economy. Practical implications for the wood sector are lacking. Objective: Design interventions to address gaps in Upcycling in the supply chain and incorporate key elements into the conceptual framework. Environment: Individual questions Via email and questionnaires. Dialectic Method.
Action and Observation	Describe how the action and observation were carried out.
Reflection and Refinement	Compared with information in the literature, address disconfirmations.

4. State-of-the-Art Analysis for the Wood Upcycling Supply Chain

This section aims to provide a clearer view of current developments and trends in the wood upcycling supply chain. It will focus on five fundamental supply chain approaches: stakeholder, collaboration, process optimization strategies, and strategies for innovative designs and upcycling marketing. The goal is to generate a conceptual framework for the wood upcycling supply chain.

The SoA analysis revealed the main contributions and gaps concerning the "wood upcycling supply chain". Table 5 presents the problems to be addressed, techniques, approaches, and contributions.

Table 5. Articles selected for state-of-the-art analysis.

Problem	Approach	Technique	Contribution	Reference
Explain the upcycling concept	Qualitative	Literature review	Upcycling art involves transforming used or waste materials into new, higher-quality products through creative processes like repair, refurbishment, redesign, and remanufacture. It supports the circular economy by promoting sustainability.	[25]
Treat the aggregate production planning problem in a green SC	Quantitative	Stochastic robust optimization	A second-hand product could pass through suppliers, factories, and customers. After its first use, instead of being remanufactured, it could be sent to collection, directed to an upcycling area, and resold to a different type of customer.	[23]
How to use resources in the wood sector efficiently	Qualitative	Cascade use of wood	The transition from waste management to resource and recycling management is illustrated in a case study on reverse logistics of waste wood and wood products, focusing on the cascade use of wood.	[22]
How to use efficiently wood waste materials	Quantitative	Material flow analysis	Improved understanding and management of wood material flows can produce higher-value products and lead to cost savings.	[8]
How to bridge the gap between circular bioeconomy agendas and territorial development	Qualitative	Interviews	Forest residues hold significant potential, which can be fully tapped if advancements in research are paired with capacity building and technology transfer at the practical level.	[1]
Unclarity of the upcycling process	Qualitative	Literature review	The reverse side of the value chain primarily involves three key processes: collection, sorting, and processing. These stages can also be broken down into three major steps such as collection, sorting, and redesigning.	[5]
How can cascade operation be integrated with the circular economy with R-imperatives (Reduce, Reuse, etc.)?	Qualitative	Literature review	An incentive-based system can improve the efficiency of collection. Research shows that collection is more effective during promotional campaigns or when handled by third parties, with the former being more cost-efficient. Collection through retailers has proven less profitable, and they tend to gather smaller quantities compared to third-party organizations or non-governmental entities.	[26]
Circular economy in the wood construction industry	Qualitative	Literature review	Wood waste can be recycled back into the production process to enhance the value of composite materials, such as by being repurposed into wood panels at the end of its life cycle. This approach seeks to provide both economic and environmental advantages to the industry rather than allowing the waste to be improperly discarded.	[27]

Table 5. *Cont.*

Problem	Approach	Technique	Contribution	Reference
Identify challenges in the development and functioning of the circular economy	Qualitative	Two case studies of material (waste) streams	The wood industry demonstrates that for high-quality wood, free from contaminants like preservatives and paints, the circular process is already complete. To further enhance circularity, it is recommended to incorporate additional stages of product reuse.	[28]
Analyzing the efficiency of cascade wood waste	Qualitative/ Quantitative	Interviews in a Multi-Level Perspective (MLP)	Resource efficiency can be attained by fostering a circular bioeconomy, which emphasizes the reuse and recycling of resources, as well as by improving wood cascading, which involves using wood in various stages to optimize its utility.	[29]
Understanding the wood supply chain and the circular process for dealing with waste	Qualitative	Literature review	It is important to have a comprehensive understanding of the global supply chain for wood products and its cascading elements. Utilizing industry mapping is an effective way to gain these insights, offering significant advantages for education and research while providing a broader perspective on the industry's dynamics.	[30]
Lack of systemic understanding of challenges and success factors relating to scaling up upcycling businesses	Qualitative/ Quantitative	Literature review, stakeholder analysis, semi-structured interviews	The main challenges identified include a shortage of materials for suppliers, insufficient affordable resources (such as space, time, equipment, skills, and materials), high marketing costs for upcycling designers and creators, and a lack of resources for retailers to promote upcycled products effectively. The success factors identified include increasing awareness of upcycling, the availability of essential resources such as skilled personnel for up-cyclers, effective marketing strategies for retailers, and enhancing the purchasing experience for consumers.	[4]

The analysis of each article revealed a common gap: there is no comprehensive proposal that fully integrates the upcycling process into the reverse supply chain and circular economy. Practical implications for the wood sector are lacking, and a holistic perspective on the upcycling process beyond the cascade method is not fully considered [29,30]. Additionally, academic research on upcycling remains fragmented and lacks cohesion.

Having a comprehensive understanding of the entire process will enable more informed decisions about which strategies to use for optimization, collaboration between stakeholders, and the development of innovative designs. These efforts will serve a market increasingly attracted to products emerging from the wood upcycling supply chain.

One of the most common contributions found in the literature was the effort to explain the concept of upcycling, aiming to define and highlight specific characteristics that could be expanded upon in the conceptual framework of this article.

Value-added upcycling transforms waste into new products, creating financial or environmental value from discarded materials. Extracting higher value focuses on altering a material's use to achieve greater benefits, such as increased monetary worth or improved environmental performance, like salvaging rare materials and converting them into useful products [26]. In addition, the authors emphasized in their research the challenges and

opportunities of upcycling and the importance of achieving synchronized collaboration between stakeholders [4].

One way to help collaboration between stakeholders, according to [1,4], is to promote training programs to enhance the entrepreneurial skills of forestry professionals while fostering collaboration between forest-wood sector firms and research institutions to create synergistic innovation pathways. In some cases, communication between the re-designer and the initial producer is necessary to manage the upcycling process better [5]. The study of [4] revealed that Stakeholder interviews identified actors that could support the success of upcycling businesses, including central government, local councils, businesses, consumers, media, activists, and volunteers.

Additionally, optimizing the wood upcycling supply chain can be enhanced through mathematical models to identify better solutions and reduce the costs of the reverse supply chain [23]. In this way, the processes proposed by the cascade method: (1) collection and remanufacturing, (2) reuse, (3) material usage, and (4) burning for energy—could become more efficient and effective by incorporating technology and digital tools [22].

Before being used for combustion, a product could first serve other purposes or be sold as a second-hand item in suitable markets, as previously mentioned [27]. Wood has diverse applications, such as in round timber, furniture, and particle boards, and can later be recycled into new particle boards. Once these products reach the end of their lifecycle, utilizing them in bio-refineries is a technically viable option. Ultimately, incineration and energy recovery can serve as the final steps in a sustainable and circular wood utilization process. Improving existing recycling methods is crucial for advancing circularity [28].

On the other hand, ref. [1] recommends increasing product value through certifications that verify social and environmental sustainability, supporting the local forest-wood supply chain, and using the "Made in [Country]" label as a strategic marketing approach.

5. Action Research for the Wood Upcycling Supply Chain

This phase has been carried out with the researchers and practitioner industrial experts of the consortium of the European Project "A Wood-to-Wood Cascade Upcycling Valorisation Approach (W2W)" 101138789 Horizon Europe funded. The project W2W focuses on four key component: (1) Advanced separation and classification technologies, (2) Upcycling processes and technologies, (3) Digital tools to enhance circular material flows, (4) Policy, market and skills support framework. Thus, the project W2W aims to reduce the demand for virgin materials, minimize waste sent to landfills or incineration facilities, and promote the creation of high-value products from waste materials, supporting the transition to a circular economy.

Dialectic methods were used to carry out the action research. This emphasizes using dialog, contradictions, and critical reflection to explore and resolve problems collaboratively. This method is especially valuable in action research, where the goal is to create practical solutions while deepening understanding of a situation. The dialectic method was conducted through asynchronous communication using questionnaires and personalized interviews for each participant; each participant had a level of participation, for example, from 1 to 5, where 1 represents no participation, and 5 represents full participation (Table 6).

The planning process, in addition to defining the scope of the study, involved generating specific questions that each stakeholder later answered.

- What specific activities are involved in optimizing the wood upcycling supply chain?
- Who might be considered the main user or stakeholder of the wood supply chain?
- What should be in a document illustrating wood product chains?
- How can circular economy principles be effectively integrated into the upcycling process within the wood supply chain?

- What practical implications could be mentioned for the wood sector?

Table 6. Detail of participants and level of contribution.

W2W Participant Experts	Details	Level of Contribution
Researchers	Expert researchers from different universities and research centers. The role was to guide all the action research and to verify and compare the theory found and the objectives and description of the problem to be developed.	4
Project partners	The project partners answered the main questions.	4
Pilot companies	There were pilot companies, but they provided very little information to interpret it as real and made sense in real life in a company.	2

5.1. Action and Observations

For the action process, the questions were sent to the project partners, who provided the following summarized responses:

- What specific activities are involved in optimizing the wood upcycling supply chain?

The activities involve managing recycling processes, maintaining stock levels, and optimizing transportation operations while minimizing costs. These activities can be monitored through demand forecasts, supplier lead times, and reliability, which influence optimal stock levels.

- Who might be considered the main user or stakeholder of the wood supply chain?

The possible 'secondary materials manager' might be considered the main user or stakeholder.

- What should be in a document illustrating wood product chains?

The wood product chains should include the following four products: sawmill, veneer mill, reconstituted wood, and pulp and paper. (1) First level: raw materials like sawdust or wood shavings; (2) Second level: wood parts/components such as boards or panels; (3) Third level: finished products like furniture or packaging).

- How can circular economy principles be effectively integrated into the upcycling process within the wood supply chain?

Reorganizing supply chain agents, valorizing secondary materials, including a secondary materials manager, and integrating all actors to align with circular economy practices.

- What practical implications could be mentioned for the wood upcycling supply chain?

The project partners Wood to Wood (W2W) tackles the challenges of wood waste valorization through an integrated framework built on four key components: advanced technologies for separation and sorting, innovative upcycling processes, digital tools to enhance circular material flows, and supportive frameworks in policy and market dynamics. The initiative showcases sustainable value chains for producing clean wood, biocomposites, biopolymers, polyols, detergents, and recovered nutrients. By streamlining cascade pathways for wood reuse, W2W reduces dependence on virgin resources, limits waste sent to landfills or incinerators, generates value-added products and advances a circular economy by enabling closed-loop systems that extend the lifespan of materials. Once the project partners have responded, the observation is conducted by research experts to compare the information with the theory found in the literature review.

The wood upcycling supply chain faces critical gaps, including lacking an integrated framework combining upcycling, reverse logistics, and circular economy principles. Addressing these gaps through optimized recycling, demand-driven inventory management,

and streamlined transportation aligned with the cascade method can enhance efficiency and sustainability. Advanced digital tools and the role of a secondary materials manager are pivotal in bridging collaboration among stakeholders and improving synchronization across the supply chain. Initiatives like Wood to Wood (W2W) demonstrate practical solutions, showcasing how innovative technologies, closed-loop systems, and local supply chain strategies can reduce reliance on virgin materials, minimize waste, and create sustainable value.

Many companies and industries have successfully adopted demand-driven inventory management and transportation optimization without strictly adhering to the cascade method, demonstrating alternative paths to efficiency and sustainability. Advanced digital tools and secondary materials managers are valuable and necessary for effective collaboration and synchronization through existing technologies and cross-functional teams.

5.2. Reflection and Refinement

Once the action and observation process were completed, the next step was to request the intervention of the pilot companies. At its core, the dialectical approach values disagreement as a tool for generating stronger and more reliable information to guide decision-making.

Reflecting on this analysis highlights the substantial potential to transform the wood upcycling supply chain by addressing its critical gaps and inefficiencies. Integrating upcycling processes with reverse logistics and circular economy principles emerges as a key priority, emphasizing the need for a cohesive, systemic approach that supports sustainability objectives. These challenges also present opportunities for innovation, stakeholder collaboration, and the development of frameworks that deliver both economic and environmental advantages.

Among the recommendations, the integration of a secondary materials manager stands out as a strategic innovation, highlighting the necessity of coordinating diverse stakeholders across the supply chain. Coupled with sustainability certifications and localized supply chain strategies, this role can significantly enhance the market value of wood products.

Ultimately, bridging these gaps is essential for building an efficient, sustainable wood upcycling supply chain that aligns with the core principles of a circular economy.

6. Conceptual Framework for the Wood Upcycling Supply Chain

In view of the significant gap detected in the literature concerning the wood upcycling supply chain from an integral perspective that facilitates a better holistic understanding of (i) its characteristics, (ii) the agents involved and their roles, and (iii) the dynamics of their operations, it is considered relevant to generate a conceptual framework.

Accordingly, this section defines a conceptual framework for the upcycling supply chain in the wood sector, serving as an analytical high-level tool that includes core concepts and central relationships. The conceptual framework definition starts with the definition of four key elements and continues with the proposal of the wood supply chain reorganization with new manufacturing actors. This follows the incorporation of supply chain agents devoted to valorizing the secondary wood materials supply chain. Next, the conceptual framework proposes a secondary materials manager in the wood supply chain, managing traditional wood stakeholders and new secondary materials vaporizers. Finally, the conceptual framework enables the integration and structuring of all supply chain actors to valorize primary and secondary materials.

6.1. Key Elements

The conceptual framework consolidates its bases around four key elements, endowed with a particular prominence (Figure 4):

- the reorganization of the existing agents making up the conventional wood supply chain, which covers all the existing stages from the sourcing of raw materials to the delivery of the final product to the user or consumer, and which includes the processes of production, logistics, storage, and distribution;
- the organization of the industry agents devoted to the valorization of secondary wood materials, with a consistent approach aligned with the organization of the conventional wood supply chain;
- the incorporation of the secondary materials manager agent into the organization of the wood supply chain for the valorization of secondary wood materials as a singular and highly relevant agent from the perspective of the upcycling success;
- the global integration and structuring of all the upcycling wood supply chain agents comprise the conventional supply chain, the industry for valorizing secondary materials, and the secondary materials manager.

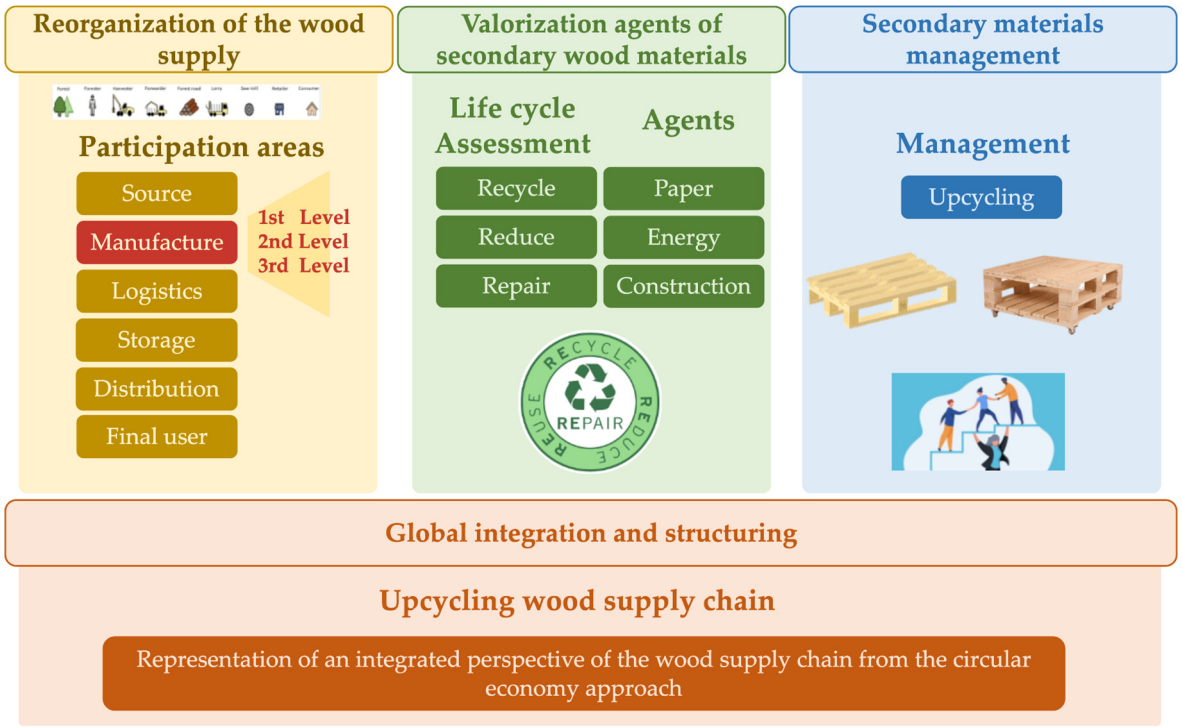

Figure 4. Conceptual framework for the upcycling wood supply chain.

The four key elements will enable an integrated perspective of the wood supply chain from the circular economy approach.

6.2. Wood Supply Chain Reorganization

Concerning the stakeholders that integrate the conventional supply chain of the wood sector and their organization in this context, it is worth highlighting the significant variety. The wood sector is a complex environment in which very diverse actors cover many functions and specialties. The complexity within the wood supply chain is guided by the existence of agents that vertically and horizontally integrate several of these functions and specialties.

On the other hand, it should be noted that stakeholders' potential, aptitude, and capacity to promote the valorization of secondary wood materials varies greatly depending,

in general, on the role played in the supply chain and, especially, in the case of the actors involved in the manufacturing processes, which, in this conceptual framework, are jointly referred to as the wood industry.

Thus, six main areas of participation in the conventional supply chain of the wood sector can be established: (i) the sources of supply of raw wood, (ii) the wood industry integrating all the manufacturers processing wood somehow, (iii) the logistics of wood materials, components and products, (iv) the storing of these products and joining manufacturers and retailers, (v) the retail marketing which deliver wood materials, components and products to the final users or consumers, and (vi) the latter, the final users and consumers.

In a second layer, specific to the wood industry players, three levels of manufacturers can be established:

- At the first level, manufacturers producing wood materials, such as sawmills or treated wood manufacturers, produce wood raw materials from trees or trunks, their main activity being the initial processing of timber.
- At a second level, manufacturers producing wood parts or components which transform wood materials into parts or components that can be subsequently reprocessed and used to assemble into final products, such as boards, veneers, panels, laminated wood, plywood, etc.
- At the third and last level, manufacturers of wood products reprocess, assemble, and manufacture finished products. They can produce anything from furniture and decorative items to architectural products, packaging, or tools. These manufacturers add the final value to the material, combining the pieces and transforming them into consumer products. Their work includes design, assembly, and finishing, bringing esthetics and functionality to the processed wood.

This second organizational layer in wood industry manufacturers is necessary for this conceptual framework, as the requirements and specifications of valorization differ significantly depending on the role played by each agent, so it has become essential to identify it. This innovative way of organizing the conventional supply chain in the wood sector is why it is referred to above as a reorganization rather than an organization.

6.3. Valorization Agents of Secondary Materials in the Wood Supply Chain

It is relevant to consider the organization of the agents that make up what can be called the industry for the valorization of secondary wood materials, responsible for collecting, classifying, and transforming waste and by-products such as sawdust, wood shavings, wood offcuts, and other secondary materials, according to their potential for reuse. When these materials are sometimes not directly reusable by the wood industry, they can be diverted to complementary industries such as the paper, energy, or construction industries for use in products such as paper or paper-based products, biofuels, or insulation.

Also, in certain situations that must be minimized, some waste is not reusable and must be disposed of in a controlled manner, ensuring the lowest possible environmental impact. In this context, five main categories of actors are involved, as follows:

- The recoverers and classifiers of secondary wood materials are responsible for collecting and categorizing wood waste and by-products. These agents typically operate at the initial stage of the valorization process, gathering materials from various sources, including consumers, sawmills, construction sites, etc. They sort the materials based on type and quality, ensuring that only suitable materials are processed further. This role is vital for maximizing the recovery of usable materials, thereby reducing waste and promoting sustainability within the supply chain.
- The valorizers of secondary wood materials are responsible for transforming and processing these materials into new value-added products. This includes shredding,

compressing, or chemically treating the wood waste to create products like particleboard, insulation, or biocomposite materials. Their work involves innovation and technology to develop efficient processes that enhance the quality and utility of the transformed materials, contributing significantly to the circular economy and ensuring that as much waste as possible is repurposed into valuable products.

- The warehouse keepers of secondary wood materials are responsible for storing and managing the inventory of recovered materials and ensuring their preservation. These agents play a crucial role in maintaining a well-organized storage system, which includes monitoring stock levels, ensuring proper storage conditions, and implementing effective inventory management practices. Their responsibilities ensure that materials remain in a suitable condition for future processing and that a steady supply of recovered materials is available for valorization, reducing delays and inefficiencies in the production process.
- Other alternative industries, such as energy, biomass, paper, and pulp products, etc., are responsible for receiving and utilizing materials that cannot be directly reused, integrating them into their production processes. These industries often seek secondary wood materials to serve as raw inputs for their manufacturing processes. For instance, wood waste may be converted into energy through combustion or gasification, while excess wood may be used to produce biofuels. Their involvement not only helps in waste reduction but also contributes to resource recovery and the development of sustainable practices across various sectors.
- The landfills or waste disposal sites are responsible for the disposing of non-recoverable wastes in a controlled manner, ensuring that they are handled safely to minimize environmental impact. While the goal is to reduce waste through recovery and recycling, some materials inevitably end up in landfills. These sites must adhere to strict regulations regarding the safe disposal of waste, including monitoring and mitigating environmental impacts such as leachate and methane emissions. They are essential in ensuring waste management practices align with environmental sustainability goals and public health standards.

Comparable approaches for identifying end-of-life products can be repurposed through high-value-added designs [10].

- Lifecycle Analysis (LCA): integrating LCA tools to assess materials' potential for reuse at the end of their service life.
- Design for Disassembly (DfD): encouraging manufacturers to design easier products to disassemble, sort, and recycle.
- Material Classification Standards: creating criteria to classify secondary wood materials based on type, quality, and potential reuse applications.
- Incentives for Innovation: providing incentives for developing technologies and processes that enhance the recovery and valorization of secondary wood materials.
- Education and Training: educating stakeholders about high-value-added reuse opportunities and promoting sustainable practices.

6.4. Secondary Materials Manager in the Wood Supply Chain

Incorporating the secondary materials manager into the organization of the industry for the valorization of secondary wood materials is pivotal to the success of upcycling.

The secondary materials manager oversees the collection, sorting, and processing of secondary wood materials, ensuring their effective utilization and minimizing waste. By analyzing available by-products, this individual or entity identifies opportunities for innovation, transforming discarded materials into valuable new products. Additionally, the secondary materials manager fosters collaboration among stakeholders, including

manufacturers. Such collaboration promotes a circular economy and yields economic benefits by reducing material costs and creating new revenue streams. Seen in this light, the manager's expertise is essential for optimizing resource flows and driving the wood supply chain towards sustainability, facilitating the transition from waste to resource.

The secondary materials manager also plays a critical role in monitoring and adhering to regulatory requirements and sustainability standards, ensuring that all processes align with environmental guidelines. By leveraging data-driven insights and advanced technologies, such as AI, for predictive analysis, the manager can enhance efficiency in material recovery and anticipate market trends for secondary wood products. Moreover, the manager's involvement in educating and training teams on best practices in material handling and recovery further strengthens the capacity of the industry to embrace circular economy principles. This role optimizes internal processes and fosters innovation through continuous improvement and cross-sector collaborations.

Once the main spaces and categories of actors in the supply chain have been introduced, it is essential to process their integration and structure in the broader context of the wood sector within this conceptual framework.

6.5. Global Integration and Structuring

The overall integration and structuring of all actors in the supply chain for the valorization of secondary wood materials are essential to creating a cohesive conceptual framework that aligns with the principles of the circular economy. All the aspects concerning the (i) wood supply chain reorganization, (ii) valorization agents of secondary materials in the wood supply chain, and (iii) secondary materials manager in the wood supply chain are depicted in Figure 5, which graphically explains the proposed conceptual framework, its structure, agents, and flows.

From this point of view, the flow should be understood as the part of the supply chain that is the focus of attention from an upcycling perspective, i.e., first of all, the direct logistics flow (or conventional supply chain), in which materials, components, and products move through the chain from the sources of supply in the direction of the user or consumer, and secondly, the reverse logistics flow (that of the industry for the valorization of secondary materials), in which secondary wood materials such as waste, reusable components, recyclable products, processed by-products, etc., are collected from the corresponding agent of the conventional supply chain, classified, processed, stored and returned to the traditional supply chain or, when this is not possible, devoted to the final disposal. A stage should be understood as each of the phases of these two flows, direct and reverse logistics, which can be identified between their ends. Finally, agent means each entity, individual, or organization that integrates each stage of the complete cycle: the integration of direct and inverse logistics flows (Figure 5).

There is a conflict between two approaches (recycling and reuse/upcycling) as they sometimes compete for the same resources. However, the W2W project focuses on secondary materials from Construction and Demolition (C&D) and the furniture industry, specifically discarded or leftover wood. If not properly coordinated, promoting upcycling strategies could negatively impact the already specialized recycling sector. Therefore, we propose the following options:

- Recognize Existing Actors: incorporate the specialized recycling segment as a key stakeholder, fostering synergies instead of replacing processes.
- Assess Waste Flows: identify waste streams that are not efficiently recycled and prioritize them for upcycling strategies.

- Encourage Coexistence: develop models that allow recycling and upcycling to coexist, minimizing the impact on the current value chain and promoting an integrated approach.
- Mitigate Conflicts of Interest: propose incentives or regulations that balance recycling and reuse goals to avoid direct resource competition.

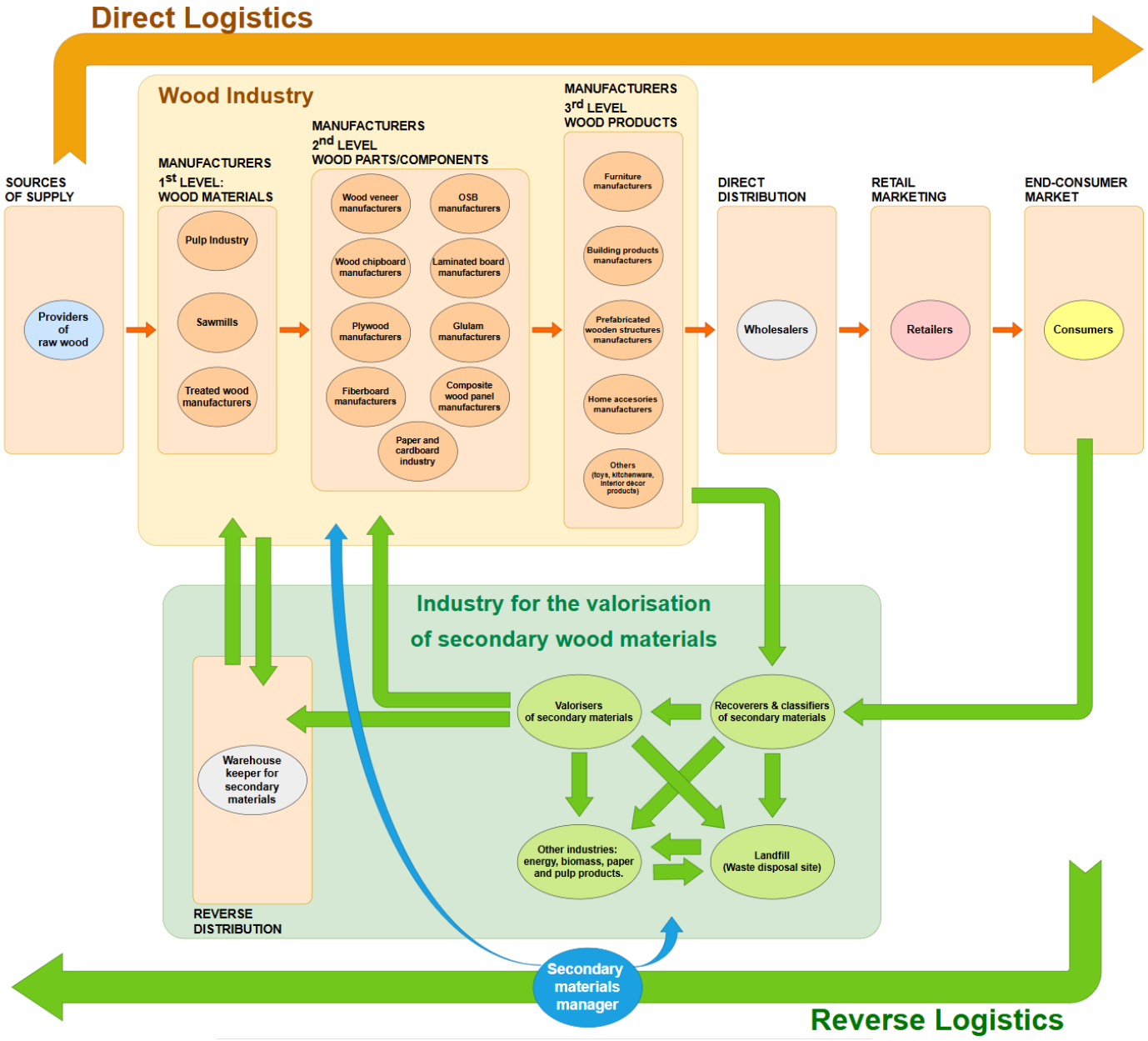

Figure 5. Global integration and structuring of the wood upcycling supply chain.

7. Practical and Theoretical Implications

The proposed framework incorporates the conventional supply chain, the emerging secondary material recovery industry, and the secondary material manager as a central figure, collectively forming a unique cycle that embodies the full sustainability potential of the wood sector.

By integrating these elements, the wood sector can move from a linear production and consumption model to a circular approach that prioritizes resource efficiency and waste minimization. The conventional supply chain focuses on extracting, producing,

and distributing new materials, often overlooking the potential of secondary materials generated during these processes.

With the inclusion of the secondary materials recovery industry, which focuses on recovering and reusing, the supply chain is evolving to recognize the value of its waste and by-products. The secondary materials manager also plays a crucial role in this integrated supply chain by facilitating communication and collaboration among various stakeholders, including manufacturers, waste management companies, and other industries that utilize secondary materials.

Ultimately, this holistic approach encourages innovation, supports job creation in emerging sectors, and fosters resilience in the face of global challenges such as climate change and resource depletion, enabling the wood industry to advance its contributions to a circular economy significantly. The result of this integration is a wood upcycling supply chain, which can ultimately be structured in three different layers: flow, stage, and agent. Some specific practical implications to achieve strategies to enhance collaboration, optimize processes, and improve market acceptance within the upcycling wood supply chain are:

- Establish Partnerships and Alliances between Stakeholders within the Upcycling Supply Chain: Create formal partnerships between manufacturers, waste management companies, and designers to facilitate knowledge sharing and resource exchange. Collaborative projects can lead to innovative solutions and shared best practices.
- Implement a Centralized Platform: Develop a digital platform that allows stakeholders to communicate and share information about available materials, production capabilities, and market demands. This can enhance visibility and coordination throughout the supply chain.
- Adopt Lean Manufacturing Principles: Implement lean practices to streamline operations, reduce waste, and improve resource efficiency. This includes optimizing cutting patterns and minimizing offcuts during production.
- Invest in Advanced Technologies: Utilize technologies such as AI and machine learning for predictive analytics, enhancing resource allocation and process optimization decision-making.
- Enhance Material Recovery Processes: Develop efficient sorting and processing systems for secondary materials to ensure high-quality outputs. This can involve investing in automated sorting technologies or advanced recycling methods.
- Focus on Sustainable Sourcing: Ensure that all materials used, including secondary products, are sourced sustainably to minimize environmental impact and enhance the overall sustainability profile of the wood sector.
- Emphasize Esthetics and Functionality: Design recycled wood products that highlight their unique characteristics, such as natural imperfections or historical significance, appealing to consumers' preferences for authenticity and craftsmanship.
- Implement Eco-Labeling and Certifications: Obtain eco-labels or certifications that validate the sustainability of recycled wood products. This can enhance consumer trust and improve marketability.
- Engage in Community Outreach: Organize workshops, demonstrations, or exhibitions that educate consumers about the benefits of recycled wood products and the upcycling process, fostering a sense of community and acceptance.
- New Business Opportunities: Valorizing secondary wood materials creates revenue streams and opportunities for cross-sector collaboration, inviting investment in sustainable innovation.
- Involvement of designers and the development of specialized skills to work effectively with secondary wood materials: The participation of designers and the cultivation of specialized skills are essential for effectively utilizing secondary wood materials.

Designers contribute innovative solutions for repurposing reclaimed wood, while specialized skills enable efficient processing, handling, and transformation of these materials, promoting sustainability and circular practices in the wood industry.

- Encourage Policy Support and Incentives: Advocate for policies and government incentives that support upcycling wood materials, such as tax breaks for companies using secondary materials or subsidies for R&D in material recovery technologies. This can help drive broader industry adoption and promote innovation in sustainable practices.

All these points can be agreed on in four key aspects: restructuring the supply chain, organizing agents for valorizing secondary wood, developing digital tools, and aligning stakeholders globally.

8. Conclusions and Future Research Directions

This paper proposes a conceptual framework for the wood upcycling supply chain The framework offers a holistic view of essential elements, stakeholders, and operational dynamics in wood upcycling, focusing on four key aspects: restructuring the conventional supply chain, organizing agents for valorizing secondary wood, integrating a secondary materials manager, and globally aligning stakeholders. It highlights the importance of incorporating secondary materials across all manufacturing stages and promotes collaborative efforts among agents to maximize reuse and reduce waste. This structured approach aims to enhance sustainability and supports a circular economy within the wood sector.

The proposed framework transforms the wood supply chain by integrating conventional processes, secondary material recovery, and a dedicated secondary materials manager. This shift from a linear to a circular model emphasizes resource efficiency and waste reduction, recognizing the value of by-products that would otherwise be discarded. The secondary materials manager is pivotal in coordinating efforts across the supply chain, fostering collaboration between various stakeholders. This holistic approach promotes innovation, job creation, and resilience, advancing the wood industry's role in the circular economy. Ultimately, the wood upcycling supply chain can be understood through three interconnected layers: flow, stage, and agent, all contributing to a more sustainable and resource-conscious wood sector.

As future research, the supply chain of secondary wood materials may involve a structured approach that begins with a comprehensive analysis of requirements and system design. Optimization algorithms could be developed, leading to the implementation of advanced simulation and modeling tools. Real-time tracking and monitoring capabilities and robust reporting and analysis functions will be introduced. The system could undergo rigorous testing and validation using synthetic data before being deployed in pilot programs that utilize accurate data for further validation. This structured methodology could significantly enhance efficiency and sustainability within the secondary wood materials supply chain, accelerating the transition to a circular economy, minimizing waste, and generating valuable new products.

Key risks associated with this supply chain could include potential shifts in the W2W project requirements and the challenges of integrating existing information systems. Concerns regarding data accuracy, system performance, and scalability could be pivotal, alongside the complexities of implementing optimization algorithms. Interoperability among various supply chain actors could pose challenges, as could ensuring robust data security and privacy. Moreover, managing real-time updates and changes could be critical for maintaining an efficient and responsive system.

The relationship between upcycling in the wood supply chain and artificial intelligence (AI) will focus on leveraging AI to optimize and enhance sustainable practices in the sector.

A deeper exploration of the primary optimization strategies and activities could be essential to fully understanding their impact.

The literature review highlights a significant gap in the wood upcycling supply chain research area, namely the absence of a comprehensive framework integrating upcycling processes into the reverse supply chain and circular economy. Practical implications for the wood sector remain underdeveloped, and research on upcycling lacks a cohesive and holistic approach beyond the cascade method. This gap underscores the need for a systemic understanding to enable informed decision-making, foster stakeholder collaboration, and support innovative designs that cater to a growing market for sustainable products.

Regarding the literature review and action research, it can be concluded that they facilitated the development of critical thinking and a more thorough examination of the knowledge and information being verified about the wood upcycling supply chain. The chosen method proved highly useful and greatly contributed to the development of the conceptual framework.

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