MASTER IN MANAGEMENT

MIM

MASTERS FINAL WORK

DISSERTATION

NAVIGATING THE LOOP:

THE EVALUATION OF CIRCULAR ECONOMY PRACTICES ON SUSTAINABLE WOOD UTILIZATION IN CONTEMPORARY INDUSTRIES – A LITERATURE REVIEW

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BERNHARD SEIER

SUPERVISOR: PROF. GRAÇA MIRANDA SILVA

JURY:

PRESIDENT: PROF. JOSÉ MANUEL CRISTÓVÃO VERÍSSIMO

RAPPORTEUR: PROF. PEDRO ALEXANDRE DE ALBUQUERQUE MARQUES

SUPERVISOR: PROF. GRAÇA MIRANDA SILVA

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ABSTRACT

This thesis extensively explores the integration of Circular Economy practices in the sustainable utilization of wood within two contemporary industries by analysing 29 distinct studies in a systematic literature review. It delves into the intricacies of CE adoption, emphasizing the critical roles of strategic partnerships, technological innovation, and policy evolution as significant drivers that facilitate the transition toward sustainability and efficiency in wood resource use. Meanwhile, it uncovers the challenges impeding this transition, such as regulatory constraints and the prevalent gap in effective information sharing between stakeholders. By conducting a comparative analysis across the wood construction and wood-based manufacturing sectors, the research reveals the unique operational challenges each sector faces, thereby advocating for bespoke strategies to navigate these hurdles. This nuanced approach highlights the necessity for a cooperative, multi-stakeholder engagement to harness the full potential of CE principles, aiming to drive both environmental sustainability and economic growth within the wood industry. Furthermore, this thesis contributes to the broader discourse on sustainable resource management, offering actionable insights for policymakers, industry stakeholders, and the academic community to foster a more circular and economically viable wood industry, paving the way for future research directions and practical implementations.

Keywords: Circular Economy, Sustainable Wood Utilization, Wood Construction, Wood-based Manufacturing

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GLOSSARY

CE – Circular Economy

SME – Small and Medium sized Enterprises

1) Introduction

The importance of integrating Circular Economy (CE) practices into the wood industry, is a pressing concern in the contemporary context. This integration is pivotal due to wood represents a significant potential resource in the transition towards sustainable resource utilization, offering a renewable and environmentally friendly alternative to non-sustainable materials.

The transition from a linear to a circular economy model is crucial in addressing global sustainability challenges. The CE emphasizes a sustainable approach, replacing the traditional "take-make-dispose" pattern with more resource-efficient practices "take, make, use, reuse, and recycle"(Kalair et al., 2021). The actuality of the topic is shown by the empirical studies in this field, the number of studies using CE as a central term has increased exponentially since 2017 and since 2019 the Circular Bioeconomy is added especially in the literature connected to the wood industry (Holzer et al., 2023). In the wood industry this transition of linear to circular is particularly vital. The urgency is underscored by the industry's substantial contributions to global carbon emissions and resource depletion, which calls for a re-evaluation of traditional construction methodologies and practices in wood-based industries (Hartini et al., 2021; Holzer et al., 2023; Komorowicz et al., 2021). Conversely, wood possesses substantial potential not merely as a renewable raw material but also as a carbon sequestration medium. This dual function of wood underscores the necessity of maintaining its presence within the economic cycle for an extended duration to maximize its environmental benefits (Singh et al., 2022). This Research Project is guided by the two contemporary industries Wood Construction and Wood-Based-Manufacturing.

The construction sector shift towards CE is driven by the need for innovative solutions that reduce environmental impacts and optimize resource use across value chains (Holzer et al., 2023). The industry is a major emitter of CO_2 and other greenhouse gases, with concrete playing a significant role in this regard, it also exhibits several inefficiencies (Laiblová et al., 2019). Taking a closer look, construction is marked by low material efficiency and productivity, alongside a substantial reliance on non-renewable resources (Hertwich et al., 2019; Ruuska & Häkkinen, 2014a).

Similarly, the use of wood products from sustainably managed forests reflects the growing importance of improved recycling and material substitution in wood-based manufacturing. However, it's crucial to consider broader implications, such as carbon storage and the impact of deforestation on greenhouse gas emissions also in this industry (Holzer et al., 2023). The wood panel production, a key component of the wood-based manufacturing, exemplifies the transition from a linear to a circular model. Traditionally characterized by excessive waste generation from the extraction of raw materials to the disposal of final products, the industry is now embracing CE principles (Araújo et al., 2019). In this thesis wood-based manufacturing is understood as a variety of products whose main resource is wood, like panels, furniture, cardboards or particleboards.

To identify ways to achieve and successfully implement the principles of a CE in a particular sector or organization, it is necessary to understand the barriers that may be encountered and drivers that stimulate the CE development (Ritzén & Sandström, 2017).

This thesis aims to systematically review recent drivers and barriers in these two different areas and providing insights into how these practices are reshaping the wood industry towards circularity.

The research question, **"How are Circular Economy Practices used in Sustainable Wood Utilization in Contemporary Industries? A Literature Review of Recent Drivers and Barriers."** is designed to explore the intersection of CE and sustainable wood utilization. To answer this question this paper applies a review of the most relevant literature from 2016 till today. It will examine the current state of CE practices in the wood industry, highlighting the opportunities and challenges faced in transforming traditional wood utilization methods into sustainable and circular processes. To that end, this study is structured as follows. This first section presents the initial considerations around the theme. Chapter 2 will present the methods used to conduct this piece of research, in other words the search strategy and how the included literature is filtered and selected. The following Chapter 3 will provide a brief theoretical background on circular economy and what is understood as sustainable wood utilization. Chapter 4 will present the main literature review separated by the two different industries. The last section will draw the discussion and conclusions of this research, followed by the cited literature.

2) Methodology

2.1. Search Strategy

The focus of this review is on a planned and structured approach to the literature search process. Due to the diversity of published academic research content, a replicable and transparent method for the selection and critical evaluation of sources is required(Moher et al., 2015a). As a first step in the search strategy the two keywords "Circular Economy" and "Wood" were identified. To ensure that also synonyms and word variations were covered the search has been extended. For Wood the synonyms "Timber", and "Lumber" and the extension "wooden" also were included in the search. For Circular Economy the abbreviation "CE" and other words like "recycling", "reusing" or "refurbishing" were used. To cover really every possible word variation truncation symbols for all the words above were used as well, for example "recycl*". The second part of the chosen search strategy involves the selection of suitable databases. The three databases used are Google Scholar, Web of Science and EBSCO. The advantage of the EBSCO electronic catalogue bibliography is that you have access to more than 350 databases (including Business Source Premier and Econlit) via a search portal. This already covers a significant spectrum of relevant journals and magazines. Web of Science, as a specialist portal for economics, expands the search process to include articles (Brink, 2013). Google Scholar, on the other hand, with one of the most comprehensive citation indices, is rated as a supplementary database for literature reviews, as grey literature is also included (Gusenbauer & Haddaway, 2020). The risk of a distorted research result, possibly due to missing relevant sources, was subsequently minimised with the help of *connectedpapers.com*. Around 50,000 sources are searched for each original article and an overview of the approximately 40 most important sources are created based on co-citations and bibliographic links (https://www.connectedpapers.com/about, n.d.).

2.2. Study Selection Process

Once a search strategy consisting of keywords and selected databases has been defined in advance, the study selection process begins. The PRISMA flowchart helps to map the process so that the literature search can be retraced retrospectively. As shown in Figure 1, a total of 608 sources were found, with the criteria explained above, in databases and other sources. Only sources written in English were considered. The first step concentrated on the title and abstract so that as many search hits as possible could be checked for suitability. The search was carried out in the period from 12/10/2023 till 09/02/2024. The Filter process started with excluding the duplicates and wrong languages found throughout the different databases. After removing all duplicates, not English-written papers and sources where the full text could not be accessed, a total of 161 potential sources were subjected to a screening process based on inclusion and exclusion criteria.

The primary inclusion criterion is that the source specifically focuses on CE practices in one of the two included wood industries, with particular emphasis on both ecological and economic aspects. Secondly, wood that is written about should be considered as a raw material in the two contemporary industries.

The main exclusion criteria is that the connection approach between wood and CE is based on a solely chemical level, which means sources that deal mainly with the chemical properties of wood regarding CE, for example how to chemical change wood in these industries to make it more convenient. Basically, everything that cuts out the whole supply chain and solely focus on how to change the resource itself, is not considered. Also, case studies which deal with a very specific niche product are excluded. After the screening process was completed, 43 articles were subjected to a full-text assessment. As a result of the process described above, 29 studies were included in the literature review. This thesis concentrates on the evolving dynamics and obstacles within the interdependence of wood and the circular economy. Consequently, literature that does not address specific barriers or drivers related to this nexus is excluded from consideration. In addition to content-related criteria, the quality of the source or publication location also determines whether a source is included.

In addition, it is noteworthy that not all citations in the *Literature Review* Chapter are out of this pool. Citations which were needed to explain certain terms or statistics in the three industries which are more general and not related to wood connected to CE were taken from different Literature which is excluded from the Pool you can find in the *Prisma Scheme*.

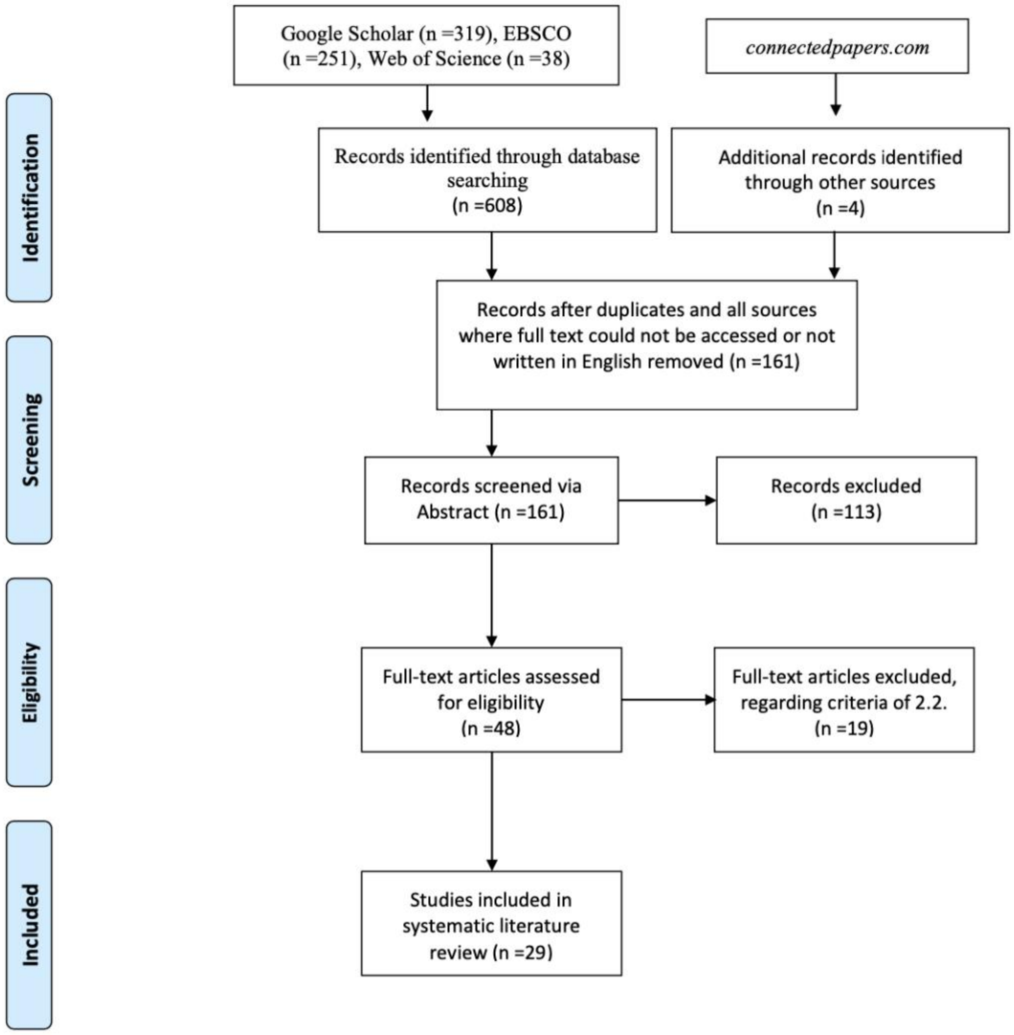

Figure 1: PRISMA Scheme based on (Moher et al., 2015)

3) Background

3.1. Overview of Circular Economy

The CE is a multifaceted concept aimed at sustainable development. The concept of a CE first emerged in 2008, introduced in China's Circular Economy Promotion Law during the eleventh National People's Congress (W. Li & Lin, 2016). The global recognition of the CE concept significantly advanced with the founding of the Ellen MacArthur Foundation (EMF) in 2010. This milestone marked a turning point in bringing CE into the international spotlight. EMF's contribution to the conversation was pivotal: it urged a re-evaluation of traditional, pre-industrial strategies, emphasizing the importance of maintaining the highest value of materials and products throughout all stages of economic cycles (*see Fig. 1*). This perspective was presented as an essential alternative to the prevailing linear models of production and consumption, advocating for a fundamental shift in how we perceive and manage resources in the future (Macarthur, 2013).

Nowadays it has been defined in various ways, reflecting its complex nature. CE is often described as a regenerative system emphasizing the reuse, refurbishment, remanufacturing, and recycling of materials (Velte et al., 2018). It focuses on keeping products, components, and materials at their highest utility and value, aiming to decouple economic development from finite resource consumption (Boggia et al., 2022).

CE is not just about waste management; it extends the added value of products and seeks to eliminate waste production (Stankovska & Dimitrieska, 2017) This approach requires significant shifts in production and consumption systems, emphasizing the reduction, reuse, and recycling of materials (Kirchherr et al., 2017). The literature reveals a lack of consensus on the exact definition, highlighting the need for a multidimensional and multi-criteria approach to evaluate the transition towards CE (Oliveira et al., 2021). However, the majority of CE approaches show that, as the concept becomes more nuanced, it is unveiling new employment and entrepreneurial prospects, positioning itself as a viable mechanism to implement sustainable development (Gagnon et al., 2022).

Another approach which will be mentioned in this thesis is wood cascading. Wood cascading is a strategy that focuses on the efficient and sustainable use of wood resources.

It involves organizing the use of wood so that it is first directed towards high-value applications before being used for lower-value purposes, like bioenergy or disposal. This approach ensures the most beneficial use of wood at every stage of its lifecycle (Olsson et al., 2018). It predominantly overlaps with the CE approach and is therefore often used in the same context.

In summary, CE encompasses strategies that harmonize economic, environmental, and societal objectives, promoting sustainable business models and a systemic shift in resource utilization.

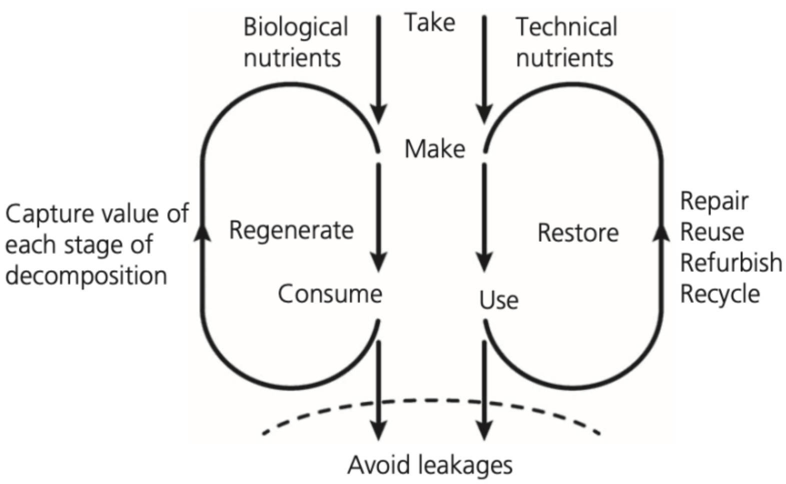

Figure 2: Economic Cycle of Biological and Technical nutrients (Raworth, 2017)

3.2. Sustainable Wood Utilization

The concept of sustainable wood utilization is gaining increasing importance due to its varied benefits. This approach focuses on balancing ecological, economic, and social aspects in forest management and wood use. One of the key aspects is the sustainable production of wood, which not only generates profit throughout the supply chain but also increases the carbon stored in wood products (Parobek et al., 2019).

Harvested wood products, when utilized sustainably, can contribute to climate change mitigation. The use of wood in place of more carbon-intensive materials like steel and concrete in construction for example can significantly reduce emissions associated with manufacturing, transporting, and installing building materials (Pasternack et al., 2022).

Moreover, sustainable wood utilization involves not only the production of renewable biological resources but also their transformation into value-added products, thereby contributing to a bioeconomy. This includes using waste wood and recycled wood aggregates to create new, environmentally sustainable products, thus closing the loop in the resource cycle (Hossain et al., 2018).

In a nutshell, sustainable wood utilization is increasingly recognized for its potential to contribute to environmental sustainability, climate change mitigation, and the development of a circular economy. This approach emphasizes the efficient and responsible use of wood resources, ensuring the long-term viability and health of forest ecosystems (Forster et al., 2023).

4) Literature Review

4.1. Wood Construction

4.1.1. Benefits to Circular Economy in Wood Construction

In the realm of sustainable development and circular economy, the construction sector emerges as a significant contributor to environmental challenges, accounting for substantial carbon emissions and waste production. In numbers we are talking about 40% of the total CO_2 emissions and between 25-30% of the total waste discarded in landfills, worldwide (Himes & Busby, 2020; OECD, 2019). In terms of annual resource consumption, offices, houses, and other infrastructure account for 50% of global material consumption (Circle Economy Foundation, 2018). The construction sector is generally characterized by a low material efficiency, low productivity, and comparatively high volumes of non-renewable resources (Ruuska & Häkkinen, 2014b). In addition, a lack of skilled craftsmen can be observed in the industrialized countries (Barbosa et al., 2017). While the energy demand of the sector increased globally between 2010 and 2018, in line with the population growth, the material consumption surpassed this trend significantly, with no prospected stagnation (OECD, 2019). Material substitution offer the greatest opportunity to make deep reductions in embodied carbon (Hoogzaad & Bayerlein, 2022). Wood may be the biggest opportunity for the Construction Sector to shift the industry in a more circular way. Given that the market share of wood-based construction in Europe is below 10% (Hildebrandt et al., 2017), there is great development potential to reduce Greenhouse Gas (GHG) emissions via the house construction sector (Sikkema et al., 2022). A recent study suggests that using wood in 50% of new urban buildings could deliver 9% of global emissions reduction required to encounter 2030 targets for keeping global warming below 1.5 °C (Khalili & Dodoo, 2023). Mass timber is often proposed as the prime example of a sustainable alternative to steel and concrete in construction. Particularly, prefabricated mass timber panels, such as cross-laminated timber (CLT) enable a new integrated building technology, revolutionizing the use of timber in construction (Ahn et al., 2022).

The construction industry needs to rethink its entire process, not just the materials used. The original expectations of eco-effectiveness, of doing good and not just less bad, are worth further clarification in relation to timber use and forestry. Similarly, emphasizing the advantages of shifting from selecting basic products to employing more comprehensive, integrated systems in engineering could yield significant benefits.

(Campbell, 2017). The longer wood can be kept in the material cycle (*see Fig. 2*), the longer it serves as a carbon store and thus as a climate-stabilising buffer for CO2-emissions. In addition, wood as a building material contributes to the substitution of fossil and mineral building materials. (Schuster & Geier, 2022a) The CE has become an important idea in this process. The concept has emerged with broad applications in the building construction context, decoupling economic profit from resource depletion or environmental degradation (vbw Zukunftsrat, 2021). In addition, it has been noted that there is a clear relationship between the CE and the UN Sustainable Development Goals (SDGs) and that CE goals are directly or indirectly linked to the achievement of these (Husgafvel & Sakaguchi, 2023). Referred to this connection of CE and the building industry the EU published an important concept that should contribute to a targeted change in that sector. The New European Bauhaus project highlights the importance of long-term and life-long thinking within the industrial ecosystem with a focus on (1) a CE and circularity; (2) circular and sustainable design and architecture; (3) the use of sustainably produced and procured nature-based building materials (e.g., wood); (4) the life extension, reuse, regeneration and transformation of existing buildings; (5) recovered and renewable materials (e.g., use and design); and (6) designs for sustainability and new business models (European Council, 2021).

4.1.2. Barriers to Circular Economy in Wood Construction

At this point the wood construction sector still faces numerous challenges in adopting CE practices. Beside to the New European Bauhaus project there is an often-mentioned lack of existing regulations and general appropriate legislation from public institutions (Ahn et al., 2022; Schuster & Geier, 2022b). Which hinders consistent implementation according to uniform construction rules. Furthermore, one of the primary obstacles to adopting CE concepts is the limited awareness and acceptance among the public and key players in the industry. There's often a gap in knowledge about the availability of second-hand materials and components in the market. In the building sector, user groups commonly show resistance to these ideas (Zu Castell-Rüdenhausen et al., 2021). This reluctance stems from a lack of familiarity with these practices and the prevailing mindset in the linear economy, where “new” is often equated with “never used before” (Schuster & Geier, 2022b). This issue is rooted in the fact that wood construction as an alternative to steel and concrete has just started to be in the industries scope again. None of the recent projects build with a CE approach has reached mid service life yet, several uncertainties remain.

These include questions about their long-term performance, ongoing maintenance expenses, durability, safety, and the eventual economic and environmental impact when the building and its components reach the end of their lifespan (Ahn et al., 2022).

Wood products used in construction are manufactured for only one- time use, doubts about long-term quality and constant supply of construction timber, unmotivated to reuse and recycle it, since at present they are primarily and efficiently going to energy recovery (Niu et al., 2021). A unique barrier in timber construction lies in integrating the load-bearing structure directly with the façade, unlike other methods where they are distinct. This integration, while innovative, presents hurdles such as developing effective connection techniques, a challenge shared with steel construction. Legal mandates have been highlighted as crucial for advancing these solutions, underscoring the need for regulatory support to address these technical challenges and advance the field of timber construction (Schuster & Geier, 2022b). For the CE approach it is crucial that the wood in the construction should be reused after the buildings end of life. This highlights the connection design of the different timber construction elements. It was noted that the percentage of material loss in the reused CLT panels was approximately 30% because of the need to reprocess parts of panels damaged by connection removal (Passarelli, 2018). But not only from the mechanical point of view their remain challenges in the recyclability also economical wise. The challenge includes a shortage of stakeholders and opportunities for adding value by reusing or recycling wood. There's also a gap in standardized methods for repurposing construction and demolition wood, making its value lower compared to other materials like metals in construction waste (Niu et al., 2021). Keeping wood in the circle is in times of an irritated energy market and high energy consumption not the current commercial focus. With significant pressure to hit renewable targets and with a constrained supply, the use of timber as woody biomass will compete with the use as a new product and determine future markets (Campbell, 2017). Biomass or pulp could be prioritized if those either provide greater immediate financial returns or represent lower risk. In the EU, fuelwood currently accounts for about 22% of all roundwood production (Eurostat, 2022).

While timber offers environmental advantages for construction, concerns about its untreated form persist, including fire resistance, competitiveness, and durability issues. Thermal modification, aimed at enhancing wood's durability, can unfortunately diminish its mechanical performance (Ghobadi & Sepasgozar, 2023). Both industry professionals and insurers highlight durability as a critical concern, suggesting a need for better waterproofing techniques and repair strategies for timber constructions to mitigate damage risks (Campbell, 2017). This underscores the inherent challenges of using chemically untreated wood in building materials which is favourable to aim a CE approach. While modifications provide better utility of the element, they alter the nature of the material and impact its future reuse or recyclability (Campbell, 2017). The future of material reusability, particularly regarding documenting their quantity and quality, remains a significant uncertainty and a major hurdle for the CE integration into the construction sector (Ahn et al., 2022). Additionally, the slow pace of CE adoption in modern timber construction is attributed to limited research on circularity and its practical application within the industry (Ghobadi & Sepasgozar, 2023). Furthermore, if studies have investigated the environmental and even economic benefit of wood cascading, they mostly been conducted at the product (e.g. particleboard or CLT) instead of project (e. g. timber building). So far, it seems that there has been no study that has considered the macro-scale together with different actors (such as manufacturers, policymakers, waste management enterprises, *see Fig.2 Business Ecosystem*) along the wood value chain (Niu et al., 2021). Economically research in wood construction with CE approach is taking its first steps. (Ahn et al., 2022). Therefore, there is a general concern about cost efficiency and profitability regarding the whole value chain. A study from Oregon State University found mass timber construction to be approximately 6.43% more expensive than concrete, mainly due to a higher frequency of change orders (Ahmed & Arocho, 2021). Additionally, another comparison of total life cycle costs showed mass timber had significantly higher initial expenses, around 26% more than concrete, with construction and utility costs being the primary factors for the increase (Gu et al., 2020). These figures were worked out in the United States and there is definitely a difference in for example Scandinavia where we have higher timber resources in relation to the area of the country, but this shows still that wood is quite an expensive resource when it comes to construction. Following to life cycle, the End-of-Life-costs for deconstruction of a wooden building is still quite uncertain. To deconstruct it in a way that the wooden materials can still stay in the circle and be reused is associated with a high labour input (Schuster & Geier, 2022b). Further on approaches such as installing used timber building components in current new construction fail to gain acceptance by business insiders and cannot yet be mapped in current planning and building routines.

The examination of wood construction challenges reveals significant barriers: notably, the absence of supportive policies and a pronounced lack of research and experience throughout the value chain, which exacerbates cost and labour uncertainties. Doubts about wood's suitability as a construction material, due to perceived issues with durability and adaptability in comparison to concrete and steel, lead to technical barriers. These barriers contribute to a sluggish adoption of the Circular Economy approach in timber construction, underscoring a critical need for expanded research and a re-evaluation of current practices to enhance wood's role in sustainable building methodologies.

4.1.3. Drivers to Circular Economy in Wood Construction

In comparison to the barriers, exploring the circular economy's role in wood construction reveals its substantial environmental drivers, especially through the cascading use of wood. It connects somehow intuitively that something that grows should have less environmental impact than something that does not (Campbell, 2017).

And in fact, research indicates this CE approach in connection with wood construction significantly lowers CO2 emissions and conserves raw materials (Sikkema et al., 2022). Cascade utilization alone can reduce greenhouse gas potential by up to 10%, with the added advantage of saving primary resources by substituting waste wood for fossil-based products. This method allows wood resources to be used sequentially, bypassing complex recycling (Schuster & Geier, 2022b). An illustrative case of an industry building which includes 4,000 square metres of manufacturing and about 650 square metres of office space showed that constructing a building with substantial wood elements prevented the emission of 682 metric tons of CO_2—equivalent to removing 250 cars from the road for a year—and stored 1183 metric tons of carbon. This conservation effort demonstrates the potential of circular wood construction to significantly impact environmental sustainability (naturally:wood, 2017).

The suitability of wood as a construction material, is often seen as a barrier, but on the other hand the characteristics of timber construction offer some real benefits and link to some scope topics of modern construction understanding. Advances in technology, such as improved gluing and fixing methods, have enabled the use of mass timber products in complex constructions, contributing to thermal efficiency and environmental sustainability (Campbell, 2017; Schuster & Geier, 2022b). Innovations include glue- and metal-free connections for easier disassembly which is one of the main technical challenges in making wood constructions more circular, at this point, there are already systems in which solid wood elements are joined together without glue or metal and thus also allow mono-materiality in the joining technology (Schuster & Geier, 2022b). Moreover, this progress enabling the use of large mass timber in complex projects, which is linked to the condition of prefabrication (Campbell, 2017). Prefabrication, characterized by assembling large-format elements, enhances the potential for reuse and therefore directly contributes to sustainability and CE (Schuster & Geier, 2022b). Additionally, prefabricated components streamline the construction process, offering time savings and avoid weather-dependent-on-site-set-ups, which makes the entire construction process more independent from external influences (Ahn et al., 2022; Komb, 2022). This prefabrication is part of a "modular-building-concept". The modular building concept involves constructing buildings from prefabricated modules. These modules are manufactured in a factory setting and then transported to the construction site, where they are assembled to form a complete building. This method is known for its efficiency, as it often results in faster construction times and reduced waste compared to traditional construction methods. Additionally, modular construction allows for greater flexibility in design and can significantly lower carbon emissions (Wang et al., 2021). In scope of CE view, it also has a generally higher deconstruct ability than traditional construction by its inherent manufacture and assembly characteristics (Ahn et al., 2022). Mass timber systems already align with many of the policy ambitions for the industry such as skills improvement, faster construction, and carbon dioxide reduction. The wider adoption of mass timber is therefore valuable in its own right as a market- ready option (Campbell, 2017). Yet not only policy ambitions align with mass timber construction, also construction and buildings are among the priority focus areas that offer the best opportunities to promote sustainable and CE-oriented public procurement in the future and the choice of material is crucial for this ambition (Husgafvel & Sakaguchi, 2023). Mass timber fits well into this model due to its renewable nature and the fact that it is often used in prefabricated constructions, making it a prime example of CE principles in action (Ahn et al., 2022). In fact, the findings from a multi-criteria decision-making analysis suggest that using dowel-laminated timber is the most effective choice for enhancing circularity in building construction (Ghobadi & Sepasgozar, 2023).

In the previous chapter, the cost uncertainty was mentioned, which is beyond question a challenge but while at present, a direct material unit cost comparison still puts those mass timber products at a slight disadvantage against steel and concrete, their renewable-based raw material and low carbon footprint of manufacturing and construction, provide key competitive edge against these traditional building industries also in economic terms (Ahn et al., 2022).

This section outlines the significant environmental advantages of implementing circular economy practices in wood construction, notably through cascading use and prefabrication. It emphasizes technological innovations that enable the utilization of mass timber in intricate designs, contributing to a reduction in CO2 emissions and raw material usage. Despite barriers like cost uncertainties, the chapter highlights the environmental and potential economic benefits of mass timber, suggesting its competitive advantage over traditional materials due to its sustainable nature and efficiency in construction.

4.1.4. Enablers to Circular Economy in Wood Construction

Nevertheless, the scope for action remains vast. It is necessary to have a legislative framework before trying to establish a new concept in an existing and fluid market. With the CE concept in wood construction many researchers find that there is still room for improvement. Formal institutions, such as legal rules and regulations, play a key role in motivating both companies and individuals towards a CE in the construction sector by supporting the coordination of stakeholders and potential beneficiaries to fully realize the advantages of a CE (Li, 2018). There is still a slow pace at which legal foundations and norms are established, which hampers the industry's move towards circularity. The market's pressure for sustainability could incentivize change, yet regulatory bodies are called upon to develop standards that promote the use of reprocessed materials, ensuring quality and performance (Ahn et al., 2022). Political demands regarding sustainability towards the building sector are increasing which is understandable in the topic of climate protection but it is also necessary to give those demands a standardised legal support. Standardization, alongside digital methods, is essential for creating new markets and facilitating resource knowledge sharing, driving the construction industry closer to CE goals (Weetmann, 2017).).

A majority of authors also mention the construction design as the next inevitable enabler of CE. Incorporating strategies for deconstruction and recycling/reuse, during the design and planning phases, opens broader possibilities for the end-of-life options for buildings and greatly affects the ease of deconstruction which is essential to the success of CE in projects (Ahn et al., 2022). Among all cascading scenarios, reuse has the highest priority and, most probably, maximizes the materials value (Niu et al., 2021). Reusing building components involves considering their longevity against technological advancements and ensuring they can be easily updated or replaced. For example, making facade or interior claddings easily separable allows for future updates or additions, providing a foundation for adaptive reuse (Mair-Bauerfeind & Stern, 2017; Schuster & Geier, 2022b).

The CE approach involves many players in the construction business and alongside the value chain. It requires collaboration among all relevant stakeholders, including general agreement on what circularity means and the support of technology development to promote deconstruction and disassembly (Gagnon et al., 2022). Architects need to actively adjust to the mentioned design necessities; engineers will need to accept reused timber as a standardised product and waste providers require better networks to customers for example in introducing pre-demolition audits (Campbell, 2017; Niu et al., 2021).

Experts raised that mandating building deconstruction does not in itself create demand for recovered materials (Gagnon et al., 2022). For wood cascading and future use of construction wood it will be an important task to build reasonable markets for these resources. To sustain those markets it is necessary to have reasonable prices for used mass timber that offsets the costs of disassembly and therefore avoid material quickly moving to use as biomass (Campbell, 2017).

Paving the way for a more circular future in the wood construction sector the enablers split in two different categories. The external influences like legal rules, regulations and a functionating market after deconstruction and the internal building factors regarding the design on how to reach reusability.

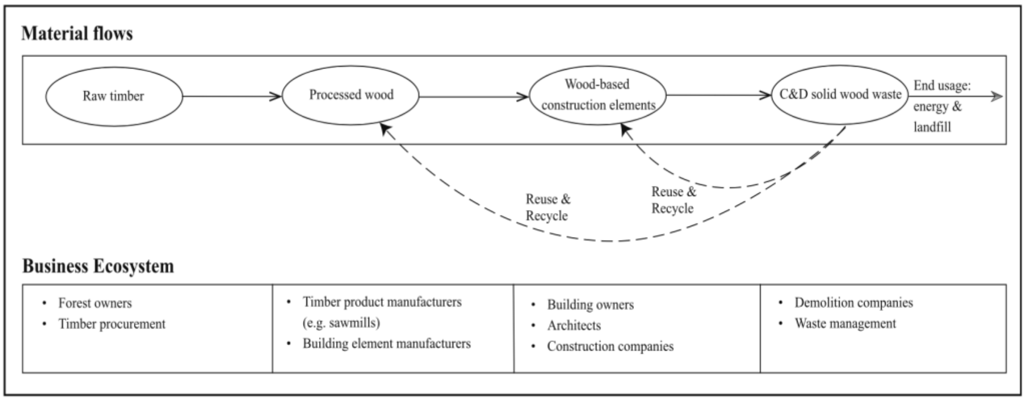

Figure 3: Conceptual framework of business ecosystem around the life cycle of Construction wood, the arrows with solid lines represent the current material flows, whilst the dashed arrows indicate the potential flows for wood reuse or recycling (Niu et al., 2021).

4.2. Wood Based Manufacturing

4.2.1. Benefits to Circular Economy in Wood Based Manufacturing

The Importance of CE in Wood Based Manufacturing starts with the forestry industry which builds the first step in the supply chain. The forest as provenance of the most abundant biodegradable and renewable material available needs to be scoped more intensively regarding CE (Araújo et al., 2019b). The forestry sector's contribution to climate change mitigation is maximized when forest management practices are aligned with the manufacturing and utilization of harvested wood products, considering their impact on forest carbon stocks (Gagnon et al., 2022). However, the prevalent use of wood for energy generation, constituting a significant share of biomass for renewable energy, raises concerns about its environmental implications, including deforestation and biodiversity loss (Holzer et al., 2023). This scenario highlights the need for a balanced approach that supports wood as a multifaceted resource in many supply chains but in respect of its regrowing but not infinite reservoir. So, it is imperative to keep products at their peak utility and build a circular solution with and around this promising resource (Holzer et al., 2023). The forestry sector is the first focus to a more circular approach, the following step is the actual wood manufacturing to different products and there are incentives especially for wood. Whereas CE is primarily seen as a mandatory solution to improve the environmental performance in the case of plastics, it is also considered as an opportunity to improve the economic performance in the case of wood. (Holzer et al., 2023). As the demand for wooden materials in various products and energy sources grows, alongside the critical need to curb pollution, there's a rising interest in enhancing their reusability, recyclability, and biodegradability (Holzer et al., 2023). The furniture industry, with its blend of large and small enterprises and a mix of modern and traditional craftsmanship, presents a prime opportunity for implementing CE practices (Nozharov, 2019). This sector, characterized by its resource and labour intensity and a fragmented supply chain, faces significant waste issues, with potential waste exceeding 50% when logs are used as raw materials (Hartini et al., 2021). An example for this is a study with furniture manufacturers in Brazil, the research discovered that the primary wood byproducts from the manufacturing are predominantly used by ceramic industries within the same local production area for combustion in industrial furnaces. This process generates the necessary heat for processing clay tiles (Ribeiro de Oliveira et al., 2017). Furthermore, the increasing demand for forestry raw materials in the furniture sector heightens the need for CE to enhance sustainability, reduce waste, and address the global competitiveness challenges (Nozharov, 2019).

In wood panel production, addressing the generation of wood solid waste, the emissions of toxic gases, and the generation of residual water can be considered. Giving this wide variety of waste the correct destination aims at avoiding possible environmental contamination and gives the company financial return. While new technologies have improved resource management in the previous linear model, its focus on consumption and disposal leads to significant production losses. This approach negatively affects raw material price stability, degrades natural ecosystems through ongoing extraction, and incurs economic losses (Araújo et al., 2019b). The potential for reusing 25% of wood waste from panel production exemplifies the opportunities within CE to transform waste into valuable resources (Araújo et al., 2019b). Furthermore, exploring wood waste or byproducts potential for cascading use is seen as a viable strategy to reintegrate them into the system.

It should be noted that there are many matching drivers for CE as in the wood construction industry, like the general eco effectiveness of wood or decoupling economic profit from resource depletion or environmental degradation, which are not specifically mentioned here, for the sake of avoiding repetitions.

4.2.2. Barriers to Circular Economy in Wood Based Manufacturing

As the wood based manufacturing industry contains a lot of small and medium sized enterprises (SME's), there are often no departments that coincidences with CE which explains a lack of access to knowledge and unavailability to technology. Furthermore, it is not common to share knowledge in this industry environment. In general, there is a lack of engagement of the industry due to a lack of green culture (Holzer et al., 2023). In wood based manufacturing, there is a noted tension in the design phase due to the rapid obsolescence of products, which complicates efforts to extend their lifespan and poses challenges for the remanufacturing process. Additionally, a notable imbalance exists in the innovation system where brand owners or change agents dictate design requirements, leaving manufacturers to navigate these directives. This dynamic underscore the complexity of aligning product design with circular economy principles, emphasizing the need for a more integrated approach to sustainability in the industry (Holzer et al., 2023).

More barriers stem from both political and managerial spheres, alongside market dynamics. A notable gap in political support, marked by insufficient incentives and limited awareness of CE's benefits, hampers change and diminishes stakeholder communication. This situation is compounded by a distinct absence of market demand for refurbished wood products, which is similar to the construction sector, indicating a broader strategic misalignment within the industry. Moreover, managerial hurdles, particularly for smaller firms, include bureaucratic pressures and a deficiency in sustainability focused marketing strategies, underscoring the critical need for enhanced managerial capabilities and market development for CE practices (Holzer et al., 2023).

In the wood-based manufacturing sector, barriers extend beyond legislative and operational issues to encompass consumer and customer-related hurdles. There is a noticeable lack of interest, acceptance, or trust among consumers, coupled with a reluctance to pay higher prices for sustainable products. Additionally, a significant gap exists in customer knowledge and awareness regarding the recyclability of products and the proper channels for their disposal and collection (Holzer et al., 2023).

The study occupied in Brazil found that the adoption of CE principles during the product conception stage is minimal, with a notable absence of using byproducts from other industries used in the furniture industry (Ribeiro de Oliveira et al., 2017). The traditional wooden furniture industry's reliance on outdated resource and production methods contributes significantly to waste, impacting environmental health. This sector often follows a linear model of 'take-make-consume-dispose,' leading to excessive waste that not only pollutes but also hampers the renewal of natural resources due to a general lack of environmental awareness (Susanty et al., 2020).

The wood panel industry stands out when waste is regarded, because panel manufacturing consists of several production stages, from log debarking to panel finishing, generating a considerable volume of waste, which is not given the correct destination for a more circular approach. In addition, toxic chemicals in the process are a significant obstacle to the realisation of CE, as it is difficult to manage hazardous material flows (Araújo et al., 2019b). Especially, the elimination of toxic chemicals, is vital for achieving a sustainable and regenerative economic model that prioritizes environmental and human health considerations (Zuin & Ramin, 2018).

The particleboard industry in depth encounters specific barriers within CE strategies. Energy recovery is a primary alternative, notably in heavy industries, while reuse and recycling, which are the more circular approach, are confined to niche markets. Particleboard faces limitations in reuse options, often requiring take-back programs and adaptable components for various product lines. A significant hurdle for particleboard recycling and lifespan extension is its susceptibility to wear and moisture damage, complicating repair and recovery processes as these materials typically end up mixed with other wastes, hindering their recyclability (Gagnon et al., 2022).

In case of cardboard boxes, the rise of e-commerce has increased the use of smaller corrugated boxes, which current recycling and reusing systems, designed for larger boxes, struggle to process effectively. This mismatch leads to material downcycling. The quality of recovered material is further compromised by mixed roadside collections and exposure to moisture, complicating the reuse of corrugated cardboard. Additionally, the recycling process's perceived ease may deter more beneficial reuse efforts, requiring intricate logistics. Lastly, the lack of coordination between waste generators, sorting centres and producers of recycled cardboard makes it difficult to maintain the appropriate level of quality and consistency across the supply chain (Gagnon et al., 2022).

The CE barriers of the wood based manufacturing industry vary through supply chain stages and go beyond the operational production and material use phase. Furthermore, they vary also in the different products which all have different characteristics, which makes it hard to find a common baseline to make this industry more circular.

4.2.3. Drivers to Circular Economy in Wood Based Manufacturing

The wood-based manufacturing industry approach to CE emphasizes knowledge exchange between academia and industry, replace the plastic industry as the main content of research (Holzer et al., 2023). Even with a lot of SME's in this industry, Green Image and a Corporate Culture that enhance innovation systems are becoming more popular. For example, flat hierarchies to create an innovative environment, transparent and comprehensible information (e.g., material flows) on the positive impacts of a CE which foster trust, and a positive reputation (Holzer et al., 2023).

Employee training and consumer awareness campaigns are key to fostering a green corporate culture, which includes transparent information to build trust and improve reputation. Recently, the shift in consumer demand towards bio-based products and the willingness to pay more for sustainability are driving industry changes which tend to be rising the more focus this industry sets to the communication of sustainable and circular products. Promoting CE as a competitive advantage is recognized as a key driver in the wood-based manufacturing industry, facilitating product differentiation through certifications or tax incentives. Furthermore, the advancement of CE is linked to a clearer understanding of its principles, regional benefits, and job creation, illustrating its integral role in industry development (Holzer et al., 2023). To go even further collaborating with customers to reduce waste and environmental costs while enhancing satisfaction will also reinforce CE practices (Susanty et al., 2020).

Adopting circular practices in the wood panel industry not only offers environmental benefits but also enhances financial outcomes. Companies are required to manage their waste responsibly. By implementing CE strategies, firms can profit from selling panel-production-waste as a resource or by recycling it themselves, reducing waste management expenses. This approach also fosters the development of new business relationships and networks, partnering with collection, disposal, and recovery centres along the supply chain, opening up avenues for innovative business models to transform wood waste into profitable, value-added products targeted at specific market niches (Araújo et al., 2019b).

Particleboard production serves as an important use for sawmill by-products, with efforts ongoing to reduce waste when manufacturing specific components like cabinetry or furniture from larger particleboard sheets (Gagnon et al., 2022). The environmental benefits are well shown by a study which conducted a life cycle assessment of polymer-based particleboard produced from recycled wood waste instead of virgin sources. This process spared approximately 70kg of CO2 on 1 ton of wood waste (Hossain et al., 2018). Especially within Particleboards not only wood offers room for manoeuvre, also the resin within these boards has some potential. Another study showed that the Melamine-Urea-Fomadehyde Resin, when compared to the Urea-Formaldehyde one presents a lower contribution to photochemical oxidation and human toxicity, and therefore is considered as a great replacement. Consequently, it can be said that this approach aims to contribute to the circular economy, since it is known that one of the greatest environmental impacts of wood panels is present in resin. Furthermore, replacing resin can allow for a more efficient recovery of materials at the end-of-life, which can lead to reuse opportunities and, thus, might diminish virgin material input (Araújo et al., 2019b).

Cardboard recycling is already very common, exhibiting high success rates. Additionally, advancements in pulp and paper mills have led to more energy-efficient operations and reduced resource use. This improvement is partly due to decreased basis weight in liners and corrugated mediums, achieved by incorporating dry strength additives (Gagnon et al., 2022). The recycling process for cardboard has been facilitated by the introduction of inks and adhesives that are compatible with repulping. This improvement means that cardboard's wood fibers can be recycled several times with minimal degradation in quality. Additionally, the limited use of tape on corrugated cardboard boxes further minimizes waste, making the recycling process more efficient. Moreover, recycling cardboard into the same quality material, rather than downgrading it, is more feasible when it's not combined with other types of paper waste. Boxes typically remain in excellent condition after one use and can undergo multiple reuse cycles prior to recycling, enhancing efficiency and sustainability in the process (Gagnon et al., 2022). Regarding the legislation the packaging industry exhibits a high Policy Readiness Level, with existing policies supporting recycling facility investments, expanded producer responsibility, and eco-design project funds for manufacturers. Additionally, new policies are being developed to ban specific single-use plastics and expand deposit refund programs, reflecting a proactive approach to environmental sustainability in this sector (Gagnon et al., 2022).

The furniture industry is a special case in the CE transition, as the design aspect must also be taken into account here. Operating within a market of monopolistic competition, the furniture industry emphasizes product differentiation, with design playing a pivotal role. The trend towards creating modular panel furniture facilitates the assembly of diverse and reusable furniture pieces. Such adaptability positions the furniture industry as a potential frontrunner in adopting circular economy principles, promoting sustainability and resource efficiency (Nozharov, 2019). The furniture study from Brazil offers concrete figures in terms of CE adoption, in the manufacturing process, 87% of companies are incorporating eco-efficient technologies such as environmentally friendly painting booths, high-efficiency wood-cutting machinery, and sustainable finishing chemicals. Additionally, 43.5% of these companies recycle liquid waste by reusing water in various industrial processes. A large majority of the companies has also been implementing cleaner production actions and increasing the environmental awareness of employees, even though they still do not have a consolidated methodology in the company (Ribeiro de Oliveira et al., 2017). Furthermore, the study discovered more initiatives that stand out of the supply chain and foster the CE approach in a community engagement. These initiatives include establishing and managing forests to boost local wood supplies, launching training programs for crafting handicrafts from industrial byproducts, and organizing leadership meetings to cultivate a cooperative culture among businesses (Ribeiro de Oliveira et al., 2017).

The Drivers in the wood based manufacturing industry highlight the increasing adoption of green practices and innovation driven by SMEs, the significance of creating a sustainable corporate culture, and the role of consumer demand in pushing for bio-based, sustainable products. The environmental and financial benefits of adopting circular practices in wood panel production, emphasizing recycling and waste management strategies that lead to new business opportunities. The advancements in particleboard production show that the CE approach is also extended beyond wood and is also applied to ancillary resources such as resin. The cardboard industry, which is more prominent than ever, due to high rates of online orders for example, has its already commonly used recycling optimized with only minimal degradation in quality and environmentally friendly adaptation of other resources such as tape. The furniture industry's move towards modular designs that support CE principles. Additionally emphasizes the importance of eco-efficient technologies, cleaner production actions, and community engagement in fostering a CE approach across the wood-based manufacturing sector.

4.2.4. Enablers to Circular Economy in Wood Based Manufacturing

In the quest for circularity within the wood-based manufacturing sector, the identification and establishment of strategic partnerships emerge as a pivotal enabler. The concept of wood based manufacturing, traditionally focuses on closed-loop systems. However, embracing open-loop chains that involve collaborations with other companies and industries presents a transformative potential with far-reaching benefits (Araújo et al., 2019b). Such partnerships not only facilitate the reuse and recycling of resources but also significantly contribute to the sector's transition towards a CE. Central to this evolution is the role of cooperation, especially its endogenous characteristic within the Linear Process Architecture. This intrinsic aspect of cooperation presents an invaluable opportunity for knowledge exchange among companies, thereby ensuring a comprehensive approach to addressing socio-environmental challenges pivotal to the CE framework (Ribeiro de Oliveira et al., 2017). Nonetheless, the effectiveness of these collaborative efforts is often hindered by a prevalent lack of information exchange, underscoring the need for open communication channels to bolster CE initiatives. Moreover, the concept of industrial symbiosis stands out as a key enabler in this context, fostering local exchanges and the optimal utilization of side streams (Holzer et al., 2023). This approach not only enhances resource efficiency but also promotes the integration of wood-based manufacturing with other industrial sectors, heralding a new era of sustainability and economic viability. Given the sector's already notable conversion efficiency, further advancements are likely contingent upon improved integration with other industries, particularly through industrial symbiosis projects. Such endeavors would unlock the value in currently underutilized resources, including harvest residues, smaller diameter trees, and non-commercial species, alongside waste heat and CO2 (Gagnon et al., 2022).

Innovative Wood Waste Management is another target to enable more circularity in the wood based manufacturing. Recognizing the environmental and economic benefits, the recycling of wood waste not only mitigates the consumption of vital resources such as water and energy in production processes but also transforms waste into a lucrative avenue through the creation of value-added products, emphasize the potential profitability in aligning waste recycling efforts with collection, disposal, and recovery centers across the supply chain, targeting specific market niches to capitalize on this untapped resource (Gagnon et al., 2022). A pivotal aspect of realizing this potential lies in the refinement of waste management policies. Currently regarded primarily as a concern of provincial and territorial jurisdictions, these policies could be enhanced by setting targets that focus on both the quantity and quality of recovered material. Such a dual-focus approach would act as a robust incentive for investing in recycling and composting infrastructure, aiming not only to elevate recovery rates but also to improve the usability of recovered materials (Gagnon et al., 2022). This is particularly pertinent in instances where source separation may prove more cost-efficient than enhancing sorting mechanisms at recycling facilities, thereby preserving the value of specific grades of material, like paper. Furthermore, the establishment of clear definitions for recyclability and compostability, alongside standards that detail the compatibility of recovered materials with various processing techniques, is crucial for optimizing material handling. This approach gains added significance in light of the anticipated influx of wood-based packaging solutions responding to consumer shifts away from certain single-use plastics. Ensuring that existing infrastructure can effectively process these new products is essential to avoid inefficiencies and contamination issues that detract from material value and necessitate additional processing capabilities (Gagnon et al., 2022). Addressing the competition between different applications of wood waste, such as its use for material recovery versus energy production, highlights the necessity for enhanced separation and processing techniques for mixed wood waste. This improvement is indispensable for making wood waste recycling not only viable but also scalable, thereby reinforcing the wood-based manufacturing sector's commitment to CE principles (Holzer et al., 2023).

The furniture industry has seen a surge in models such as product-service systems, sharing initiatives and strategies aimed at enhancing resource and energy efficiency. These models, which also include product life extension and sufficiency approaches, are not only crucial for conserving resources but also for reducing operational costs, thereby marrying environmental stewardship with economic viability (Holzer et al., 2023). Furthermore, the significance of fostering collaboration across the value chain cannot be overstated. Emphasizing the need for the wooden furniture industry to engage in proactive collaboration with both suppliers and customers. This tripartite synergy acts as a lever, enhancing the sector's capability to address and mitigate environmental impacts while steering towards economic sustainability. The collaboration extends beyond mere transactions, embedding environmentally conscious practices into the core of customer interactions and supply chain management (Susanty et al., 2020). The shift from a traditional linear economy towards a CE critically depends on heightened social customer consciousness. This essential awareness can be encouraged through various educational initiatives, including programs, campaigns, and seminars, which should be backed by public entities and receive endorsement from the industry sector (Ribeiro de Oliveira et al., 2017). The concept of Extended Producer Responsibility marks a shift towards holistic accountability, urging furniture manufacturers to extend their environmental stewardship beyond the point of sale. It highlights the necessity for the industry to transcend traditional practices such as reverse logistics, advocating for the creation of specific incentives and guidance tailored to the furniture sector. Such strategies not only align with regulatory expectations but also foster a culture of innovation and sustainability within the industry (Ribeiro de Oliveira et al., 2017). Lastly, the competitive and regulatory landscape, especially within the European Union, necessitates a reevaluation of material sourcing and utilization as there is considerable eco-dumping from competitors outside the EU (Nozharov, 2019).

The cardboard sector could achieve more circularity through better separation at the source or improved sorting technologies, preventing the contamination of cardboard with lower-grade papers. The sources also propose upstream reductions in packaging material and the exploration of reuse options in business-to-business contexts. Furthermore, identifying new applications for cardboard in the creation of durable products could advance sustainability efforts within the industry (Gagnon et al., 2022).

The journey towards a Circular Economy in wood-based industries hinges on embracing strategic partnerships, sustainable practices, and innovative recycling technologies. By prioritizing collaboration, extended producer responsibility, and material innovation, these sectors can markedly advance environmental sustainability and economic growth. These concerted efforts are crucial for realizing a more circular and sustainable future in wood-based manufacturing.

5) Discussion

The exploration of CE practices in wood utilization across the two contemporary industries reveals the complex interplay of drivers and barriers influencing their integration. Key drivers such as strategic partnerships, technological innovations, and policy advancements are central to promoting efficient and sustainable wood resource use. These facilitators are mirrored across both wood construction and wood-based manufacturing sectors, underscoring a universal commitment to sustainability, resource efficiency, and minimizing environmental footprints. Focussing on the construction sector the research emphasizes the embrace of technical innovations and the strategic incorporation of wood as a pivotal construction material, aligning seamlessly with modern building practices while also offering substantial environmental advantages as key drivers in this industry. On the other hand, cooperation along the supply chain and an effective circular waste management are the key drivers in the wood based manufacturing. However, the adoption of CE principles is not without its barriers, distinct challenges emerge when comparing the two industries, including construction sector-specific issues like building policies, product longevity and uncertainty in costs due to the absence of an established market. CE in wood based manufacturing faces varying hurdles throughout the different products, which are often connected to waste management in the production process and managerial hurdles in SME's.

This comparative analysis emphasizes the need for a collaborative, multi-sectoral approach to overcome barriers, suggesting that advancing research, refining industry practices, and shaping adaptive policies are essential for fostering a more circular and sustainable approach to wood utilization. Tailored strategies reflecting the unique characteristics and demands of each sector are pivotal, highlighting the necessity for sector-specific innovations and regulatory frameworks to leverage drivers and mitigate barriers effectively, thereby facilitating a successful transition towards a more circular economy.

However, this analysis is constrained by the available literature, focusing on studies published between 2016 and the present. Future research could expand this scope, incorporating more diverse perspectives and empirical studies to deepen the understanding of CE practices in these sectors.

6) Conclusion

Upon examining the integration of CE practices within the wood-based construction and manufacturing sectors, this study underscores their significant potential for promoting sustainability and resource efficiency. Strategic partnerships, technological innovations, and policy advancements are identified as key enablers, facilitating a transition towards more sustainable practices. Conversely, challenges such as regulatory constraints and inadequate information and resource handling pose barriers to full CE adoption. The discussion highlights the importance of tailoring strategies to the unique characteristics of each sector, advocating for collaborative efforts across industries to overcome these obstacles. The findings emphasize the need for continued research, industry adaptation, and policy support to fully realize the benefits of CE in wood utilization, contributing to environmental sustainability and economic growth.

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