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The Potential of Wood Construction Waste Circularity

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Abstract: Wood construction waste circularity presents enormous potential to significantly decrease total greenhouse gas (GHG) emissions in the European Union (EU). Latvia could become a frontrunner due to its historic relationship with forestry, wood construction practises and unused potential of the innovative application of wood. This research examines what the potential of "circular wood" in Latvia is, how ready the Latvian wood house construction sector is to engage in a circular economy and wood waste circularity and whether the legal framework is ready to support wood waste management in the country. This study presents a combined approach for systematic wood construction product circularity assessment that includes a review of existing EU and Latvian frameworks for construction and demolition waste (CDW) management and wood construction, a general analysis of wood waste recycling systems and technologies, a quantitative data analysis of construction waste management in Latvia and qualitative data analysis of the Latvian wood house construction sector, and interviews with a focus group of Latvian wood industry representatives. The Latvian scope has allowed us to clarify the pattern methodology and impact points to be replicated, tested and measured further on a broader scale, in other countries, or throughout the whole EU. The main findings reveal a potential life cycle assessment (LCA) verifying the circularity of wood and limitations of wood construction waste circularity in Latvia in terms of wood house construction industry readiness and a legal framework as well as overall social prejudices for circular construction. Findings indicate an overall awareness and level of willingness to participate and engage in the circular construction models among Latvians; however, proactiveness and support (legal and financial) is expected from the government and municipalities. The recommendations point towards improvements in wood waste data management, the wood construction sector and the overall impact on sustainable development goals.

Keywords: circular economy; waste circularity; construction wood; construction waste; wood construction waste; sustainable development

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1. Introduction

The traditional, linear economic development model is based on a take–make–consume–throw away society pattern. This model relies on large quantities of low-cost, accessible materials and energy. Meanwhile, the circular economy is a model of production and consumption which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products, keeping materials in the economic cycle for as long as possible. Thus, the life cycle of products is extended. In practise, it means reducing waste to a possible minimum. When a product reaches the end of its life, its materials are kept within the economy wherever possible thanks to reuse, refurbishment or recycling. Therefore, there are multiple benefits of the circular economy that can be pointed out when it comes to the environment as well as to reducing raw material dependence. Sustainability, circularity and the life cycle of products have become increasingly important to the more sustainable future. The sustainable development and the benefits of circularity can be very well assessed in the form of LCA; however, it goes beyond quantifiable measures and involves multiple business model factors and an operational mindset [1–3].

The built environment has a significant impact on different sectors of the economy, local jobs and quality of life, often underestimated or unseen by society and policymakers. The built environment has become the major contributor of greenhouse gas (GHG) emissions, generating 40% of annual global CO_2 (carbon dioxide) emissions [4]. Of those total emissions, building operations are responsible for 27% annually, while building and infrastructure materials and construction or carbon emissions that are released before the building or infrastructure begins to be used (hereafter referred to as embodied carbon) are responsible for an additional 13% annually. In the EU, the construction sector is responsible for over 35% of the EU's total waste generation [5]. Greenhouse gas emissions from resource extraction, the manufacturing of construction products, and the construction and renovation of buildings are estimated to contribute 5–12% of total national GHG emissions [5,6]. Decarbonising the sector is one of the most cost-effective ways to mitigate the worst effects of climate breakdown.

The global new construction floor area is expected to double by 2060 [4]. To accommodate the largest wave of urban growth in human history, an expected 230 billion m^2 of new floor area will be added to the global building stock, the equivalent of adding an entire New York City to the world, every month, for 40 years. Regions such as Southeast Africa are under the strongest pressure for new dwellings at an emerging pace. In Europe, North America and Asia, it is more about renovation, reconstruction and rebuilding due to the fact that space for expansion is limited.

Most global, regional and national initiatives and guidelines lean towards zero emission or net-zero construction approach. Achieving zero emissions from new construction will require energy efficient buildings that use no local fossil fuels and are 100% powered by local and/or off-site renewable energy. Construction emissions are considered in two scopes—embodied and operational emissions. Of these, embodied carbon plays a critical role, especially considering the new construction that is projected to take place between now and 2040. Unlike operational carbon emissions, which can be reduced over time with building energy upgrades and the use of renewable energy, embodied carbon emissions are locked in place as soon as a building is built. It is essential to handle embodied carbon now if zero emissions are to be achieved by 2040. Addressing build-related embodied carbon emissions is an important part of reducing the building and construction industry's carbon footprint. Achieving zero embodied emissions will require adopting the following principles:

- Reuse, including renovating existing buildings, using recycled materials and designing for deconstruction;
- Reduce, including material optimisation and the specification of low- to zero-carbon materials;
- Sequester, including the design of carbon sequestering sites and the use of carbon sequestering materials.

The principles mentioned above align with a circular economy approach in the construction industry and correspond to LCA.

The built environment in the EU requires vast amounts of resources and accounts for about 50% of all extracted material. Greater material efficiency could save 80% of the EU's GHG emissions from material extraction, the manufacturing of construction products, and the construction and renovation of buildings [5]. Just three materials—concrete, steel and aluminium—are responsible for approx. 23% of total GHG emissions. Targeted strategies and actions are required to endorse greater use of sustainable wood-based materials in the construction sector, which is the primary consumer of these materials.

Global, European and national policies promote a circular economy and use of wood construction materials. The EU is developing a 2050 roadmap for reducing whole life cycle carbon emissions in buildings, alongside a methodology to quantify the climate benefits of wood-based products and other building materials [7,8]. In addition, the New

European Bauhaus initiative [9] will provide support for innovations in wood construction. Engineered wood products, such as glue-laminated timber, laminated veneer lumber and cross-laminated timber, allow an increased use of wood in large scale construction [10–15]. Given that the market share of wood-based construction in Europe is below 10% [16], there is great development potential to reduce GHG emissions via the house construction sector [17].

In 2021 and 2022, a couple of EU countries, such as France, Denmark, the Netherlands and Sweden, have issued local climate, sustainability, circularity and waste management legislation, which refer largely to the construction sector and initiate a paradigm shift on demands that interest this study regarding wood construction and the use of ecological construction materials. In this regard, Latvian policymakers still delay to issue proactive regulations in the construction sector and apply rather soft actions. However, it is vital to mention that the Latvian Ministry of Economy and state administrative institutions, as well as non-governmental organisations and state capital companies, agreed to collaborate in promoting the production and use of wooden construction materials for building projects and construction products with high added-value in built environment, promoting sustainable construction and the growth of Latvia's economy, by signing the Memorandum of cooperation on promoting the use of wood in construction on 23 April, 2021 [18]. In addition, in order to promote the availability of low-cost housing, including low operating costs, ergonomics, ease-of-use and energy-efficiency, a demo project for a multi-apartment residential building based on modular wooden construction has been developed by order of the Ministry of Economics in 2022.

From a sustainability and circularity perspective, wood as a natural raw material offers several advantages over other building materials. The natural life cycle of wood begins in the forest, where trees grow by utilising solar energy and absorbing carbon dioxide, both of which are critical inputs for wood formation. The cycle persists through the conservative extraction of timber from sustainably managed forests, facilitating its utilisation across a wide spectrum of industrial applications. When incorporated into industry through cascading use, wood participates in the technical cycle, where it can be reclaimed either at the end of its initial service life or as residual material or by-products from manufacturing processes. In construction, wood can be employed in a variety of roles, either as integral components of buildings (e.g., structural frames, wall and roof sheathing, flooring, decking, window frames, and doors) or at various phases of construction activities (e.g., as foundation framework supports and scaffolding).

The renewable nature of wood, coupled with its conversion into useful products with relatively low reliance on fossil fuels, renders it less environmentally burdensome compared to materials like steel, masonry and reinforced concrete. However, these environmental benefits are realised only when the wood is sourced from forests or plantations that are sustainably managed and responsibly harvested [19].

The construction sector in Latvia (as in most of the EU countries) plays a pivotal role in the growth of the national economy, as it is one of the largest industries from the material consumption perspective [20]. Therefore, by increasing the demand for circular as well as sustainable construction materials and construction products produced from the local renewable natural resources or recycled, downcycled materials, the construction industry could endorse the pace at which Latvia achieves its sustainable development goals. Since the 2008–2009 crisis, the share of prefabricated (wooden) housing out of the total market share of single-family houses in the EU has remained relatively stable, consistently hovering around 15% [21]. However, lately, there has been a steady growth in demand for wooden housing; the number of loans issued for the construction of wooden houses has increased by approximately 25% according to the banking sector in 2021 [22]. Demand for wooden housing is likely to increase even more due to an increasing awareness about the impact of climate change.

The utilisation of wood in construction offers a more circular and sustainable alternative compared to conventional building materials. Wood possesses intrinsic advantages due to its natural origin, allowing it to be transformed into building components with minimal environmental impact. Structures incorporating wood demonstrate lower life cycle energy consumption and reduced CO_2 emissions compared to non-wood alternatives. The substitution of wood for materials such as steel or reinforced concrete in construction significantly lowers embodied carbon emissions. Furthermore, substantial carbon capture can be achieved within the built environment through the use of wood, provided that it is diverted from landfills at the end of a building's life. Wood usage in construction also leads to reduced consumption of fossil fuels and lowers embodied fossil energy within the built environment. Additionally, the reduction in greenhouse gas (GHG) emissions and the reliance on renewable bioenergy during wood product manufacturing further enhance its role in promoting circularity and sustainability. LCA is a useful methodology to verify the circularity of wood across the building's life.

An optimal pathway for circular wood use in construction would prioritise repair, refurbishment and repurposing at the end of the material's first service life. Recycling into alternative products would be a secondary option, as it typically requires additional energy and resources. Ultimately, energy recovery through biomass conversion would represent the final stage, pursued only when all other avenues for reuse have been fully exhausted. However, this idealised model of wood circularity remains largely unachieved in current practise.

In 2018, the EU-28 generated an annual total of 52.9 million tons of wood waste. Of this volume, 48% was associated with municipal solid waste (MSW), 38% related to construction and demolition waste (CDW), and the remaining portion originated from the wood industry. Within the CDW category, wood constitutes only 2–4% of the total waste in most countries [23–27], but reaches 25–30% in the Nordic countries where wood construction is dominant [28]. Wood is estimated to constitute approximately 7.5–11% of the municipal solid waste (MSW) stream [29]. Several reports provide insights into the management of wood waste within the EU. It is estimated that 31–35% of wood waste is recycled, primarily for the production of particleboard, while 33–34% is processed for energy recovery. The proportion of wood waste that is either landfilled, composted or incinerated without energy recovery ranges from 28% to 37%, although these disposal methods have been steadily declining across the EU [30]. An assessment of recovered wood from house deconstruction in Germany [31] found significant quantities of wood (26%) in appropriate condition for further application, with over 25% having potential for high-value secondary use.

In 2010, the United States generated 64 million tonnes of wood waste. Of this total, 22.5% was derived from MSW, 51.5% from CDW, and the remainder from yard waste, which includes woody trimmings from trees and shrubs [32]. More recent statistics [33] show a similar trend in wood waste in MSW, with 17% recycled, 16% combusted for energy recovery and 67% landfilled. The majority of wood classified as recycled was repurposed for use as animal bedding or mulch. Nearly all of the 27 million tonnes of CDW generated in 2018 was directed to landfills. However, an increasing volume of waste wood is being diverted for reuse through more than 900 retail ReStore20 facilities across the United States, operated by the non-profit organization Habitat for Humanity. In 2010, approximately 55% of yard waste was recycled, primarily for conversion into mulch or bedding [32].

The United Nations Committee on Forests and the Forest Industry, in their 2022 report [34] presented at the Geneva forum on circularity concepts in wood construction, reports the following: "Although wood use in construction offers substantial sustainability and circularity benefits, there is also additional innovation that is needed. Currently, waste from building deconstruction is not being recovered effectively. Designing for building adaptability or disassembly and effective material recovery needs to be accomplished to improve the circularity of wood in the construction sector. The data suggests that there is considerable room for improvement in wood recovery and recycling at the end of life of buildings. The greatest opportunity for improved circularity of wood in existing buildings is in the recovery and reuse or recycling of building demolition waste". Wood construction product circularity can support not only Latvia's climate goals, but also the EU's chances of reaching total GHG emission deduction by 55% by 2030 [35].

The present paper looks at the potential of wood construction waste circularity in Latvia within the context of global, regional and national circumstances. The research examines what the existing wood waste management systems and technologies are, what the potential of "circular wood" in Latvia is, how ready the Latvian wood house construction sector is to engage in circular economy and wood waste circularity and whether the legal framework is ready to support wood waste management in the country.

The research is based within the framework of the EU LIFE programme integrated project "Waste as resources in Latvia—Promotion of regional sustainability and circulation by introducing the concept of using waste as resources" (LIFE20 IPE/LV/000014) (LIFE Waste to Resources IP).

Following this Introduction section, the paper is structured as follows—Section 2 presents a general analysis of wood waste recycling systems and technologies. Section 3 overviews existing EU and Latvian frameworks for construction and demolition waste management and wood construction. Section 4 highlights the methodology used for the study of Latvian potential to implement the circular wood approach in construction. Section 5 summarises the findings, and makes suggestions for discussion.

2. General Analysis of Wood Waste Circularity Systems and Technologies

2.1. Circular Economy Principles for Wood Waste

2.1.1. Circularity of Wood Material

The adjusted circularity principles were introduced to express the hierarchy of options available at the end of the useful life of a building, called the "zero waste hierarchy" (Figure 1) and referred to as the "R circularity principles": rethink/redesign; reduce; reuse; recycle/compost; material recovery; residue landfilling; restriction [36].

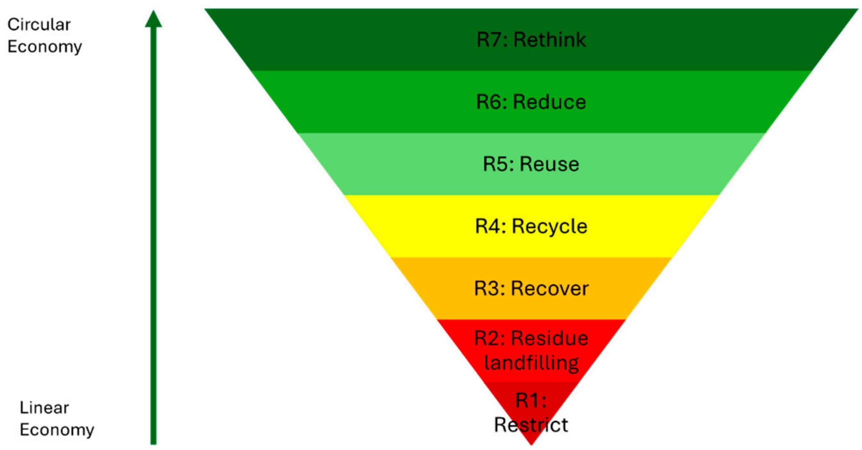

Figure 1. The zero waste hierarchy 8.0. *Source*: *by authors*.

Wood exhibits favourable performance as a building material compared to alternative options across several key dimensions. It is a natural and renewable resource, characterised by its lightweight yet high strength, allowing for the use of relatively low material quantities for structural applications. Additionally, wood demonstrates lower environmental impacts across various categories, including reduced emissions contributing to climate change [37]. With respect to its sustainability attributes, wood stores carbon during its service life, which in turn offers opportunities to transform buildings into so-called "carbon sinks". Wood is a natural carbon sink, as trees absorb CO_2 from the atmosphere through photosynthesis and store it in the biomass. Using timber and wood-based materials in construction, such as cross-laminated timber (CLT) and engineered wood products, can effectively sequester carbon for the lifespan of the building. It also provides extra motivation to keep wood longer into the lifespan, thereby supporting the circularity of wood and wood-based products. Circularity in wood construction refers to designing, building and managing wood structures in a way that reduces waste, minimises environmental impact and maximises the reuse of materials. In the context of wood construction, circularity can be achieved through several strategies, which are depicted in Figure 2 below.

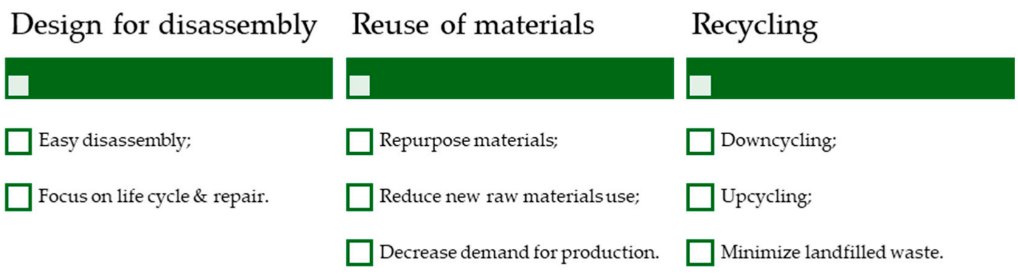

Figure 2. Circularity strategies. *Source: by authors*.

There are other aspects that contribute to circularity in wood construction. The initial use of sustainable materials, certified sustainable wood and other environmentally friendly materials reduces the environmental impact of buildings. Building with wood can also contribute to energy efficiency, as wood has excellent insulation properties, which can reduce energy consumption for heating and cooling.

Inefficient building design, in conjunction with the conventional linear economic model of production, utilisation and disposal, is one of principal causes of building materials ending up in landfills. With only one end-of-life option in mind, buildings end up being demolished or require complex and expensive renovation work, thereby generating considerable waste. The EU-funded BAMB (2015–2019) project fostered a paradigm shift where materials, components and buildings are conceived and evaluated based on effective circularity requirements and introduced the concept of "buildings as material banks" [38]. The concept of "buildings as material banks" (sometimes also referred to as "urban mining") refers to the idea that buildings need to be designed and constructed in a way that maximises the potential for materials to be reused, recycled or repurposed at the end of their useful life. Instead of treating buildings as disposable structures, this approach considers them as valuable repositories of resources that can be harvested and reintegrated into the construction and manufacturing processes. The concept corresponds to the principles of the circular economy, in which the aim is to minimise waste and keep materials in use for as long as possible. By designing buildings with disassembly and material recovery in mind, the potential for reuse and recycling increases, decreasing the demand for new materials and minimising the environmental impact of the construction sector.

2.1.2. Design for Disassembly

Circular design takes into account the potential end-of-life outcomes of a product. The potential strategies include prioritising material reuse through various methods. Materials can be repaired, refurbished or repurposed to prolong their functional lifespan. To facilitate these options upon reaching the end of a material's service life, modifications to its initial design or intended use may be necessary. Designing for disassembly is an approach to building design that aims to facilitate the disassembly and recycling of materials at the end of a building's life cycle. This approach is particularly important for wood construction, as wood is a renewable resource that can be recycled and reused many times. The key design principles for disassembly in wood construction include the following (Figure 3):

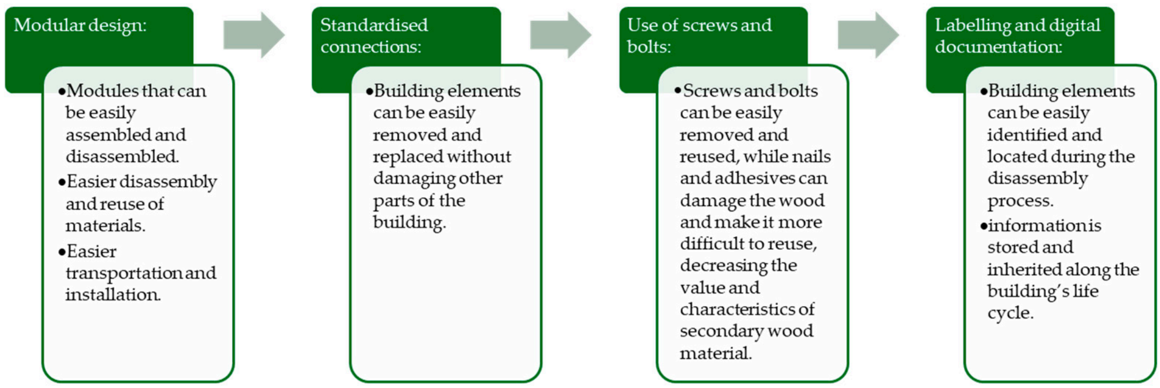

Figure 3. The key design principles for disassembly in wood construction. *Source: by authors*.

By making modifications in design and usage, deconstruction and reconfiguration can be facilitated to adapt to changing needs. If reuse is not feasible, the next step is to recycle the material into a new product. Should recycling be unfeasible, energy recovery through the material's use in thermal or electric energy production becomes a viable alternative. Disposal via landfilling, leading to eventual biodegradation, represents the lowest priority in the circularity hierarchy and should be avoided whenever possible.

2.1.3. Wood Waste Recycling Technologies

Wood construction material recycling technologies refer to the various methods used to recycle and downcycle wood waste generated during construction or demolition. Some of the most common technologies used for recycling wood construction materials are presented in Figure 4.

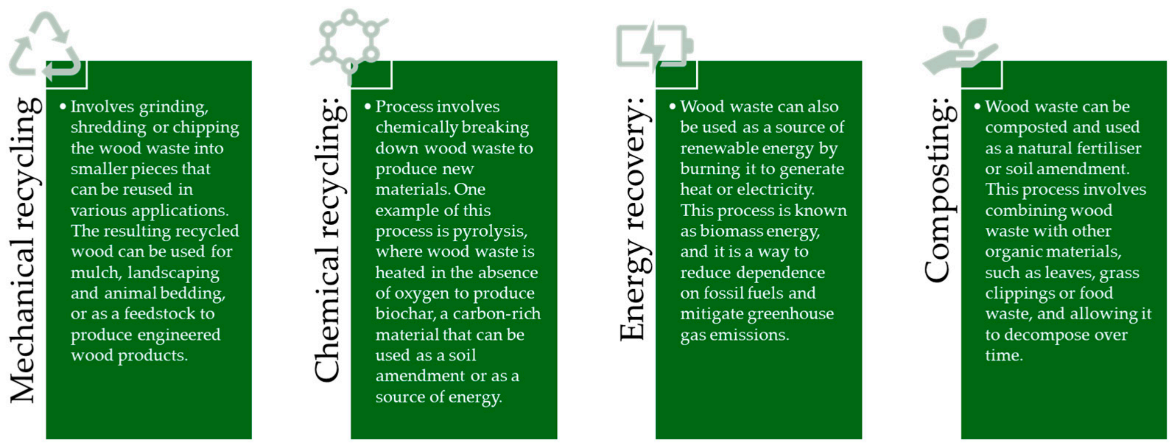

Figure 4. The most common technologies for recycling wood construction materials. *Source: by authors*.

The downcycling of wood waste refers to the process of recycling waste material into a lower-grade product than the original material. The downcycling of wood waste is often a less desirable option than recycling because it does not retain the original quality of the material. However, in some cases, downcycling may be the only option available for certain types of wood waste. In the case of wood construction waste, downcycling can involve the use of technology to convert the waste into products such as particleboard, fibreboard or mulch. Some common downcycling technologies for wood waste are depicted in Figure 5 below.

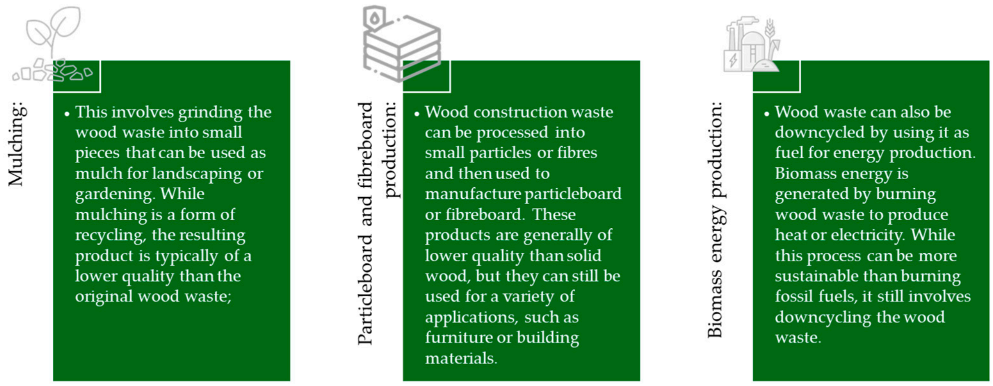

Figure 5. Downcycling technologies for wood waste. *Source: by authors*.

A wood waste recycling facility specialises in collecting, processing and recycling wood waste. The facility may accept a variety of wood waste materials, including construction and demolition debris, pallets, furniture and other wood products. The process for recycling wood waste typically involves several steps, including sorting, cleaning and processing. The wood waste is first sorted to remove any non-wood materials, such as nails, screws and other metals. The wood waste is then cleaned to remove any dirt or other contaminants. After sorting and cleaning, the wood waste is processed using mechanical recycling methods, such as chipping, grinding or shredding. The processed wood waste can then be applied to produce a range of products, such as mulch, animal bedding, composite materials and fuel for boilers or energy production. Wood waste recycling facilities may also use advanced technologies, such as chemical recycling or pyrolysis, to convert wood waste into biofuels or other valuable products.

The quality and purity of incoming wood waste is considered to assign the proper technology of recycling or downcycling. In many cases, wood waste consists of plenty of adhesives, chemicals or harmful impurities that cannot be separated or removed from the wood waste, and thereby cannot be recycled, downcycled or reused due to their toxic reaction.

2.1.4. Wood Construction Material Effects on Life Cycle Assessment

In principle, the sustainability of a building is assessed by quantifying its economic, social and environmental impacts across its entire life cycle. Life cycle assessment (LCA) is a well-established methodology used to measure the environmental impacts at each stage of a building's life cycle. This cycle begins with the extraction, production and transportation of raw materials, followed by construction, operation and maintenance, and extends through to demolition and waste management at the end of the building's service life [39]. Construction materials used in load-bearing structures, external walls and facades represent key "hot spots" for material impacts across most impact categories in building life cycle assessments (LCAs). Mitigating these impacts requires attention to the contributions of the most significant material flows—namely concrete, brick, ceramic, steel and timber—to the building's life cycle impacts. The environmental impacts associated with each of these materials are distinct and cannot be addressed by focusing on a single impact category or design aspect. While material efficiency may sometimes serve as a proxy for design improvements, a comprehensive approach is necessary to fully address the unique environmental impacts of non-metallic mineral, metal and wood-based materials.

Wood construction materials can have a significant impact on the LCA of a building. In Europe, good practise examples and solutions have been sought for a long time; this is related to the Waste Statistics regulation—a report on waste generation and treatment is submitted every second year. Unfortunately, the current accounting does not show a strict approach separately for wood waste from construction, because it is not shown whether wood waste from construction is reused or if any wood constructions or wood material is recovered [40–42].

The use of wood construction materials can affect the LCA in several ways, including the following:

- Carbon sequestration: Wood is a renewable resource that can sequester carbon dioxide from the atmosphere. This means that the use of wood construction materials can help reduce the carbon footprint of a building by storing carbon over its lifetime. Wood stores carbon during its service life, which provides an opportunity to make buildings so-called "carbon sinks" [43,44];
- Energy use: The production of wood construction materials generally requires less energy than the production of traditional construction materials such as concrete and steel. This can result in lower embodied GHG emissions and a lower overall environmental impact;
- Recycling and disposal: Wood construction materials can be easily recycled or disposed of in an environmentally friendly manner. Recycling wood can significantly reduce the volume of waste sent to landfills, while disposal in an environmentally friendly manner can help prevent pollution;
- Durability: The durability of wood construction materials can affect the LCA of a building. Wood that is properly treated and maintained can have a longer lifespan, reducing the need for replacement and minimising waste.

In the built environment sector, we can point to two scopes of CO_2, embodied carbon and operational carbon [45]. Embodied carbon emissions are those associated with materials and construction processes throughout the entire life cycle of infrastructure or a building. These emissions encompass the extraction of materials, transportation to manufacturers, manufacturing processes, transportation to construction sites, construction activities, and impacts during the use phase (e.g., concrete carbonation, excluding operational carbon), and extend through maintenance, repair, replacement, refurbishment, deconstruction, transportation to end-of-life facilities, processing, and disposal. Historically, embodied carbon emissions (also referred to as "upfront emissions") have been largely overlooked but account for approximately 11% of global carbon emissions. Emissions released prior to the operational phase of a building or infrastructure will constitute about half of the total carbon footprint of new construction from now until 2050, posing a significant risk of consuming a substantial portion of the remaining global carbon budget [45]. Statistically, without building sector engagement and changes, the share of embodied carbon is a constant [4,46]. Operational carbon emissions are associated with energy used to operate, manage and maintain the building or the operation of infrastructure, such as heating and cooling. Operational carbon is commonly addressed as efforts for high-performance or net-zero-energy buildings [45].

Most building life cycle assessments assume that the carbon sequestered in wood parts will be retained at the end of the building's life. However, if this assumption does not hold—such as in cases where wood materials are incinerated without energy recovery—the life cycle carbon advantage of wood compared to alternative materials is significantly reduced [47]. A study assessed net carbon emissions for a cross-laminated timber (CLT) multi-storey residential building under various end-of-life scenarios, including reuse of building components, recycling, incineration, incineration with energy recovery and landfilling. The findings disclosed that net emissions stayed negative in all scenarios (carbon storage exceeded emissions) except in cases of incineration without energy recovery. However, incineration with energy recovery reduced the CO_2 emissions benefit of wood to half of what it would have been with reuse or recycling. These results emphasise the importance of adhering to the hierarchy of circularity principles. Another study on this topic [48] reported a 22% life cycle emissions advantage for a CLT building compared to one made of reinforced concrete. However, this advantage decreased to 13% if carbon retention in the wood was not ensured at the end of the building's life. These findings highlight the critical importance of end-of-life management in achieving circularity goals.

Within the research, the author has pivoted to an applied study of wood construction product circularity in a decommissioned building at Tērbatas Street 10a, Valmiera, Latvia, owned by Vidzeme University of Applied Sciences, where LCA was conducted to verify the wood construction circularity in typical dwellings. Further articles on the findings will be published revealing the specifics.

3. Legal Framework Prerequisites for Wood Construction and Wood Construction Waste Management in European Union and Latvia

3.1. Overview of Existing European Union Framework for Construction and Demolition Waste Management and Wood Construction

The European Union has established several legal frameworks and regulations aimed at promoting circularity in the construction industry and reducing the environmental impact of construction waste. These frameworks and regulations provide guidance and support for member states, industry stakeholders and other actors involved in the construction industry to promote sustainable practises and contribute to a more circular economy. Some of the key legal frameworks and regulations in descending order include the following:

- Circular Economy Action Plan: In March 2020, the European Commission launched a new Circular Economy Action Plan [49], which includes several initiatives aimed at promoting circularity in the construction industry. These initiatives include the development of a voluntary certification system for circular buildings and the promotion of the use of recycled content in construction products;
- Circular Economy—Principles for Building Design: In February 2020, the European Commission launched the Circular Economy—Principles for Building Design initiative [50], the focus of which is to present a set of principles for the sustainable design of buildings with the aim to generate less construction and demolition waste, as well as facilitate the reuse and recycling of construction materials, products and building elements, and help reduce the environmental impacts and life cycle costs of buildings;
- Strategy for the sustainable competitiveness of the construction sector and its enterprises (Construction 2020) [51]: The EU Construction and Demolition Waste Protocol and Guidelines [52] was introduced as a non-binding guideline within the Construction 2020 strategy and within the Communication on Resource Efficiency Opportunities in the Building Sector [53];
- Waste Electrical and Electronic Equipment Directive (2012/19/EU) [54]: This directive requires member states to establish systems for the collection, treatment and recycling of electrical and electronic waste, including waste generated by the construction industry;
- Packaging and Packaging Waste Directive 94/62/EC [55]: This directive sets out measures for the prevention and management of packaging waste, including wooden packaging materials. The directive aims to reduce the environmental impact of packaging waste by promoting the use of reusable and recyclable materials, and by setting targets for waste reduction and recovery;
- Construction Products Regulation (EU) No 305/2011 [56]: This regulation establishes harmonised rules for the marketing of construction products in the European Union. The regulation requires manufacturers to declare the environmental performance of their products, including their impact on the circular economy. This includes wood construction products;
- Waste Framework Directive (2008/98/EC) [57]: This directive sets out a framework for waste management in the European Union. The directive requires member states to establish waste management plans and take measures to prevent and reduce waste, including construction and demolition waste. The directive encourages the use of waste hierarchy principles, which prioritise waste prevention and minimisation, followed by reuse, recycling and energy recovery;
- Landfill Directive (1999/31/EC) [58]: This directive aims to reduce the amount of waste sent to landfills in the European Union. The directive requires member states to

take measures to prevent or reduce the landfilling of waste, including construction, demolition and wood waste.

Other EU legal frameworks and regulations aimed at promoting sustainable wood management and management of wood waste include the following:

- Timber Regulation (EU) No 995/2010 [59]: This regulation prohibits the placing of illegally harvested timber and timber products on the European market. It requires operators to exercise due diligence in ensuring that the timber they place on the market is legally harvested and traded and includes provisions for monitoring and enforcement;
- Industrial Emissions Directive (2010/75/EU) [60]: This directive regulates emissions from industrial activities, including wood processing activities. The directive sets out emission limit values and promotes the use of the best available techniques to minimise the environmental impact of wood processing activities;
- European Waste Catalogue (EWC) (2000/532/EC2) [61]: It is a standardised coding system for waste classification in the European Union. The EWC provides a common language for waste management and facilitates the tracking and monitoring of wood construction waste.

EU initiatives for further support and endorsement of wood construction and wood waste management include the following:

- EU Guidelines for the waste audits before demolition and renovation works of buildings [8]: This document offers guidance on best practises for assessing construction and demolition waste streams prior to the demolition or renovation of buildings and infrastructure, a process referred to as a "waste audit". The guidance aims to facilitate and maximise the recovery of materials and components for beneficial reuse and recycling during demolition or renovation, while ensuring compliance with the safety measures and practises outlined in the European Demolition Protocol, as part of the Construction 2020 strategy;
- Level(s)—A common EU developed framework of main sustainability indicators for office and residential buildings [62]: Developed as a common EU framework of main indicators for assessing the sustainability of residential and office buildings, Level(s) can be applied from the early stages of conceptual design to the projected end of life of a building. Besides environmental performance, it also enables other important related performance aspects to be assessed using indicators and tools for health and comfort, life cycle costs and potential future risks to performance. Level(s) aims to provide a common language of sustainability for buildings. This common language can enable actions to be taken at the building level that can make a clear contribution to broader European environmental policy objectives;
- New European Bauhaus [9]: This initiative aims to promote sustainable and inclusive design, with a focus on the built environment. As part of this initiative, there is a specific focus on promoting the use of sustainable materials, including wood, in construction. Wood is seen as a particularly promising material for sustainable construction, as it is renewable, biodegradable and has a lower carbon footprint than many other construction materials;
- Forest-based Sector Technology Platform [63]: This is a European research and development platform that aims to promote innovation in the forest-based sector, including the use of wood in construction. The platform supports research and development projects, provides networking opportunities for stakeholders and promotes sustainable forest management practises;
- European Innovation Partnership on Raw Materials [64]: This is a platform that brings together stakeholders from across the raw materials value chain, including the forest-based sector. The partnership aims to promote sustainable raw material use, innovation and resource efficiency, including in the use of wood in construction;

- LIFE programme [65]: This is a funding programme for environmental and climate action projects in the European Union. The programme provides funding for projects that promote sustainable resource use, including in the forest-based sector and in the management of wood waste;
- Horizon Europe [66]: This is the European Union's funding programme for research and innovation. It provides funding for research and innovation projects in a range of areas, including sustainable materials and waste management;
- Interreg Baltic Sea Region [67]: A Programme 2021–2027 includes several priorities that support sustainable construction and circular economy principal integration in the public and private sectors. One of such projects within Priority 2 is the non-hazardous city project (NonHazCity 3) that helps municipalities, entrepreneurs and individuals construct and renovate buildings with tox-free materials in order to protect their health and the environment [68].

3.2. Latvian Framework for Construction and Demolition Waste Management

The legal framework for construction and demolition waste (CDW) management in Latvia includes several laws and regulations aimed at promoting proper waste handling and environmental protection. However, ambiguity exists among stakeholders about how CDW regulations should be applied and about responsible parties and reliabilities, as uncovered in a construction waste management stakeholder survey, which included experts from construction administration departments, inspectors of the state environmental service and others [25,27].

Some of the key CDW regulations in Latvia include the following:

- The Waste Management Law [69]: This law sets out the general framework for waste management in Latvia. It includes provisions related to waste classification, collection, transportation, treatment and disposal. The law also addresses waste prevention and recycling. The regulations of the Cabinet of Ministers were issued on its basis;
- The Construction Law [70]: This governs the construction sector in Latvia. It includes provisions related to waste management during the construction process, including the responsibility of construction companies to handle and dispose of construction waste in a proper and environmentally friendly manner;
- The Environmental Protection Law [71]: This law sets out the legal framework for environmental protection in Latvia. It includes provisions related to waste management, pollution prevention and environmental impact assessment;
- Cabinet of Ministers Regulations (referred to as MK regulations) [72]: The Cabinet of Ministers has issued several regulations that provide more detailed guidance on construction waste management.

In January 2021, the Latvian Cabinet of Ministers approved the state waste management plan for 2021–2028 [73], which includes provisional actions towards sustainable CDW management system establishment. Main references from the state waste management plan for 2021–2028 regarding CDW management system establishment include the following:

- Reach at least 70% by weight of non-hazardous construction debris and CDW prepared for reuse, recycling and other material recovery, including backfilling;
- Support the reuse of construction materials in construction processes (inclusion in Green Public procurement and standards);
- Promote and popularise construction practises that decrease waste and use efficiently as much waste as possible in the construction process (e.g., training, inclusion of criteria in competitions for the best building or awards for the most environmentally friendly building);
- Mostly addresses the preparation for recycling and energy regeneration of CDW material;
- Five (5) waste management regions with a waste landfill and deposit facility.

According to the plan, concrete actions to promote wood CDW management system establishment were outlined:

- Until 2021: Development of the necessary regulatory base for turning waste into resources and for reuse, including CDW;
- Until 2023: Transformation of the State Information System for accounting for waste transportation (APUS) into a complex information system for accounting for and controlling waste flows;
- Until 2027: A pilot project for assessing the possibilities of processing wood waste (especially emerging from construction and household waste) by adding substances synthesised from other waste types and developing new products with higher added-value and suitable for long-term use.

Regulations and state management frameworks were developed for wood construction waste management in Latvia. The main regulation is the "Procedure for ending the application of waste status to chips, shavings and dust obtained from wood packaging or certain types of wood construction waste" [74]. Thereafter, in the sense of these regulations, chips, shavings and dust obtained from wood packaging, from certain types of wood construction waste or from wood waste obtained from wood mechanical processing processes (referred to as wood waste) are considered secondary raw materials. A certain type of wood construction waste in the sense of these regulations shall be considered to be wood waste generated during the construction process by dismantling wooden structures, including moulds, racks and scaffolding.

Beyond the legal framework, a few initiatives and guidelines have been developed in accordance with EU initiatives and guidelines with the support of various grant programmes, as well as public and private funding. The recommendations for sorting construction waste on construction locations for commercial projects and public construction projects have been developed by the Latvian Construction Association (Latvijas Būvuzņēmēju apvienība, LBA) within the framework of the European Commission's LIFE Integrated Project "Waste to Resources Latvia—boosting regional sustainability and circularity" (Life project) [75] based on the document of the European Commission "Circular economy—Principles for Building Design" [50]. The aim of the guidelines is to provide knowledge and practical support in the construction of buildings based on circular economy principles, maintenance, renovation and demolition, as well as buildings and management of the construction field, both in Riga and other Latvian municipal departments, institutions, capital companies, procurement specialists and others in the field of construction, such as existing and future specialists, as well as to the general population. Guideline development was ordered by the Riga municipal agency "Riga energy agency" as part of URBACT III 2014—2020 funding [76] within the project "Transition to circular economy in urban construction (URGE)" [77] and prepared by diverse team of professionals.

LBA has identified key areas for improvement in real estate, design, construction, and construction waste management processes. In collaboration with local government procurement experts, construction professionals, construction material manufacturers, construction waste managers, and public authorities responsible for construction and environmental protection, the following requirements have been outlined to enhance the efficient circular management of resources [78]:

- Common practises for the use of recycled materials in construction;
- Lacking regulations for the end-of-waste status of mineral construction waste;
- Up-to-date information on potential market for secondary resources;
- Up-to-date information on construction waste recycling possibilities and capacities;
- Audit procedures for accounting of resources in dismantling of buildings;
- Financial means or incentives to use secondary resources.

At the conclusion of the Life Waste to Resources IP project [75] research phase, the LBA developed conceptual-level schemes and defined processes for fostering the circulation of construction products and CDW in the construction works of public and commercial buildings. Considering the general requirements of the regulatory frameworks of the EU and Latvia, the in-force regulations, as well as examples and good practises from other countries, principal schemes of six processes that correspond with the Latvian situation have been developed for the following stages of the construction products and CDW circulation:

1. Real estate development;
2. Feasibility study;
3. Design phase;
4. Construction;
5. Waste management, including transportation, storage and processing;
6. Production.

According to the report [78], full-fledged, functioning circular construction products and a CDW system in Latvia require the following:

- Regulation of the end of waste (EoW) for the CDW to be collected separately, according to Article 20, Part 7 prim of the Waste Management Law [69];
- Methodology for determining the volume–mass ratio, as well as waste codification;
- Clear, unified procedure for testing secondary raw materials, properly documented and safe, so that the circulation process can be proved;
- The competence of the experts for the correct implementation of all six processes;
- Technical regulation for construction works, facilitating use of secondary raw material or CDW-recycling material;
- General comprehension of the market participants about sustainable construction solutions and materials.

According to information requested by the LBA to The State Environmental Service (SES) of Latvia, in existing data systems there are no publicly available, structured, up-to-date data on the types of recycling available for construction waste and technological capacities. Accordingly, the building merchant does not have access to current data to evaluate and provide the most economically advantageous construction waste management process that would meet the requirements while developing the Work Organization Project (DOP) and the Work execution project (DVP). Such tasks must always be addressed from the beginning of DOP and DVP development. The main problems in Latvia with CDW management identified by parties at the Life Waste to Resources IP project [25,27] by the end of 2022 are as follows:

1. Unclear interpretation of legislative acts;
2. Unclear division of responsibility for monitoring the process;
3. A lack of mutual understanding among construction industry professionals about the further use of the second-hand materials (construction waste);
4. A lack of awareness (in a lot of cases, intended lack of awareness) among society at scale about proper management of construction waste (including repairing, renovation and reconstruction works).

Methodology of the Study of Latvian Potential to Implement Circular Wood Approach in Construction

Methods:

- Quantitative data analysis of construction waste management in Latvia and qualitative data analysis of the Latvian wood house construction sector;
- Qualitative data analysis and interviews with a focus group of Latvian wood industry representatives.

In order to understand the potential of wood construction waste circularity, the authors analysed primary data provided in the Life Waste to Resources project, which included a survey of 2005 respondents (permanent residents of Latvia between the ages of 18 and 75) on their construction waste habits (November 2022); a municipality survey with 25 respondents (November 2022); focus group interviews with waste management system shareholders responsible for construction waste in the municipalities (2022–2023); and a survey of 20 municipality procurement experts.

Considering that primary data provided by the Life Waste to Resources project regarding wood construction waste were insufficient for reference, the authors performed one (1) primary survey of Latvian wood construction companies (manufacturers) with 20 respondents to determine the level of understanding of "circular wood" opportunities, the existing practises of wood waste management and opportunities and threats for wood construction waste circulation implementation among the Latvian wood construction industry stakeholders; and one (1) focus group with three wood construction industry stakeholders to validate the results of the survey, as well as to share opinions on industry readiness to take up wood construction waste circularity potential in Latvia. The authors visited three (3) wood house construction (manufacturing) companies during the period of the study. The data gathering was performed in April and May 2023.

In order to evaluate the readiness of Latvian municipalities, the authors considered two (2) quantitative data sets produced within Life Waste to Resource IP project activities, and the authors organised a panel discussion within the monthly meeting of the Latvian Union of Local Governments on 12 May, 2023 (Forum for Latvian municipal decision-makers, at which the goals of European climate neutrality have been avoided in the development of wood construction in Latvia), to validate the results and gather qualitative opinions for conclusions and recommendations. The Life Waste to Resource IP C2 activity team conducted a more generic survey of 25 municipality respondents from various departments, and focus group interviews in 2022–2023 regarding construction waste management in general were analysed in the context of the survey in order to understand the general perspective of the construction waste management systems in the Latvian municipalities and prevent the release of household CDW in nature.

The Association of Latvian Construction Contractors (LBA) conducted another survey of 20 municipal procurement specialists in December 2022 within the LIFE Waste to Resources IP project. The project was implemented with the financial support of the LIFE programme of the European Union and the State Regional Development Agency. The purpose of the survey was to understand the opinions of public sector buyers of construction works and the existing practises in the organisation in the orderly development of real estate and in the stages of design preparation or research.

4. Results

4.1. Readiness of Latvian Society

The main findings from the public survey, carried out by researchers in November 2022 [25,27], that were applicable to the issues of wood construction waste management are as follows:

- According to the results of a survey of Latvian citizens, slightly more than two-thirds of respondents (67%) have carried out repair or construction in their household in the last 5 years, which resulted in generation of CDW.
- In the last 5 years, 47% of respondents have carried out repair and/or construction work in their apartments, compared to 36% in private houses and 6% in summer houses.
- Summer houses as well as private houses in Latvia are mostly constructed from wood and wood-based materials [79].
- Most respondents (73%) who have carried out repair or construction work in their household in the last 5 years, which resulted in generation of CDW, did not carry out work that required approval from the building authority. In total, 17% of respondents made an agreement with the building authority for those works that required it, but 3% of respondents indicated that the works were only partially coordinated with the building authority; not all works that required approval were agreed upon. A total of 7% of respondents stated that they do not know whether the works performed required approval from the building authority.

- The most common type of waste generated during repair or construction works were cardboard and paper (61%). A large proportion of respondents also indicated timber (46%).
- Most often, respondents discarded repair and construction waste by throwing it into the unsorted household waste container (34%) or burning waste (29%). Respondents also tended to get rid of repair and construction waste by taking the waste to the landfill via waste management company, providing a special container for construction waste (19%), to the landfill themselves (16%) or to a company or private person that they found on the Internet or through the recommendation of others (16%). A total of 14% of the respondents got rid of the CDW by using it to strengthen the road, and 10% used it for backfilling. Respondents also got rid of repair and construction waste by taking it to the landfill with special construction waste bags (6%), selling it (4%), burying it (3%) and throwing it in a forest, quarry, ditch or similar places (1%). A total of 17% of respondents stated that the waste (or part of it) was still stored with them.
- A little less than two-thirds of respondents (63%) had sorted the CDW for disposal, for example, to reduce costs. However, almost one-third of the respondents (31%) did not sort CDW and 10% knew that sorting could reduce costs and 20% lacked this knowledge.
- Repair and construction waste was sorted more often by respondents who carried out repairs in a private house and summer house/garden house, as well as respondents living outside of Riga.
- Considering the higher probability that wood and wood-based CDW was sorted indicates potential to take part in wood product circularity.
- In total, 41% of the respondents believed that there was a considerably high possibility that the leftover materials after repair or construction works would be offered to others on a special portal. However, one-third of respondents (33%) indicated that the likelihood of offering leftover repair/construction materials to others was generally low or minimal.

A few findings indicate general awareness and willingness to participate and engage in a circular construction model:

- More than half of respondents (58%) would be ready to use recycled construction waste material in construction. A total of 19% of respondents would not choose this option. It can be observed that men and younger respondents would use recycled construction waste material more often in construction.
- The majority of respondents (89%) believed that giving a "second life" to construction waste is essential and reduces the use of natural resources. Only 5% of respondents had an opposing view.
- In total, 45% of respondents showed readiness to pay a higher price for the removal of household repair or construction waste, knowing that it will in no case be thrown into nature and will be recycled for the production of new raw materials or building materials. However, 38% of respondents were not ready for an increased price for the service. The readiness mostly correlated with younger age and higher income.
- The overwhelming majority of respondents (91%) stated that a state support programme is generally necessary in Latvia to help citizens get rid of dangerous repair and construction waste with lower costs [25,27].

Proactiveness and both legal and financial support is expected from the state and municipalities, which might endorse or suppress the potential for construction waste circularity in general.

4.2. Readiness of Latvian Municipalities

The survey was conducted to collect the opinion of municipalities on household CDW. The authors address some of the aspects of the survey's findings that relate to the CDW circularity understanding in general regarding the potential of wood construction product circularity.

The surveyed municipalities believed that most construction waste problems in nature lie in how households manage the construction sites, which they considered to be a bigger problem compared with objects of legal entities, and pointed out that there is a significant lack of understanding of how to handle household construction waste. The expenses to manage waste properly were also too high in their opinion.

When asked "What do you think are the main obstacles preventing the use of construction waste in recycling and reuse?" (Question 12), respondents thought that the majority of CDW cannot be reused or recycled or there is no structure and system to do so due to the CDWs being of various sorts; expensive waste management; the legal barrier for "end of way" (EoW) status and the reuse of CDWs as materials; "out of date" practises in the construction industry; and reluctance to adopt and adapt for more sustainable means.

The survey conducted by The Association of Latvian Construction Contractors (LBA) included seven questions regarding the organisation of the procurement of construction works and whether procurement processes foresee research tasks that contribute to the circular economy, such as:

- Material audit before dismantling;
- Evaluation of construction methods to promote efficient demolition and reuse of resources, as well as construction waste management at the end of the building's life cycle;
- Reduction in the use of natural resources;
- Promotion of the use of materials and building systems that use recycled or reused components;
- Evaluation of the planning of the building to enable the flexibility of its functions (potential change of purpose of use in the future).

In regard to this study, the authors analysed responses in the context of the potential effects on wood construction product circularity, considering whether and if the public sector is aware of construction circularity and willing to engage in it, searching for arguments to support wood construction and as such, building from wood in public procurement.

In the first question, "*Does your organisation evaluate any of the following aspects when purchasing design and/or construction services?*", the authors looked at how many respondents picked the following multiple-choice options, indicating Latvian public sector (municipality) readiness for wood construction product circularity. In total, 50% of respondents showed readiness to support construction circularity; of these, 44% of respondents indicated potential to support wood construction product circularity in public procurement. The other 6% included other circularity aspects that are not directly related to wood construction product circularity. In contrast, 50% chose the option "*does not evaluate any of the mentioned aspects*". The survey results, however, do not consider respondents' interpretations of the multiple choices offered and the authors are not aware if respondents would consider wood products and systems in the context of given choices.

Only 6 (30%) out of 20 respondents actually perform a "circularity study" in construction procurement, either in-house or outsourced, when answering the second question, "*How does your organisation conduct research before procurement of construction works, which would promote circularity?*". In addition, only three respondents (2%) from those who performed a circularity study did so in the preparation phase of procurement, before finalising procurement documentation, which allowed more flexibility and decisional operation to support circularity. Another three (2%) mentioned that a circularity study was included in the technical specification of procurement (third question). In contrast, 55% of respondents did not include a circularity study at all during construction procurement.

Only one (<1%) respondent noted that "*To ensure most effective circularity study research*", the competency should be part of the public procurement team. A vast majority of 15 respondents (75%) answered that "*such a task should be provided in the design and/or construction procurement specification and should be provided by the contractor*". Another 24% would outsource the task or delegate it to a special construction procurement department.

The vast majority—19 (99%)—of municipal procurement specialists surveyed rely on compliance with legal framework requirements and do not implement specific requirements for the sorting of construction waste in the procurement of construction works (fifth question). Thus, the legal framework clarity and directness regarding wood construction product circularity in construction would work as a "top-down" force with the necessity to comply.

4.3. Readiness of Latvian Wood Construction Industry

The main findings are drawn from surveys and interviews with Latvian wood construction companies (April–May 2023). During this period, 20 respondents from the Latvian wood house construction and manufacturing sector submitted their answers to a survey that was structured in three following parts:

1. Information about the company (two questions);
2. Wood house (product) specifics and potential for circular wood effect on LCA (six questions);
3. Circular economy solutions in the company (three questions).

According to the data of the Latvian Wood Construction Association, there are around 100 wood house construction companies in Latvia; however, no precise data were gathered to monitor establishment of new companies on a yearly basis. As such, the authors assume that the survey results represent between one fourth and one fifth of the Latvian wood housing market. The majority of surveyed manufacturers of wooden buildings create products in the price range up to EUR 100,000 (Figure 6). In this category of buildings, there are summer houses, garden houses, tiny houses and cabin houses with a living area of 20–45 m^2.

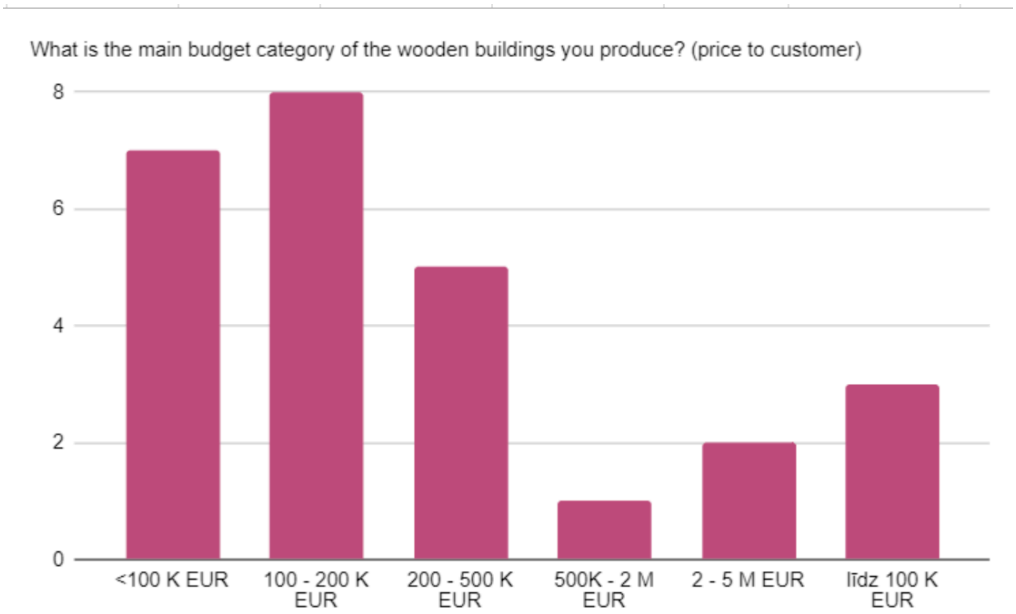

Figure 6. Budget categories of buildings produced by respondents; wood house construction company survey, April–May 2023.

The majority (50%) of surveyed manufacturers believe that buildings should last more than 50 years or at least 10–50 years (45%), leaving only 5% of respondents believing in a short lifespan (Figure 7).

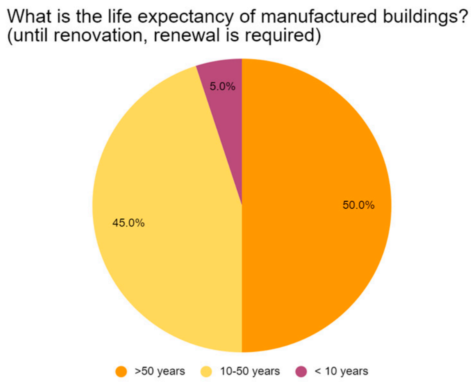

Figure 7. Life expectancy of wood buildings produced by respondents; wood house construction company survey, April–May 2023.

However, when questioned about actual warranties offered to clients, a vast majority (77.8%) of respondents (manufacturers) provide only up to a 5-year guarantee, and only a few respondents provide more than a 10-year warranty on a wood house building (product) before it needs renovation and/or reconstruction, as seen in Figure 8.

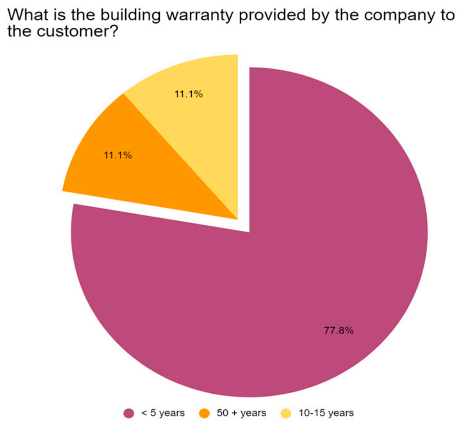

Figure 8. Warranty period of wood house buildings (product) provided to clients by respondents; wood house construction company survey, April–May 2023.

Respondents were asked about the application of modular design principles; engineered connections between building elements (screws and/or bolts), which refer to the means of easy/difficult building disassembly; and the means and composition of material layers in building parts, use of adhesives and chemicals, fusible roofing materials and other options that would indicate whether it is easy or difficult to further reuse or recycle wood products used in a building product produced by a manufacturer.

The overview of materials other than wood used in the construction of wooden buildings and their intensity of presence is presented in Table 1. Other wood-based products (e.g., wood fibre) (29%), wool type materials (rockwool, glass wool, etc.) (24%) and plastic/membranes (22%) are most commonly used in building parts. Other wood-based materials and wool type materials can be reused in production; however, plastic/membranes are complex polyurethane hybrids that are not possible to recycle and most probably end up disposed. The authors note that respondents might have a wide interpretation of the meaning of “other wood-based products (e.g., wood fibre)” option. Buildings with wood fibre insolation are considered premium level and were not commonly requested by focus group interviews with experts.

Table 1. Materials other than wood used in construction mentioned by respondents; wood house construction company survey, April–May 2023. *Source: by authors*.

Materials	Times Mentioned	% of Total
foam materials decorative plaster limestone, clay industrial wool plastic/membranes fusible roofing materials other wood based products (e.g., wood fibre) other: straw, sheep wool, hemp, organic materials, schindels	0 4 3 15 14 18 1 2	- 6 5 24 29 2 3

In order for wood products, materials and building parts to be reused or recycled, it is essential that the material contains as few adhesives, coatings and other chemicals as possible that limit material circularity. Figure 9 presents that in only 17.6% of cases, wooden materials are made without any chemical treatment; in 29.4% of cases, materials are treated with ecological means of treatment, and in the remaining 52.9%, chemical treatment (impregnated, coated) is used.

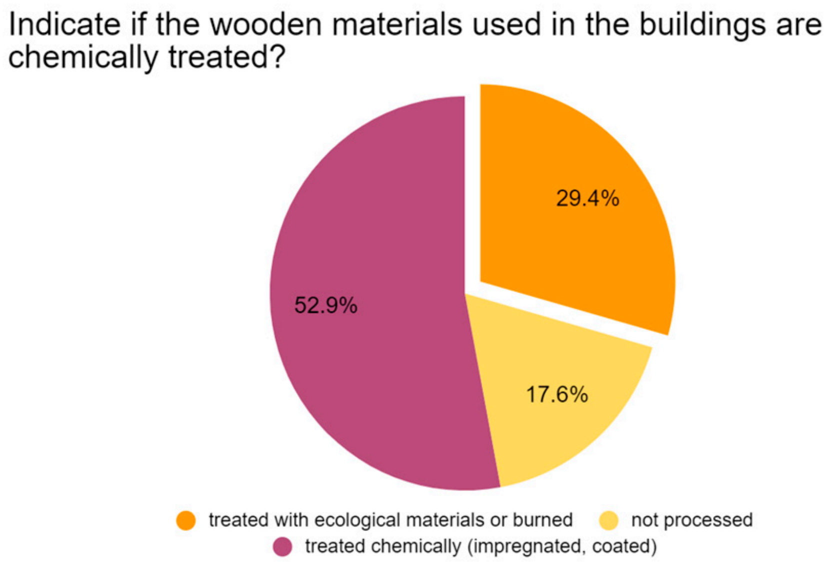

Figure 9. Percentage of chemically treated wood construction materials/parts in buildings of respondents; wood house construction company survey, April–May 2023.

One of the main principles of design for disassembly is that connections between elements must be easy to disassemble and material must be reusable. "Design for disassembly" means standardised connections and the use of screws and bolts in the engineering connections. Table 2 shows that screws and bolts are used in 25% of cases, followed by nails (20%), in the engineering connection types present in the products of respondents. Connection types such as nails, metal clamps and glued joints make it difficult to separate the elements and, in most cases, damage the element, thus decreasing its circularity value and creating additional waste (metal elements) that also cannot be used repeatedly.

Table 2. Engineering connection types present among respondent products, mentioned by respondents; wood house construction company survey, April–May 2023. *Source: by authors*.

Products	Times Mentioned	% of Total
nails	14	20
bolts (incl. various plates)	17	25
metal clamps	10	14
glued joints	9	13
pins	6	9
connections that are intended to be opened several times (e.g., rothoblaas)	5	7
timber–timber joints	6	9
other: connectors, timber "dovetail" connections	2	3

The final section of questions was dedicated to better understanding how ready wood house construction companies are to engage in a circular economy and what potential circular construction and manufacturing activities could be considered to improve their ability to engage in wood construction product circularity. Respondents were asked what kind of leftovers or offcuts arose from the production process, if any, that would indicate the potential for reuse and recycling. All of the respondents shared that they have offcuts in the production process, and some respondents said that all the leftovers are used for further processing or reuse/recycle material themselves (e.g., CLT leftovers). The next step would be to measure the volume and size of the leftovers (see Table 3).

Table 3. Leftovers or offcuts arose from the production process mentioned by respondents; wood construction company survey, April–May 2023. *Source: by authors*.

Open Answers
Materials of mineral origin
Practically not. . .because the necessary lengths are ordered!
Materials of mineral origin
Practically not. . .because the necessary lengths are ordered!
Scraps of wood, cotton wool, diff. membrane, metal, osb, wood fiber
Of natural origin
Used for the second time.
Cotton wool, wood
Timber
Cotton wool
Of all the above materials
There is some wood left
Thermal insulation scraps, material packages,
All kinds of leftovers
Some wood shavings, Packaging material
Various scraps of materials—plasterboard, membranes, OSB, etc.
MDF, re-plaster
Wood chips, timber
Scraps of wood, plasterboard and mineral wool. All material materials are used for further processing
Wooden
CLT (but we recycle it ourselves), membranes, foam
Wood chips

The question "Do you have stable partners who take/purchase surplus and/or scraps from you?" indicates whether companies are taking part in a wood construction product (waste) management system or if they have partners who can support the management system illustrated in Figure 10. The respondents showed a positive tendency to take part in wood construction waste circularity; 25% indicated that they reuse the material in their existing products or even develop new products and exercise the potential already and 30% indicated that they have partners to delegate reuse or recycling. However, still 45% of respondents did not indicate any partners to delegate the reuse or recycle of leftover construction materials.

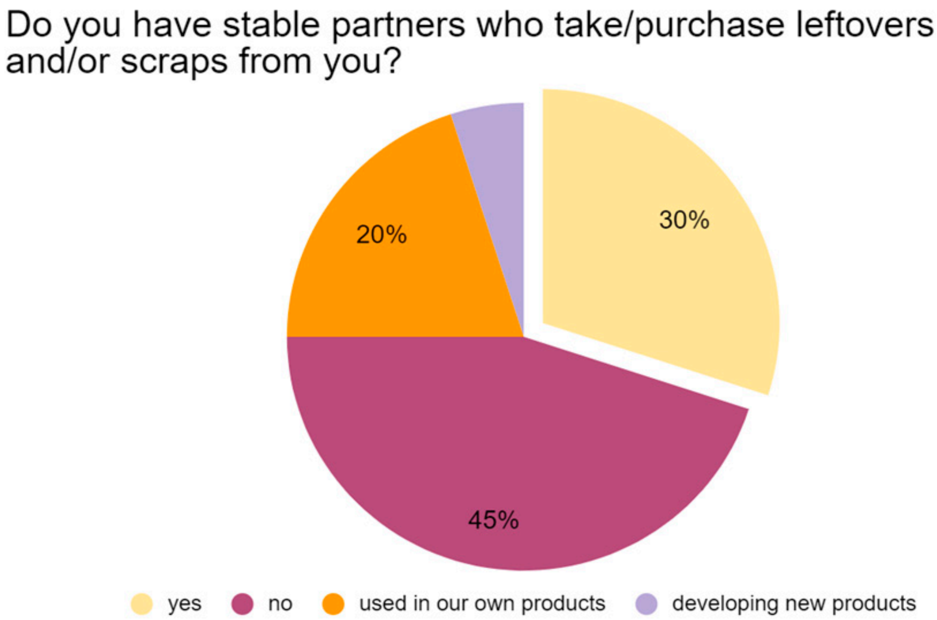

Figure 10. Percentage (%) of respondents who have/do not have stable partners who take/purchase leftovers and/or scraps from respondents' company; wood house construction company survey, April–May, 2023.

In the next question, respondents were asked to evaluate their company's readiness to engage in the circular economy using the following range: 1—"we are not interested in that"; 2—"we have heard about it"; 3—"would like to know about it"; 4—"it is in our strategic goals (until 2025)"; 5—"we have planned in the 2023 activities/action plan"; and 6—"already implemented". The valuation metrics also indicate if company is or would be ready to implement the EU directives and actions elaborated in Section 3.1. The following aspects were given for evaluation to determine the company's readiness to engage in the circular economy and present potential to participate in wood construction product circularity. We looked at the extent to which a company was ready to do the following:

A. Implement circular economy principles in the company;
B. Take back all or parts of your product for reuse or recycling;
C. Reuse materials in their products;
D. Develop new products from recycled material;
E. Adapt the connection solutions in your products for easier assembly/disassembly;
F. Invest in the development of existing/new products, in the processing of wood materials within the circular economy;
G. Store information about your buildings digitally at least during the warranty period.

A colour-coding method was used to illustrate the "wishful" scenario in green, with the darker shades indicating greater willingness to engage in circular economy, as opposed to red colour-coding, which illustrates the density of respondents' responses in Table 4.

Table 4. Latvian wood house construction company readiness to engage in the circular economy, colour-coded according to respondents' answers; May 2023. *Source: by authors*.

Questions to Wood House Construction Companies	**1**	**2**	**3**	**4**	**5**	**6**		
In implementing circular economy principles in the company?	2	7	5	2	1	3		0-1
Are you ready to take back all or parts of your product for reuse or recycling?	7	5	4	2	0	2		2-3
Reuse materials in their products?	7	4	4	0	1	4		4-5
Develop new products from recycled material?	5	6	4	1	1	3		6-7
Adapt the connection solutions in your products for easier disassembly/disassembl	5	5	3	0	2	5		8-9
Invest in the development of existing/new products, in the processing of wood materials within the circular economy?	2	9	4	1	1	3		
Store information about your buildings digitally at least during the warranty period?	1	4	6	0	1	8		

Based on the results, the Latvian wood house construction companies can be split into four groups:

- Group 1: (1) not interested in considering a circular approach within the company or engage in a circular economy value chain;

- Group 2: (2–3) ready to know more about why and how a circular approach could be implemented in the company and processes;
- Group 3: (4–5) taking action or planning to do so in the next years and has marked a circular approach as a strategic objective;
- Group 4: (6) already taking part in a circular economy in one or another way; however, actual activities and value chains should be considered in detail to confirm that actions fall into the circular approach, based on answers to previous questions in the survey.

The results also show that companies are very much interested in learning more about how and where to invest to develop new circular products and are generally open to know more about the circular economy in wood construction (option A, value 1;2;3). In addition, companies are progressing digitally and implementing new digital solutions to gather and store data, at least during the warranty period, and many companies have already developed those kinds of systems (option G, value 3;6). Labelling building elements and documenting their location and connections can make it easier to disassemble and reuse materials. This approach ensures that building elements can be easily identified and located during the disassembly process. A digital logbook of building materials ensures that information is stored and inherited along the building's life cycle. This principle also refers to the "buildings as materials banks" concept of performance.

On the other hand, respondents were reluctant towards the "take back and reuse" mechanism, valuing option B "Are you ready to take back all or parts of your product for reuse or recycling?" and option C "Reuse materials in their products?" mostly at 1—"we are not interested in that". The take-back and reuse mechanisms are essential parts of a circular, life cycle approach and are a common practise among European construction material producers.

The majority of the companies in Group 2 were "ready to know more about why and how a circular approach could be implemented in the company and processes" or "beginners" of circular economy. Group 4, with high score in "digitalisation" (option G, valued 6), followed; however, this reflected only part of circular economy principles that are related to digitalisation, engineering solutions (option E, value 6) and the reuse of one's own products (option C, value 6).

Furthermore, the interviews with three (3) wood house industry stakeholders confirmed that the majority of wood house construction companies are very interested in exploring in depth the possibility of engaging in wood construction product circularity and foresee the benefit of it. However, companies generally lack an understanding of the circular economy, and they are not aware of current actions that weaken or strengthen their position and valuation against sustainable and circular measurements. For most industry stakeholders, circular construction and wood product circularity are new topics that have not come up in the front line yet, due to challenges in wood construction in general, frequent misinterpretation of the legal framework in Latvia, a lack of foresight of upcoming EU requirements, and the difficulties of organising the timber material value chain at large.

5. Discussion and Recommendations

By diverting wood waste from landfills and reusing it in various applications, we can reduce the environmental impact of wood construction and create a more sustainable economy. Wood waste recycling facilities play an important role in reducing waste and conserving resources by diverting wood waste from landfills and creating new products from old materials. By using sustainable practises to recycle wood waste, we can reduce our environmental impact and promote a circular economy.

The reality of existing building stock under reconstruction, renovation or demolition consists of a mix of materials and construction techniques usually cannot split materials in clean fractions. In this regard, a lot of wood waste material is not clean enough, meaning that without admixtures and adhesives, it is not ready to be returned to use, recycled or downcycled. An extra effort is required to clean materials properly, so that they can be returned to a circular cycle. The survey shows that 46% of construction waste is wood or wood-based, mostly among private or garden house repair and construction. However, it is a much better situation with cross-laminated timber and modular building construction approaches and techniques deployed in the market.

New wood construction must improve timber construction techniques and avoid chemical treatment and the intrusion of wood material used in construction so that it can be returned into the cycle, and preferably reused in case of reconstruction or renovation.

A mandatory prerequisite for the termination of the waste status is the possibility to commercialise the material as a secondary resource and demonstrable market demand for the material [80]. On the other hand, industry demand cannot arise for a material which has no use in construction; therefore, the obtained secondary raw material, material or by-product, must meet the same eligibility requirements as construction products (as determined by the Construction Products Regulation and construction products market supervisory procedure in Latvia). Likewise, if there is no public information on the second-hand market availability of the resource, demand for it cannot rise. Since construction waste as a potential resource flow is a strictly documented process, there is a possibility to offer this resource for secondary use on the market in a way that is necessary and usable by market participants. However, the existing information flow takes place in closed data systems within the framework of one construction project (site).

Properly prepared, checked and documented received building material that has been granted EoW status will be more expensive than the by-products of construction waste that are currently available on the market. Such material will not be competitive against the substitute mineral source material. Accordingly, participants of construction projects (developers, architects, builders) need motivation and commercial considerations to use second-hand raw materials obtained from construction waste.

There is a lot of "green washing" around eco-timber building, which presumably addresses only using wood as a one-time construction material with its sole benefits instead of looking at building life cycle analysis and calculations. Consumers are also not educated on the life cycle analysis of wood houses and are "bought in" by idea that "wood equals sustainable building".

Wood and wood-based repair and CDW make up the third most common construction waste group among the Latvian population (46% of respondents in survey), after paper and cardboard (61%) and polyethylene (cellophane) (49%) arising from repair and construction works in the past 5 years (survey dated 2022). Findings of survey (2022) indicate a general awareness and willingness to participate and engage in circular construction models among Latvians; however, proactiveness and support (legal and financial) is expected from the state and municipalities, which might endorse or suppress the potential for construction waste circularity adoption in general.

In the vast majority of cases, the management of the construction waste decision has been up to individuals (73%, data 2022) and has not been registered, dated or recorded, leaving no open trace of waste flow. It could be named "shadow construction waste".

The various admixtures and wood processing technologies limit the recycling and further use of wooden building materials within the framework of the currently established procedure. (The procedure for ending the application of waste status to chips, shavings and dust obtained from wood packaging or certain types of wood construction waste.)

The recommendations of this study point towards improvements in wood waste data management, wood construction sector organisation and the division of the responsibilities of involved parties. The amount of reporting requirements in connection with the fulfilment of the goals set by the EU directives is constantly increasing, covering both a more detailed and wider scope of waste flows, as well as regular monitoring of the achievement of new types of goals, requiring the raising of competence in public administration institutions to strengthen reporting, control and monitoring capacities.

Based on the research carried out, the authors present the following recommendations:

1. To support involvement and decisions of the public to engage in the circular construction approach, consider the following:
    1.1. Awareness. Accelerate public awareness by preparing informative materials and digital solutions about CDW management. It is also necessary to provide wider methodological support and consultations to public and companies, including by developing guidelines or explanations on the application of regulatory acts regarding the problematic flow of construction waste (depicting wood construction waste and wood processing waste) in accounting.
    1.2. Redefinition and reconsideration of terminology used in communication with the public from "waste" to "material"; for example, renaming a "waste recycling facility" as a "material recycling centre".
    1.3. Access. Improving CDW accounting and reporting processes and implementing digital solutions for better waste management and material flow management are important. APUS and BRAPUS system integrations with the Construction Information System (BIS) system should be implemented. For any kind of system, the user experience, responsive design and user interface are essential.
    1.4. Open data. It is important to create an integrated, digital circulation system of recycled construction materials by expanding the connection with the Construction Information System—BIS, which the Ministry of Finance plans to implement in the next round of BIS system development.
    1.5. Within the framework of the establishment of five (5) Waste Management Regions (Atkritumu Apsaimniekošanas Reģioni) in Latvia mentioned in the State Waste management plan 2021–2028, specialisation is recommended not only in household waste management activities, but also in the preparation of special waste groups, such as construction waste, including the grounds for secondary use material, reuse, recycling and energy regeneration.
    1.6. Data-driven decisions. To be able to make justified and circular economy-fostering decisions, it is important to embed LCA into decision-making processes and to verify the circularity of wood across a building's life.
2. To support the circular approach among wood house construction companies, the following should be considered:
    2.1. Training and education on circular construction, obligatory modules for study programmes (Ministry of Education, Ministry of Economics) and qualification increase modules (Ministry of Economics) should be implemented. Providing the introduction and further education of circular design (design for disassembly), technologies for recycling and reuse of CDW and strategic guidance and general education on circular economy principles in wood construction companies is key.
    2.2. Extend the BIM information—add in-depth data about wooden products (elements), their bearing and purpose in buildings in order to ease the reuse in structural components in future life cycles. Allowing the elements to be used in the construction according to their depreciation level is important. The tracing of construction details allows for the precise measurement and redirection of wood elements back into the circular cycle.
    2.3. Develop a support system (structural and financial) for companies who are interested to invest in circularity of wood construction products, wood waste and ready to work on new product development.
    2.4. Expand the list of wood construction waste definition with "other unprocessed timber", which would include CLT and GLULAM (Clause 4, MK 317, 2022).
    2.5. Implement "green corridors" from financial institutions for companies who are engaged in wood construction product circularity systems or are ready to invest to take part in such models, such as ALTUM guarantees and "green financial" tools from banks.

    2.6. Integrate LCA as a decision-making tool for construction, architecture and design companies—to be able to easily compare different types of materials and their environmental footprint, in order to choose the most appropriate circular materials for a specific project.

3. To support legislation, the following are important:
    3.1. Develop the necessary regulatory base for turning construction waste into resources for reuse. Changing the formulation and meaning of "construction waste" to "construction material" is key. Implement a reverse regulatory base that enables reuse without losing track of waste flow.
    3.2. Improving waste accounting and reporting processes and implementing digital solutions for better waste management and material flow management are key, including the creation of an integrated circulation system of recycled construction materials (in synergy with the electronic construction volume monitoring system (BRAPUS) linked to BIS; this data should be accessible to the public as open data blocks.
    3.3. Start to collect material audit data (BoM) in buildings and life cycle assessment (LCA) calculations using the BIS system, to better understand the local abilities of CO_2 limitations (regulations) for new construction.
    3.4. Eliminate unnecessary precautions for wooden construction products (elements such as coatings, adhesives, admixtures) to prevent fire and humidity. Apply a prescriptive approach to the regulatory environment, instead of the typical approach.
    3.5. Expand the EoW status procedures for wood construction materials, encouraging the circular approach according to the 9R pyramid, where reuse is the first step instead of downcycling.

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