Research Paper

Timber Buildings and the Environmental Benefits of Cascading: LCA Application to Circular Practices in the Wood Value Chain

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Abstract

The construction industry is a significant resource consumer and a key contributor to greenhouse gas emissions worldwide. Timber buildings in general, and particularly those using mass timber construction products, have the capacity to change the current carbon emission trend in the construction sector and instead act as a net carbon sink. However, the current timber value chain remains linear, prioritizing energy recovery over reuse due to insufficient standards and low demand for recovered materials.

This study compares the environmental benefits of reusing mass timber elements designed for deconstruction versus the current practice of energy recovery. The findings highlight that extending the value chain by retaining timber's structural function is more environmentally advantageous than downgrading or direct energy production. These results underscore the need for regulatory changes to promote timber reuse and a circular timber economy.

Keywords

Engineered timber, timber building, LCA, end-of-life, reuse, Design for Deconstruction and Reuse

1. Introduction

1.1. Study Background

The population increase combined with transformation in social processes like population aging, increased affluence, and global warming is contributing to an increased need for shelter and infrastructure. (EEA, 2024). As a result, the construction industry is a major contributor to socio-economic development, and, at the same time, it is the most environmentally impactful sector in the EU, accounting for over 30% of the EU's environmental footprint. (EEA, 2024)**.** A significant portion of these impacts is embedded in the materials used for construction (IPCC, 2023), making material selection crucial for reducing the sector's environmental impacts (Hu, 2023; Pomponi et al., 2020). Against this background, mass timber construction products such as cross-laminated timber (CLT) and glued laminated timber (glulam) have gained increasing attention: on one hand, they have lower global warming potential and life cycle primary energy than those built from concrete or steel (Duan et al., 2022). On the other they have the potential to transform the construction sector from a carbon emitter to a net carbon sink (Churkina et al., 2020): buildings made using mass timber construction products materials are able to store carbon over their lifespan, acting as "second forests" by sequestering carbon while real forests absorb new CO2 (Amiri et al., 2020; Arehart et al., 2021; Garcia et al., 2020).

Nevertheless, CLT and glulam are manufactured using smaller-diameter trees and wood by-products, yet offer high strength and durability, becoming a good material for circular practices, as they are durable, lightweight, and easy to disassemble through dry connections (Klinge et al., 2019; Munaro et al., 2022), they result suited for Design for Deconstruction and Reuse (Cristescu et al., 2020; Klinge et al., 2019), allowing the reuse with their original function, extending their lifecycle and reducing waste.

Although the benefits of cascading applied to wood products have been acknowledged (Arias et al., 2025, Niu et al., 2021; Thonemann and Schumann, 2018), research specifically addressing the reuse of structural timber components is limited (Niu et al., 2021; Vis et al., 2016). Moreover, a lack of European standards and regulations for wood recovery, along with low demand for recovered materials (Cristescu et al., 2020), results in a predominately linear timber value chain, with energy recovery often prioritized (Niu et al., 2021). The linear approach amper the expression of the environmental advantages of extending the lifecycle through cascading.

1.2. Aim of the Study

This study quantitively evaluates the environmental benefits of reusing mass timber elements within a multi-stage cascading system, maintaining their structural function across multiple lifecycles. Life Cycle Assessment (LCA) is applied to a five-story timber building designed for multi-stage cascading. The study assesses and compares the environmental benefits of reusing mass timber elements designed for deconstruction versus the current practice of energy recovery. It aims to emphasize the importance of incorporating cascading use into end-of-life modeling for timber buildings.

2. Material and methods

2.1. Case Study

The subject of the study is a five-story commercial timber building with an area of 7,290 m² and a height of 20 meters. The building presents prefabricated elements, a post-and-beam system, and a non-structural façade. Core components such as reinforced concrete foundations, glulam beams, CLT slabs, and laminated veneer lumber (LVL) façades were included in the assessment, while interior finishes and non-structural elements were excluded. Approximately 55% of the building's weight consists of concrete, adhering to Danish standards (Danish Ministry of Economic and Business Affairs, Danish Enterprise and Construction Authority, 2010. The Building Regulations 2010). The building's Reference Service Life (RSL) is set at 50 years, in line with ISO 15686-1: 2011) and BS EN 1990 requirements.)

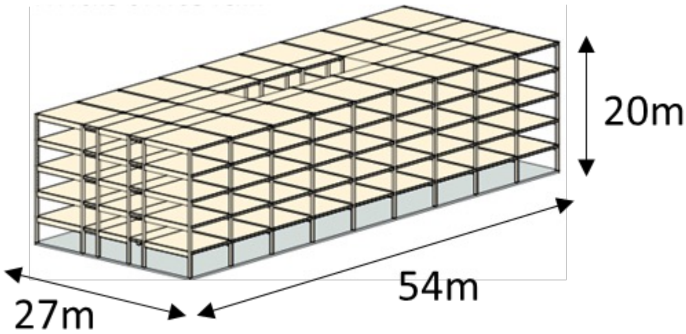

Figure 2.1 The case study examined: structural frame of a five-story commercial timber building with an area of 7,290 m² and a height of 20 meters.

The study aims to evaluate the environmental impact of reusing mass timber elements designed for deconstruction versus the current practice of energy recovery. In order to do so, two different scenarios are hypnotized: Extended Lifespan scenario and Conventional Disposal scenario.

In the Extended Lifespan scenario, Figure 2.2, timber components—such as glulam beams, CLT slabs, and LVL façade elements— are dismantled and reused for the same function after the building's 50-year lifecycle. Approximately 98% of the timber is reused and it is assumed to maintain its integrity and meet required standards, allowing it to serve the same role in the new building. While the scraps are incinerated. After the second building lifecycle, timber is cascaded into Particle Board (PB) and then incinerated. The PB obtained from dismantling the 2nd building is 2,199 m3, a technical loss of 5% due to transport and production processes was included in the PB calculation (Hoglmeier et al., 2015).

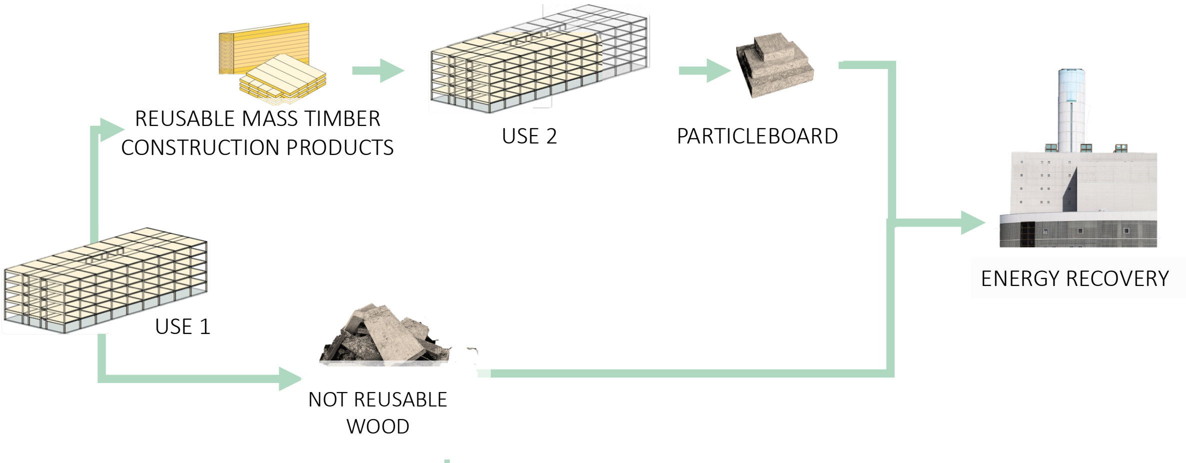

Figure 2.2 Extended Lifespan Scenario, at the end of the building's 50-year reference service life, the structural components are dismantled and reused in new construction for an additional 50 years. Wood scraps generated during disassembly incinerated, with virgin materials replacing any portion that cannot be reused.

In the conventional Disposal scenario, Figure 2.3, although the structural components in this scenario are also designed to be dismantled and reused, they are not reused. After 50 years, the building is demolished, and all wood elements, including (reusable) glulam beams, CLT slabs, and LVL façades, are incinerated in line with the EN 15804:2012+A2:2019.

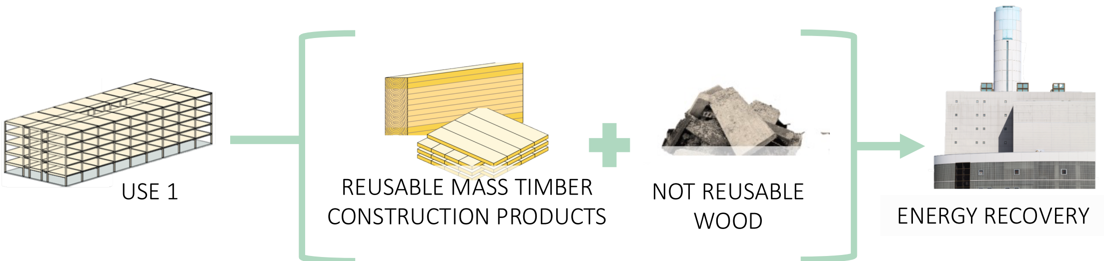

Figure 2.3 Conventional Disposal Scenario, at the end of the building's 50-year reference service life (RSL), the structural components are incinerated, with no reuse of materials.

2.2. Use of the paragraphs

The LCA follows ISO 14040:2006 and 14044:2020 standards, and is implemented to compare the Extended Lifespan and Conventional Disposal scenarios. To allow comparison, the commercial service provided by the building's structure over 100 years is set as the functional unit (see Figure 2.4). This results in different reference flows for the two scenarios.

In the Extended Lifespan scenario, the reference flow is two buildings and particleboard: the first building is made from virgin wood. The second uses wood from the deconstruction of the first, with some virgin wood added, each lasting 50 years for a total of 100 years. The particle board, 2199 m^3, is made of post-consumer wood from recycling the wood from the second building. In the Conventional Disposal Scenario, the reference flow is two buildings built using virgin wood, each lasting 50 years for a total of 100 years, and particle board, 2199 m^3, from pre-consumer scrap external sources. It was necessary to add PB from external sources in the Conventional Disposal Scenario in order to have the same output for both scenarios to ensure comparability.

The temporal system boundary is 100 years and the geographical scope is limited to European countries.

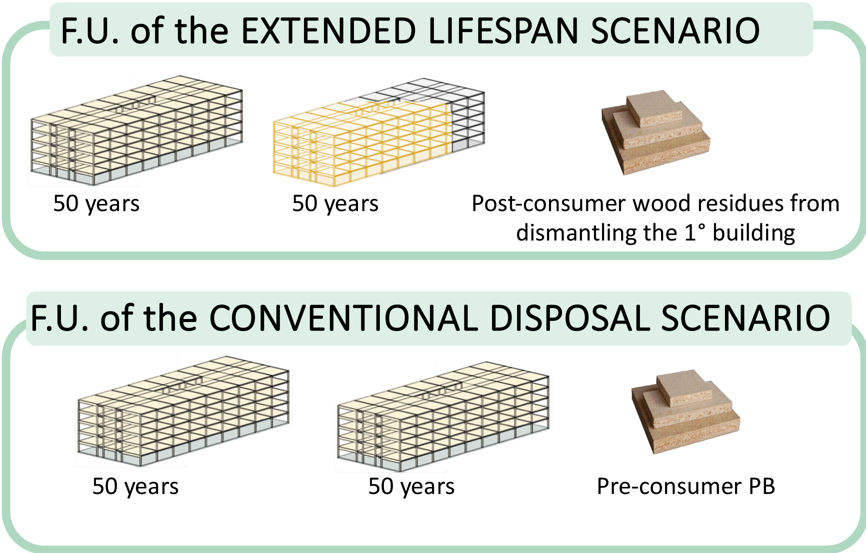

Figure 2.4 The figure describes the functional unit for each scenario. In the Conventional Disposal Scenario, two 5-story timber buildings are built using virgin wood, each lasting 50 years for a total of 100 years. The wood comes from virgin sources, and at their end of life, the buildings are demolished and the wood is incinerated. In the Extended Lifespan Scenario, the first building is made from virgin wood, but the second uses wood from the deconstruction of the first, with some virgin wood added after 50 years, the wood from the second building is recycled into particle board, using post-consumer wood from both buildings.

Foreground data for the building's composition—including the list of structural components and their quantities—was collected and used for the Life Cycle Inventory (Table 2.1).

Table 2.1 Life Cycle Inventory of the timber building.

	Scenario	*Conventional Disposal Scenario*	*Extended Lifespan Scenario*
Component	Material	Amount (kg)	Amount (kg)
Groundwork	Sand	393,660	393,660
	Gravel	415,530	415,530
	Concrete	729,000	729,000
	Reinforcement steel	11,868	11,868
	XPS	46,656	46,656
	PVC	2,916	2,916
Foundation	Concrete	1,140,000	1,140,000
	Steel	42,750	42,750
Framework	Glulam (columns)	48,384	968
	Brackets (columns)	750	750
	Glulam (beams)	125,355	2,507
	Brackets (beams)	1,125	1,125
	Concrete (stairs)	31,250	31,250
	Steel (stairs)	3,000	3,000

Floors	CLT	595,350	11,907
	Concrete	992,250	992,250
	Rockwool	33,750	33,750
	Gypsum board	182,250	182,250
Internal walls	CLT	221,466	4,429
	Steel	1,200	1,200
Envelope	Steel plates	48,600	48,600
	Windbreaker	38,880	38,880
	Wood skeleton (LVL)	30,618	612
	Mineral wool	29,160	29,160
	Plasterboard	87,480	87,480
	Plaster	24,300	24,300
	Paint	1,118	1,118
Roof	Mineral wool	510	510
	PVC	2.92	2.92
	Bituminous film	7.29	7.29

The LCA analysis was conducted using SimaPro v.9.0 software.

Background data were obtained from the Ecoinvent 3.6 database, covering most materials' upstream production and raw material extraction for timber elements (glulam, CLT, LVL). Primary data for timber manufacturing were gathered from industry sources, supplemented by literature (Rüter, 2012), while for other materials, production data were derived from Environmental Product Declarations (EPDs). The transportation of materials was modeled over a 100 km distance (Höglmeier et al., 2015), using 16-32 metric ton trucks adhering to Euro V emission standards. Energy demand during the construction phase was based on diesel and electricity consumption reported in EPDs. In the Extended Lifespan Scenario, disassembly energy was assumed to be equal to the energy required for assembly, while fuel consumption for demolition in the Conventional Disposal Scenario was estimated using the model provided by Ivanica et al. (2022). Waste treatment for steel and concrete was modeled using European waste treatment statistics, while for other materials, statistics from EPDs were used. The Life Cycle Impact Assessment was conducted using the EF 3.0 method (Eurostat, 2018; Fazio et al., 2018), in accordance with EN 15804:2019. The selected impact indicators included Climate Change, Ozone Depletion, Acidification, Freshwater Eutrophication, Tropospheric Ozone Formation, and Abiotic Depletion for both fossil and non-fossil resources. In line with standard LCA practices, biogenic CO_2 uptake during forest growth and emissions at the end of life were not accounted for. A conservative approach was also taken by excluding credits for avoided impacts, such as energy recovery from wood combustion. Therefore, "incineration" will be used instead of "energy recovery" when describing the end-of-life treatment for wood components.

3. Results

The Extended Lifespan Scenario showed a 13% reduction in Global Warming Potential compared to the Conventional Disposal Scenario (3,283 t CO2 eq vs. 3,788 t CO2 eq). This was mainly due to a 28% decrease in emissions from the second building materials. Additionally, PB production saw a 20% reduction in emissions and lower timber incineration impacts (Figure 3.1).

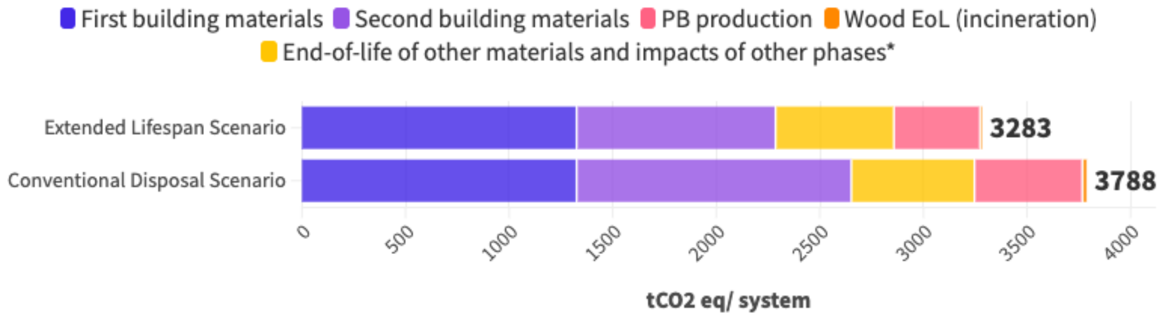

Figure 3.1 Comparison of Global Warming Potential for Extended Lifespan vs Conventional Disposal scenario. The chart illustrates the contribution of different lifecycle stages to the total GWP (t CO_2 eq) for each scenario. The Extended Lifespan scenario shows reduced emissions, particularly from the second building materials and particle board production phases. Note that Timber EoL is set to zero since no biogenic carbon is accounted for such process

As shown in Table 3.1, Ozone Depletion Potential was reduced by 20%, Photochemical Ozone Formation by 24%, Acidification Potential by 16%, and Eutrophication by 24%. Resource Use for Fossil Energy decreased by 16%, though Resource Use for Minerals and Metals showed only a 1% reduction.

Table 3.1 Comparison of the results of Life Cycle Impact Assessment of both scenarios. The indicators selected were: Climate Change, Depletion Potential of the stratospheric Ozone layer, Acidification Potential, Eutrophication Potential freshwater (EP-freshwater), formation potential of tropospheric ozone, Abiotic Depletion Potential for non-fossil resources, and Abiotic Depletion Potential for fossil resources.

Scenario	Climate change	Ozone depletion	Photochemical ozone	Acidification	Eutrophication, freshwater	Resource use, fossils	Resource use, minerals and metals
	t CO_2 eq	g CFC11 eq	t NMVOC eq	kmol H+ eq	kg P eq	GJ	g Sb eq
Conventional Disposal	3,788	450	19	20	165	58,183	41,200
Extended Lifespan Scenario	3,283	360	14	17	125	48,657	40,700
	-13%	-20%	-24%	-16%	-24%	-16%	-1%

4. Results

The results of this study add to the expanding body of research on timber reuse and cascading principles (Cordier et al., 2022; Duan et al., 2022; Szichta et al., 2022; Thonemann and Schumann, 2018). While prior studies have highlighted the potential of mass timber products like CLT and glulam to reduce emissions in the construction sector (Churkina et al., 2020; Duan et al., 2022), few have explored the environmental advantages of designing timber buildings for reuse at the end of their lifecycle. Most research either overlooks this reuse potential or discusses timber in the context of recycling for lower-grade applications or energy recovery, with Niu et al. (2021) being an exception. By adopting an ex-ante design for disassembly and reuse, this study shows how timber can retain its high-value structural role, thereby extending its lifecycle and avoiding downgrading. It fills a critical gap by providing quantitative assessments of the environmental benefits of timber reuse, in contrast to previous speculative discussions.

The reuse strategy presented in the Extended Lifespan Scenario results in emissions reductions compared to the Conventional Disposal Scenario. Although our analysis focuses on a commercial building, the reuse strategy can be adapted to various building types, including residential structures. The combined use of post-and-beam system and reusable timber components, makes the benefits of reuse applicable across different architectural designs. This versatility provides policymakers and urban planners with a scalable solution for reducing urban carbon emissions.

However, the full environmental potential of timber reuse is restricted by current international standards, like EN 16485:2014, that do not set reused as a possible end of life. Our study demonstrates that timber can be dismantled and reused, effectively doubling its service life. Revising standards to formally recognize timber reuse with the same function as a legitimate end-of-life scenario in Life Cycle Assessments would broaden system boundaries and functional units, fully capturing the environmental advantages of timber reuse and supporting the shift toward circular economy practices in the construction sector.

5. Conclusion

Embracing circular economy practices can lead to drastically decrease resource and emissions levels in the construction industry. Timber, a renewable and abundant material, offers a unique advantage over fossil-based options like concrete and steel thanks to its high potential for reuse and recycling. Even minimal reuse of engineered timber can can have a significant positive impact on the environment.

Our research marks an important step towards quantifying the environmental advantages of wood multiple cascading, focusing on the reuse with the same function. It addresses existing knowledge gaps and highlights the shortcomings of current regulations, calling fora revision of circular economy practices and LCA standards (Malabi Eberhardt et al., 2021).

It proposed a shift from the traditional building-focused perspective to a a systematic outlookthat includes the entire value chain and encompass both reuse and recycling stages. Such an approach amplifies environmental and socio-economic benefits, engaging a range of stakeholders in the process (Bastianoni et al., 2023). As a matter of fact, reusing engineered timber components for the same purpose aligns with the goals of the Circular Economy Action Plan to increase circularity in the construction sector and addresses two out of three UNEP's (2023) critical paths for decarbonizing the industry.

Designing timber buildings for easy deconstruction and maximizing the recovery of timber elements is essential for unlocking a new economic sector. Currently, this potential is hindered by the lack of reusable engineered timber and insufficient regulations. The regulatory framework must be updated to fully harness engineered timber's advantages. Specifically, EN 16485:2014 should be revised to formally recognize timber reuse for the same function as a possible end-of-life scenario in Life Cycle Assessments. Extending the lifespan of timber products and enhancing biogenic CO2 storage through cascading reuse also supports the goals of the EU Green Deal (Sikkema et al., 2023). Although this study did not address biogenic carbon accounting or the benefits of temporary carbon storage, these aspects must be considered to fully realize the environmental benefits of timber in construction and cascading reuse practices.

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During the preparation of this work the authors used the Grammarly software (preminum verison) and ChatGPT (4o mini version) in order to spell and grammar check the article and make the test as fluent as possible . After using this tool/service, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

References
Amiri, A., Ottelin, J., Sorvari, J. and Junnila, S., 2020. Cities as carbon sinks—classification of wooden buildings. *Environmental Research Letters*, 15(9), p.094076. https://doi.org/10.1088/1748-9326/aba134

Arehart, J.H., Hart, J., Pomponi, F. and D'Amico, B., 2021. Carbon sequestration and storage in the built environment. *Sustainable Production and Consumption*, 27, pp.1047–1063. https://doi.org/10.1016/j.spc.2021.02.028

Arias, A., Feijoo, G., Moreira, M.T., Tukker, A. and Cucurachi, S., 2025. Advancing waste valorization and end-of-life strategies in the bioeconomy through multi-criteria approaches and the safe and sustainable by design framework. *Renewable and Sustainable Energy Reviews*, 207, p.114907. https://doi.org/10.1016/j.rser.2024.114907

Basquill, S., Neily, P., Quigley, E., Stewart, B. and Keys, K., 2011. *Nova Scotia Department of Natural Resources Renewable Resources Branch: Report For 2011-1*.

Bastianoni, S., Goffetti, G., Neri, E., Patrizi, N., Ruini, A., Sporchia, F. and Pulselli, F.M., 2023. LCA based circularity indices of systems at different scales: a holistic approach. *Science of The Total Environment*, 897, p.165245. https://doi.org/10.1016/j.scitotenv.2023.165245

BS EN 15804:2012+A2:2019, 2019. *Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products*. Brussels: British Standards Institute.

BSN Eurocode, 2002. *BS EN 1990:2002 + A1:2005 - Basis of structural design*. Brussels: British Standards Institute.

Churkina, G., Organschi, A., Reyer, C.P.O., Ruff, A., Vinke, K., Liu, Z., Reck, B.K., Graedel, T.E. and Schellnhuber, H.J., 2020. Buildings as a global carbon sink. *Nature Sustainability*, 3, pp.269–276. https://doi.org/10.1038/s41893-019-0462-4

Cordier, S., Blanchet, P., Robichaud, F. and Amor, B., 2022. Dynamic LCA of the increased use of wood in buildings and its consequences: Integration of CO2 sequestration and material substitutions. *Building and Environment*, 226, p.109695. https://doi.org/10.1016/j.buildenv.2022.109695

Cristescu, C. et al., 2020. *InFutURe Wood Report 1: Design for deconstruction and reuse of timber structures – state of the art review*. https://doi.org/10.23699/bh1w-zn97

Duan, Z., Huang, Q. and Zhang, Q., 2022. Life cycle assessment of mass timber construction: A review. *Building and Environment*, 221, p.109320. https://doi.org/10.1016/j.buildenv.2022.109320

European Committee for Standardization, 2019. *EN 15804:2012+A2:2019 Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products*.

European Committee for Standardization, 2014. *EN 16485:2014. Round and Sawn Timber, Environmental Product Declarations, Product Category Rules for Wood and Wood-Based Products for Use in Construction*.

European Environment Agency, 2024. *Addressing the environmental and climate footprint of buildings*. https://doi.org/10.2800/1800539

Eurostat, 2018. *Circular economy indicators - Recovery rate of construction and demolition waste*.

Fazio, S. et al., 2018. *JRC Technical Reports: Supporting information to the characterisation factors of recommended EF Life Cycle Impact Assessment method: New models and differences with ILCD*. Ispra: Joint Research Centre, European Commission.

Garcia, R., Alvarenga, R.A.F., Huysveld, S., Dewulf, J. and Allacker, K., 2020. Accounting for biogenic carbon and end-of-life allocation in life cycle assessment of multi-output wood cascade systems. *Journal of Cleaner Production*, 275, p.122795. https://doi.org/10.1016/j.jclepro.2020.122795

Höglmeier, K., Steubing, B., Weber-Blaschke, G. and Richter, K., 2015. LCA-based optimization of wood utilization under special consideration of a cascading use of wood. *Journal of Environmental Management*, 152, pp.158–170. https://doi.org/10.1016/j.jenvman.2015.01.018

Hu, M., 2023. A look at residential building stock in the United States - mapping life cycle embodied carbon emissions and other environmental impact. *Sustainable Cities and Society*, 89, p.104333. https://doi.org/10.1016/j.scs.2022.104333

International Standard Organization, 2011. *ISO 15686-1:2011. Buildings and constructed assets — Service life planning — Part 1: General principles and framework*. Geneva: ISO.

IPCC, 2023. Buildings. In: IPCC, *Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge University Press, pp.953–1048. https://doi.org/10.1017/9781009157926.011

Ivanica, R., Risse, M., Weber-Blaschke, G. and Richter, K., 2022. Development of a life cycle inventory database and life cycle impact assessment of the building demolition stage: A case study in Germany. *Journal of Cleaner Production*, 338, p.130631. https://doi.org/10.1016/j.jclepro.2022.130631

Klinge, A., Roswag-Klinge, E., Radeljic, L. and Lehmann, M., 2019. Strategies for circular, prefab buildings from waste wood. *IOP Conference Series: Earth and Environmental Science*, 225, p.012052. https://doi.org/10.1088/1755-1315/225/1/012052

Malabi Eberhardt, L.C., van Stijn, A., Kristensen Stranddorf, L., Birkved, M. and Birgisdottir, H., 2021. Environmental Design Guidelines for Circular Building Components: The Case of the Circular Building Structure. *Sustainability*, 13(10), p.5621. https://doi.org/10.3390/su13105621

Munaro, M.R., Tavares, S.F. and Bragança, L., 2022. The ecodesign methodologies to achieve buildings' deconstruction: A review and framework. *Sustainable Production and Consumption*, 30, pp.566–583. https://doi.org/10.1016/j.spc.2021.12.032

Niu, Y., Rasi, K., Hughes, M., Halme, M. and Fink, G., 2021. Prolonging life cycles of construction materials and combating climate change by cascading: The case of reusing timber in Finland. *Resources, Conservation and Recycling*, 170, p.105555. https://doi.org/10.1016/j.resconrec.2021.105555

Pomponi, F., Hart, J., Arehart, J.H. and D'Amico, B., 2020. Buildings as a Global Carbon Sink? A Reality Check on Feasibility Limits. *One Earth*, 3(2), pp.157–161. https://doi.org/10.1016/j.oneear.2020.07.018

Rüter, S., 2012. *Ökobilanz-Basisdaten für Bauprodukte aus Holz*. Braunschweig: Johann Heinrich von Thünen-Institut.

Sikkema, R., Styles, D., Jonsson, R., Tobin, B. and Byrne, K.A., 2023. A market inventory of construction wood for residential building in Europe – in the light of the Green Deal and new circular economy ambitions. *Sustainable Cities and Society*, 90, p.104370. https://doi.org/10.1016/j.scs.2022.104370

Szichta, P., Risse, M., Weber-Blaschke, G. and Richter, K., 2022. Potentials for wood cascading: A model for the prediction of the recovery of timber in Germany. *Resources, Conservation and Recycling*, 178, p.106101. https://doi.org/10.1016/j.resconrec.2021.106101

Thonemann, N. and Schumann, M., 2018. Environmental impacts of wood-based products under consideration of cascade utilization: A systematic literature review. *Journal of Cleaner Production*, 172, pp.4181–4188. https://doi.org/10.1016/j.jclepro.2016.12.069

United Nations Environment Programme (UNEP), 2023. *Building Materials and the Climate: Constructing a New Future*.

United Nations Environment Programme (UNEP), 2021. *2021 Global Status Report for Buildings and Construction: Towards a Zero Emission, Efficient and Resilient Buildings and Construction Sector*. Nairobi: UNEP.

Vis, M., Mantau, U. and Allen, B., 2016. *CASCADES: Study on the Optimised Cascading use of Wood*. Luxembourg: Publications Office of the European Union.

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E. and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. *International Journal of Life Cycle Assessment*, 21, pp.1218–1230. https://doi.org/10.1007/s11367-016-1087-8