COMPARATIVE LIFE-CYCLE ASSESSMENT OF A MASS TIMBER BUILDING AND CONCRETE ALTERNATIVE[1]

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Abstract. The US housing construction market consumes vast amounts of resources, with most structural elements derived from wood, a renewable and sustainable resource. The same cannot be said for all nonresidential or high-rise buildings, which are primarily made of concrete and steel. As part of continuous environmental improvement processes, building life-cycle assessment (LCA) is a useful tool to compare the environmental footprint of building structures. This study is a comparative LCA of an 8360-m^2, 12-story mixed-use apartment/office building designed for Portland, OR, and constructed from mainly mass timber. The designed mass timber building had a relatively lightweight structural frame that used 1782 m^3 of cross-laminated timber (CLT) and 557 m^3 of glue-laminated timber (glulam) and associated materials, which replaced approximately 58% of concrete and 72% of rebar that would have been used in a conventional building. Compared with a similar concrete building, the mass timber building had 18%, 1%, and 47% reduction in the impact categories of global warming, ozone depletion, and eutrophication, respectively, for the A1-A5 building LCA. The use of CLT and glulam materials substantially decreased the carbon footprint of the building, although it consumed more primary energy compared with a similar concrete building. The impacts for the mass timber building were affected by large amounts of gypsum board, which accounted for 16% of total building mass. Both lowering the amount of gypsum and keeping the mass timber production close to the construction site could lower the overall environmental footprint of the mass timber building.

Keywords: Cross-laminated timber, environmental assessment, life-cycle analysis, tall wood building.

INTRODUCTION

The building industry is a heavy user of resources and is responsible for more than 30% of total global energy consumption and for about 40% of global

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carbon dioxide emissions (Jones et al 2016; Berardi 2017). Developing energy-efficient and low-impact buildings has become increasingly important. The use of wood as a building material can provide substantial economic and environmental benefits (Ritter et al 2011). Mass timber products, including cross-laminated timber (CLT), glue-laminated timber (glulam), and nail-laminated timber, have been demonstrated to be green building materials with a lower carbon footprint than their concrete and steel alternatives (Perez-Garcia et al 2005; Karacabeyli and Douglas 2013; Bowers at al. 2017; Gu and Bergman 2018). Also, CLT and other mass timber products offer additional advantages such as faster erection times, easier material handling, a high level of prefabrication at the material manufacturing site, and less waste generation and noise pollution during the construction stage (Kremer and Symmons 2015; Connolly et al 2018; Smith et al 2018). In particular, the construction phase of a mass timber building can result in substantial savings with quicker erection times, more than 50% faster than other alternative materials (APA 2019).

CLT is a massive structural composite panel fabricated with kiln-dried dimensional lumber stacked in three to nine layers arranged perpendicular to each other (APA 2012). The production of similar perpendicular engineered wood products dates back to the early 20th century in the United States (Walch and Watts 1923). The use of CLT in mid- to high-rise buildings began to appear several decades ago in European countries (FII 2016; Espinoza and Buehlmann 2018). More recently, CLT and other mass timber technologies have captured the interest of designers, developers, property owners, industry, and governments in North America (Podesto and Berneman 2016; Williamson and Ross 2016). The revised 2021 International Building Code includes provisions for new construction Type IV-A/B/C for up to 18 stories for business and residential buildings using mass timber (Breneman and Richardson 2019). Using mass timber in building systems could be a boost to the wood industry sector, but to gain the support of green building advocates, rigorous scientific analysis on the environmental impacts is required. The whole-building life-cycle assessment (LCA) is a method to analyze building environmental impacts based on ASTM E2921 (ASTM 2016) and EN 15978 (EN 2011) standards. However, only few LCA studies on CLT and other mass timber buildings are publicly available (Cadorel and Crawford 2018). These studies all agree that mass timber buildings have better environmental performance such as lower greenhouse gas (GHG) emissions compared with alternative concrete buildings, although different study periods or system boundaries were applied (Robertson et al 2012; Durlinger et al 2013; Grann 2013; Bowick 2015, 2018). LCA case studies for mass timber buildings in the United States are very limited (Gu and Bergman 2018; Pierobon et al 2019) because few buildings have gone beyond the concept stage. More importantly, there are very few studies that directly compare the LCA implications for mass timber and concrete steel buildings, with similar size, function, and operational energy performance. It is critical to conduct more studies to assess the environmental impacts of mass timber buildings and to further analyze the impacts on local communities, forest health, and the regional economy.

This study conducted a building LCA for a 12-story mixed-use tall wood building in Portland, OR, that comprises CLT and glulam as the main structural building materials. The LCA of this mass timber building was compared with a functionally equivalent concrete building system, with no wood structural elements. The environmental impacts of the two buildings were categorized using the Tool for the Reduction and Assessment of Chemical and other environmental Impacts (TRACI) 2.1 impact method (Bare et al 2012), and a detailed contribution analysis and carbon accounting metrics were performed. This research is part of a more comprehensive project investigating the CLT supply chain along with potential economic contributions and environmental implications of increased CLT and other mass timber building construction (Kelley and Bergman 2017). Results generated from this study will provide solid, transparent evidence on the environmental performance metrics for CLT and other mass timber buildings that can inform the public, building developers and owners, and policy makers.

MATERIALS AND METHODS

Goal and Scope

The goal of this study was to quantify the environmental impacts of a tall wood building built primarily with CLT and glulam structural elements and compare those impacts with a functionally equivalent building with traditional concrete materials. The target building for this cradle-to-site LCA study is an 8360-m^2, 12-story, mixed-use office and apartment complex. The building was designed to be built in Portland, OR, and to have the same fire-proofing performance, insulation, and energy consumption outcomes as a functionally equivalent concrete building design. Both building designs were completed by LEVER Architecture (Portland, OR) with additional structural design and analysis from their partner, KPFF Engineering (Seattle, WA). Both buildings comply with Type 1B fire-resistant construction code with noncombustible capacities of 2-h exterior walls, 2-h structural frame, 2-h ceiling/floor separation, and 1-h ceiling/roof assembly (Heppner 2019). The building structure components to compare include ceiling–roof, floors, foundation, postbeams, and walls.

Functional Unit and System Boundary

The functional unit for this study is defined as 1 m^2 of floor area of the whole building. The system boundary of this building LCA is defined as cradle-to-site, as illustrated in Fig 1, and includes the modules A1-A3 *Product Stage* and modules A4 and A5 *Construction Process Stage*. More specifically, in this study, module A1 *Raw materials supply* covers raw material acquisition (eg from tree seeding to log harvest, or cement and aggregate mining and production); module A2 *Transport* covers the transportation of raw materials to the manufacture plant (eg truck loading logs and transporting to primary and secondary wood products manufacturers, or transportation of cement and aggregate and rebar); module A3 *Manufacturing* covers the gate-to-gate production of secondary products (eg mass timber products processing and packaging at the plant, or formulated concrete); module A4 *Transport* covers the transportation of materials and products from the factory gate to the building site (eg trucking all construction materials to the building site), whereas the transportation of construction equipment to and from the site was excluded; and module A5 *Construction installation process* only covers the energy consumption to install building materials into the building (eg diesel usage by crane to lift CLT and pour/pump concrete), whereas ground works, labor assembly, land use, and other things were excluded.

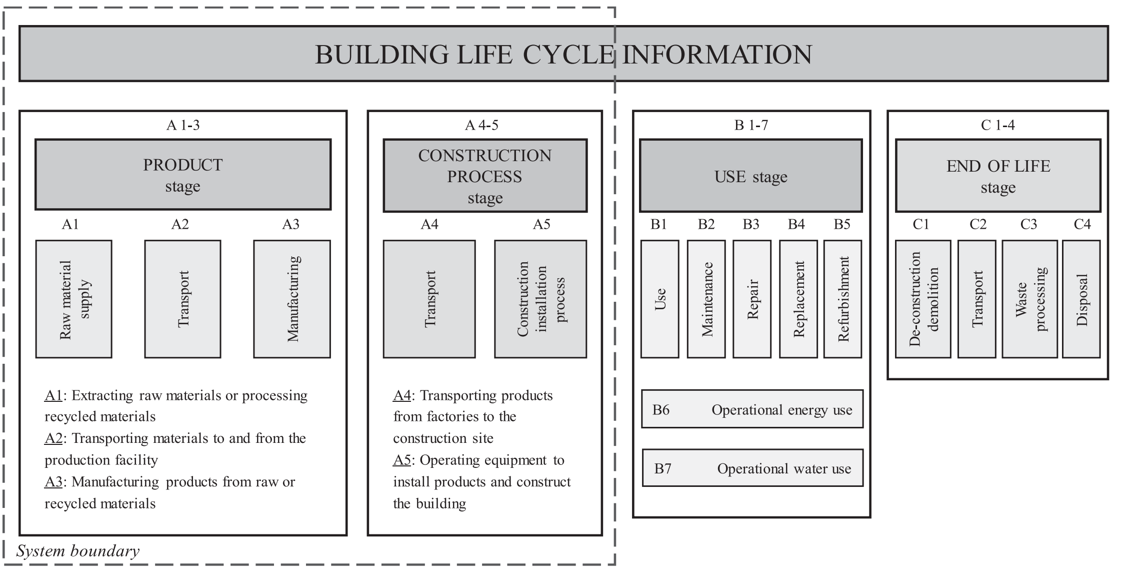

Figure 1. Cradle-to-site life-cycle assessment system boundary for the mass timber and concrete buildings.

Life-Cycle Inventory (LCI) and Impact Assessment

The LCI phase in this study measures the materials use (modules A1-A3), transportation (module A4), and direct energy (module A5) inputs for the construction process of the proposed CLT and concrete buildings. Table 1 summarizes the quantities of building materials used for the two buildings, which were designed with the same U-value. These quantities were provided by the building designer (LEVER Architecture). The building materials transport distances to the

Table 1. Quantities of materials and life-cycle inventory data sources for mass timber and concrete buildings.

Building section/material	Unit	Mass timber building	Concrete building	Database/source
Ceiling and roof				
Hollow structural steel	kg	11,449	7415	AIE
CLT	m^3	0.95		Chen et al 2019
1-inch mineral wool	m^2	285	285	DataSmart
Acrylic latex paint	L	3096	1548	DataSmart
1-inch polystyrene board	m^2	144	144	DataSmart
Steel sheet	kg	5693	5693	DataSmart
5/8-inch gypsum board, fire-resistant	m^2	14,907	5945	AIE
1/2-inch gypsum board, regular	m^2	4154	3337	AIE
Floors				
Acrylic adhesive	L	117	117	
CLT	m^3	1279		Chen et al 2019
Coated steel deck	kg	110	110	AIE
Hollow structural steel	kg	400	400	AIE
Concrete	m^3	932	1878	DataSmart
Mortar	kg	4737	4737	DataSmart
3/8-inch plywood	m^2	661	661	DataSmart/USLCI
1-inch polystyrene board	m^2	4067	4067	DataSmart
Rebar	kg	53,177	170,348	DataSmart
Steel sheet	kg	4193	875	DataSmart
Steel welded wire mesh	kg	110	110	AIE
60-mil TPO membrane	m^2	351	351	AIE
Foundation				
Concrete	m^3	125	149	DataSmart
Rebar	kg	38,590	57,884	DataSmart
Post and beam				
Hollow structural steel	kg	43,527	39,230	AIE
Composite wood I-joist	kg	60	60	DataSmart/USLCI
Concrete	m^3		162	DataSmart
Glulam	m^3	557		DataSmart/USLCI
Rebar	kg		22,089	DataSmart
Steel sheet	kg	830	823	DataSmart
Walls				
Aluminum extrusion	kg	31,039	31,051	DataSmart
CLT	m^3	502		Chen et al 2019
Hollow structural steel	kg	31,947	30,026	AIE
Concrete	m^3	48	438	DataSmart
Concrete masonry unit	kg	71,031	70,908	DataSmart
3/8-inch plywood	m^2	3230	3230	DataSmart/USLCI
Mortar	kg	90,113	89,824	DataSmart
Acrylic latex paint	L	9100	5143	DataSmart
1-inch polystyrene board	m^2	7643	7644	DataSmart
Silicone sealant	L	503	503	DataSmart
Rebar	kg	12,078	125,951	DataSmart
5/8-inch gypsum board, fire-resistant	m^2	57,330	47,097	AIE

construction site were provided by LEVER Architecture (Heppner 2019). It is noteworthy that concrete used a transportation distance of 24 km, and the CLT and glulam were sourced with a transportation distance of 320 km. Direct energy inputs for the construction installation were estimated as diesel usage using an empirical equation provided by Athena Sustainable Materials Institute (Finlayson 2019). The LCI of the CLT production process model was provided by the University of Washington (Chen et al 2019). Other building materials, transportation, and energy LCI data were sourced from the USLCI and US Ecoinvent 2.2 (DATASMART 2019) and Athena Impact Estimator (AIE) databases and from the Pacific Northwest forest resources, as listed in Table 1.

The life-cycle impact assessment (LCIA) integrates the LCI data of each building stage (modules A1-A5) to quantify the total life-cycle environmental impacts, following the ISO 14040 (ISO 2006a) and ISO 14044 (ISO 2006b) environmental management standards. The total environmental impacts were modeled using data sources in SimaPro 8.5 software (PRé Sustainability, Amersfoort, the Netherlands) and AIE for Building 5.6 software (Athena Sustainable Materials Institute, Ottawa, Canada), and the TRACI 2.1 impact method (Bare et al 2012) was used in SimaPro and AIE. The primary energy consumption, categorized as nonrenewable (fossil and nuclear) and renewable (biomass, solar, wind, and hydropower), was calculated using the embedded cumulative energy demand (CED) method v1.10 in SimaPro and AIE. The impact indicators calculated for each building material from the two software were extracted into Microsoft Excel spreadsheets and then integrated for further analysis.

Sensitivity Analysis

Although the United States has significant lumber manufacturing capacity, there is limited CLT manufacturing capacity. However, with increasing interest in this emerging product, new capacity is developing across the United States. Thus, CLT transportation distances to the construction site were varied in determining the portion of this specific variable on the whole-building environmental impact. The current distance was 320 km, which assumes transport from a nearby local facility. Sensitivity analyses included *middle distance* by truck (768 km) from Inland Northwest (INW), *long distance* by truck (465 km) and rail (4189 km) from eastern United States; and *oversea distance* by sea (21,333 km) from Europe, rail (1103 km), and truck (335 km).

RESULTS AND DISCUSSION

Comparison of Building Materials

The quantities of building materials of each building section (ceilings-roof, floor, foundation, postbeam, and wall) for the mass timber and concrete buildings are shown in Table 1. Generally, the mass timber building uses a total of 2376 m^3 of wood products with 98% CLT and glulam. In this study, mass timber usage is about 0.28 m^3 per m^2 of floor area. Other CLT and mass timber building designs have used between 0.1 and 0.45 m^3 per m^2 of floor area (Gustavsson et al 2010; Oregon BEST 2017; Gu and Bergman 2018). Specifically, the walls use 502 m^3 of 7- and 9-ply CLT, the floors use 1279 m^3 of 5-ply CLT, and the postbeams use 557 m^3 of glulam for columns and beams. In addition, the mass timber building also uses a significant amount of concrete and steel, eg 1104 m^3 concrete and 103,845 kg rebar. The concrete and steel are used on the foundation and also to stiffen the CLT floor elements. The concrete building uses no mass timber but uses 2627 m^3 of concrete and 376,272 kg of rebar. In addition, to comply with Type 1B fire-resistant construction code, approximately 36% more gypsum board is applied to the mass timber building than the concrete building.

As shown in Fig 2, the total mass of the mass timber building is about 68% of the functionally equivalent concrete building. It is important to keep in mind that the density of concrete (2400 kg/m^3) is much higher than the density of the two mass timber products and wood building products in general (550 kg/m^3). The total mass of the concrete building is 7.5 million kg for all

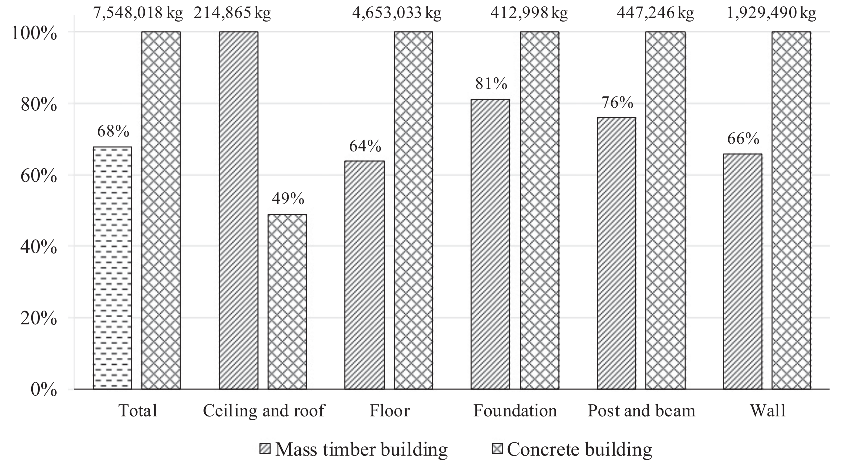

Figure 2. Total mass for the mass timber and concrete buildings.

five structural sections, whereas the total mass of the mass timber building is only 5.1 million kg. In the mass timber building, except for the ceilings-roof which uses more gypsum board and attached materials for fire resistance purposes, the mass of other building sections is about 64%, 81%, 76%, and 66% of the concrete building for floors, foundation, postbeams, and walls, respectively. Light-weight mass timber buildings tend to have lower carbon footprints and lower costs than heavier concrete buildings (Connolly et al 2018).

Environmental Impact Analysis

The comparative cradle-to-site whole-building LCIA results for 1-m^2 floor area of the mass timber and concrete buildings are shown in Table 2. Global warming contribution of the mass timber building was found to be 18% lower (193 kg CO_2-eq/m^2) than that of the concrete building (237 kg CO_2-eq/m^2). The mass timber building performs better in eutrophication than the concrete building (47% lower), whereas the concrete building has better performance in the impact categories of smog and acidification (3% and 16% lower than the mass timber building, respectively). In addition, the two buildings are essentially the same for ozone depletion (1% difference), which is dominated by the use of polystyrene insulation boards (XPS). The two buildings used about the same amount of XPS.

Primary energy consumption, also called CED, which describes the direct and indirect energy use throughout the life cycle of products, is an

Table 2. Life-cycle impact assessment results for 1-m^2 floor area by building types.

Impact category	Unit	Mass timber building	Concrete building	Percentage difference (%)
Global warming	kg CO_2 eq	193	237	−18
Ozone depletion	kg CFC-11 eq	1.91E-04	1.93E-04	−1
Smog	kg O_3 eq	15.74	15.22	3
Acidification	kg SO_2 eq	1.03	0.89	16
Eutrophication	kg N eq	0.19	0.36	−47
Total primary energy	MJ	2868	2673	7
Nonrenewable, fossil	MJ	2344	2371	−1
Nonrenewable, nuclear	MJ	198	242	−18
Renewable	MJ	326	61	439

important driver of environmental impacts and is indicative for many environmental problems (Huijbregts et al 2006). As shown in Table 2, the mass timber building has 7% higher CED than the concrete building, which is mainly caused by the relatively higher unit CED of 2629 MJ/m^3 for CLT than 1540 MJ/m^3 for concrete. In the mass timber building, the large mass of CLT results in CLT having the highest CED (23% of building CED), followed by 22% for glulam. In the alternative concrete building, rebar has the greatest CED, accounting for 47% of building CED, followed by 21% for concrete. In addition, fossil fuel accounts for 82-90% of building CED for both buildings, and renewable energy accounts for 12% and 2% of building CED for the mass timber and concrete buildings, respectively. As expected, the mass timber building also uses substantially higher renewable energy than its concrete alternative building. This was mainly because of the wood products manufacturer using mill residue as an alternative heating source to dry the lumber before CLT and glulam production (Bowers et al 2017; Chen et al 2019).

The normalized environmental impacts and energy demand for the mass timber and concrete buildings at different life-cycle phases are illustrated in Fig 3. The product phase (modules A1-A3) is the dominant contributor, accounting for 88-98% in all impact categories for the two buildings. The transport phase (module A4) contributes 3-8% to the impact categories of global warming, smog, acidification, eutrophication, total primary energy, and fossil fuel consumption for the mass timber building. Because of the longer transportation distance of wood building materials from the manufacturer to construction site, eg 320 vs 24 km for materials for the concrete building, the transportation impacts are greater in the mass timber case than in the all-concrete case.

The construction installation phase (module A5) contributes a small fraction (1-5%) in all impact categories except for ozone depletion, although the impacts are consistently lower for the less dense mass timber materials than for concrete. The assessment for this phase, module A5, is based on the estimation of diesel consumption used for lifting all the building materials (Finlayson 2019). When more empirical data on diesel consumption by construction equipment and time for mass timber building construction are collected, more precise LCIA results can be reported for this phase.

Figure 4 compares the product phase (modules A1-A3) environmental impacts from each building section for the mass timber and concrete buildings. Floor is the largest contributor for both

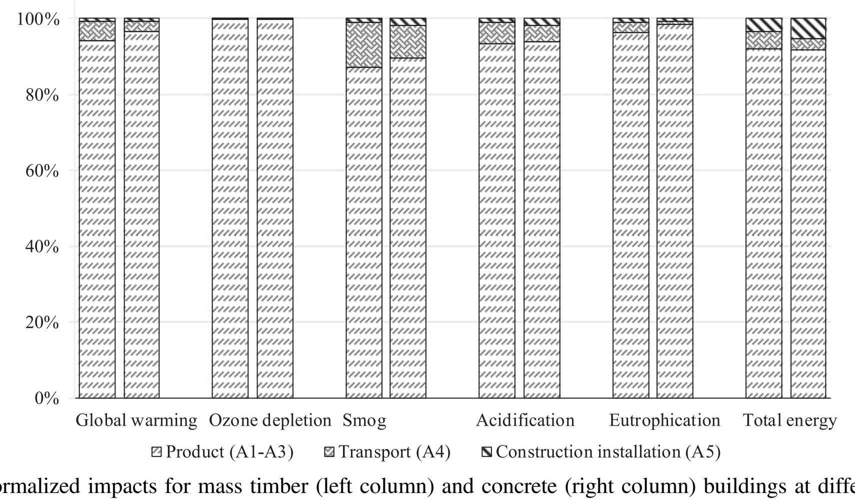

Figure 3. Normalized impacts for mass timber (left column) and concrete (right column) buildings at different life-cycle phases.

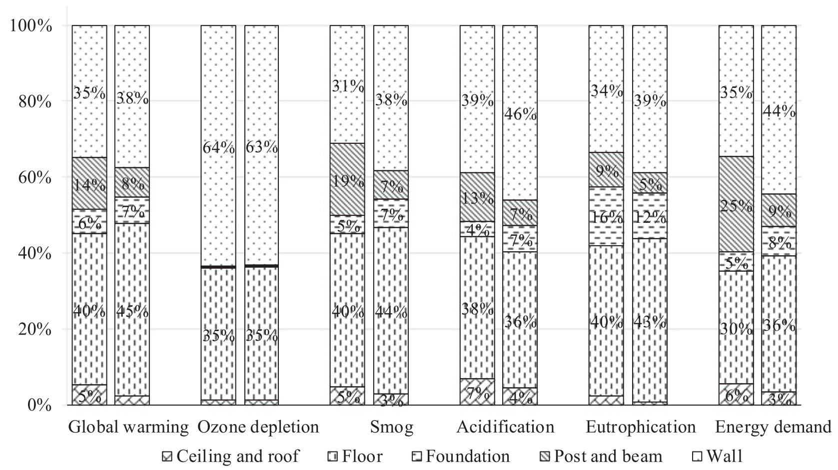

Figure 4. Normalized impacts (A1-A3) from different building sections for mass timber (left column) and concrete (right column) buildings.

buildings and accounts for 40-50% in the impact categories of global warming, smog, and eutrophication, followed by the wall sections at 31-39%. Specifically, the building materials of CLT and concrete/rebar in the mass timber building, as well as concrete/rebar in the concrete building, dominate the impacts of the floor component (93-99%). For acidification, wall is the largest contributor, accounting for 39-48% of impacts for the two buildings. This is caused by the use of gypsum board. Wall and floor together contribute 98-99% of the ozone depletion for both buildings, which is because of the insulation material, eg polystyrene boards (XPS). Although XPS accounts for only 0.4% of the total mass quantities in wall components in the mass timber building, it contributed more than 99% of total ozone depletion impacts. We strongly suggest that an alternative product be considered. The ceilings-roof, foundation, and postbeams together contribute less than 27% to all impact categories for the two buildings, although the mass timber building contributes a higher fraction than the concrete building in these building sections. These differences are caused by the greater use of gypsum board in the ceilings-roof, rebar in the foundation, and glulam in the postbeams.

MasterFormat is a standard for organizing specifications and other written information for commercial and institutional building projects in the United States and Canada. It provides a structured hierarchy for building construction requirements and associated activities (Tecchio et al 2018). To further analyze the environmental impact contribution, the building materials' LCIs were grouped into individual construction divisions based on MasterFormat (CSI 2016), eg *Division 03: Concrete*; *Division 04: Masonry*; *Division 05: Metals*; *Division 06: Wood, Plastics, Composites*; *Division 07: Thermal and Moisture Protection*; and *Division 09: Finishes*. Figure 5 shows the comparison in the product phase (modules A1-A3) of the environmental impacts from individual construction divisions for the mass timber and concrete buildings. The two buildings have significant differences in all impact categories except for ozone depletion, which was dominated by *Division 07* for both buildings, eg XPS. Because the insulation packages are essentially the same, materials such as XPS, aluminum panels, mineral wool, sealants, adhesives, and TPO membranes dominate the impacts. The total environmental impact of the concrete building is dominated by *Division 03,* consisting of concrete and rebar, which accounts for 72%, 72%, 61%, and 86% in the impact categories of global warming, smog, acidification, and eutrophication, respectively. These numbers range

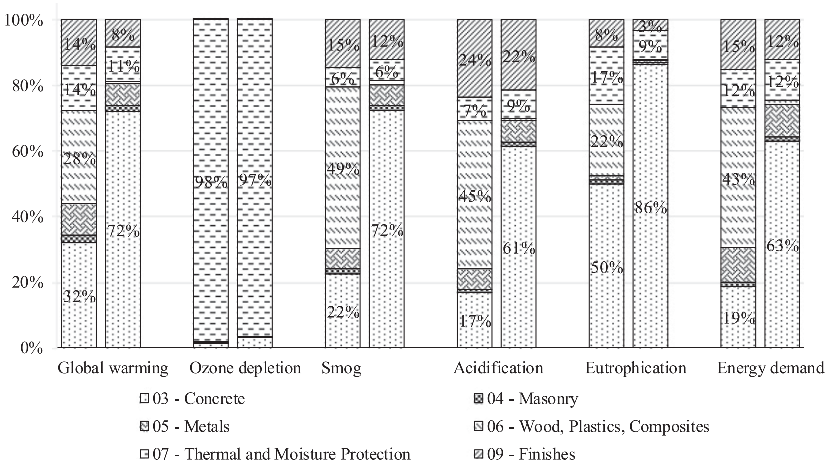

Figure 5. Normalized impacts (A1-A3) of different construction divisions for mass timber (left column) and concrete (right column) buildings.

from 17% to 50% for the mass timber building. Approximately 58% concrete and 72% rebar in *Division 03* of the concrete building are substituted by 2339 m^3 CLT and glulam in *Division 06* for the mass timber building, which resulted in *Division 06* in the mass timber building contributing 28%, 49%, 45%, and 22% to the impact categories of global warming, smog, acidification, and eutrophication, respectively. The two buildings have no significant differences in *Division 07*. In addition, in the mass timber building, *Division 09* contributes relatively more to all impact categories than it does in the concrete building, which is largely caused by the use of 36% more gypsum board in the mass timber building compared with the concrete building.

Carbon Analysis

Biogenic carbon refers to CO_2 emissions that originate from biological sources such as plants, trees, and soil (Harris et al 2018). In LCA studies of durable wood products, it is assumed that harvested timber products will be replaced sustainably by new growth in managed forest land, and therefore, the biogenic CO_2 emissions are considered to be carbon neutral from the climate change prospective. The Intergovernmental Panel on Climate Change (IPCC 2006) also supports the carbon neutral hypothesis, which considers the CO_2 emissions from biomass as part of the natural carbon cycle. The carbon in wood is accounted for as stored CO_2 during the lifetime of the product or building. Such stored carbon is estimated by average carbon content of 50% of dry mass of wood products. This analysis assumed a service life of 100 yr for the mass timber building, which equates to the same time frame used for accounting for GHG emissions in this study. As shown by this LCI analysis and Fig 6, biogenic CO_2 emissions from the mass timber and concrete buildings were 81 and 3.4 kg/m^2 of floor area, respectively. These results were closely aligned with the consumption of renewable energy in the two building types. The

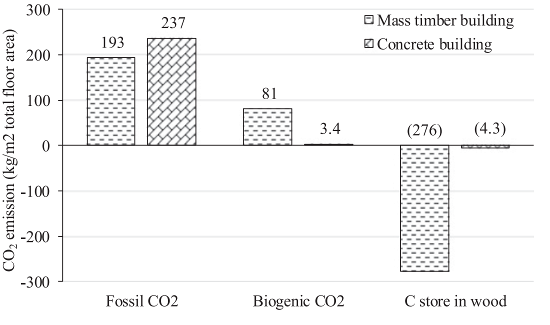

Figure 6. Comparison of CO_2 emissions for mass timber and concrete buildings under different carbon accountings.

sequestered CO_2 values in wood products were about 276 and 4.3 kg/m^2 of floor area for the mass timber and concrete buildings, respectively. As previously calculated, the GHG emissions for the CLT and concrete buildings were 193 and 237 kg CO_2 eq/m^2 of floor area, respectively, which is about 18% different. More significant differences were observed when biogenic carbon and sequestered carbon were combined, resulting in values of CO_2 emissions for the mass timber and concrete buildings of -2.7 and 236 kg/m^2 of floor area, respectively.

Sensitivity Analysis

Transportation accounts for about 5% of the total global warming impact emissions for the mass timber building. But given that there is a limited production infrastructure for CLT, it is worth considering the effects of different production/transportation alternatives on the overall global warming impacts of the building. CLT transportation has a global warming impact of 3.4 kg CO_2 eq/m^2 of floor area when assuming local production and transportation (320 km). Thus, with limited CLT production in the United States, it is important to understand the implication of longer transportation distances. Figure 7 shows the global warming impacts of different CLT transport distances and, specifically, the effects of sourcing CLT from INW, the eastern United States, or Europe. This analysis shows that the global warming impact of CLT transportation increased from 3.4 to 8.2, to 16, to 47 kg CO_2 eq/m^2 of floor area with the increasing levels of distance, respectively (Fig 7), which also accounts for 59%, 73%, and 89% of total impacts in the transport phase (module A4) for the three projected regions. Meanwhile, as shown in Fig 7, the transport phase (module A4) contributes less than 5% to the global warming impact compared with the module A1-A5 impacts under the local (within 320 km) assumption, and this ratio would increase to 7%, 10%, and 22%, respectively, if sourcing the CLT material from the three other locations.

The CLT transport distance revealed substantial changes to the differences between the mass timber and concrete buildings in environmental impacts. The mass timber building outperformed the concrete building in global warming with 18%, 16%, and 13% lower impacts when sourcing from local and projected INW and eastern US regions. However, the mass timber building had 0.2% higher global warming impact than the concrete

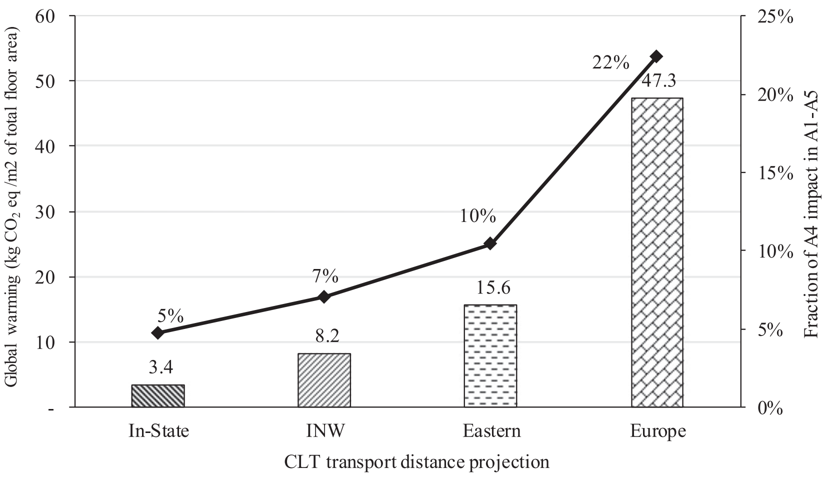

Figure 7. Global warming impacts from transportation of cross-laminated timber (CLT) materials to the building site (assuming CLT manufacturer in-state with a distance of 375 miles; INW: Inland Northwest region in the United States, Eastern: eastern United States, and Oversea: Europe) and the fraction of A4 impact in total A1-A5 for the mass timber building.

building if CLT was sourced from Europe because of the long transportation distance.

Study Strengths and Limitations

A strength of this study was the detailed building design information for two equivalent buildings by our highly qualified architectural and structural engineering partners. The study evaluated the structural elements, modules A1-A5, with the expectations that the bill of the materials for the two buildings incorporated the same U-value. Although mineral wool was incorporated into the analysis at the same quantities, its impacts were less than 0.3%. A limitation of this study was the lack of detail on the CLT manufacturing process. This lack of detail includes energy consumption in the manufacturing, proprietary details such as resin use, and the yield of CLT from dimensional lumber. In this study, the building components were limited to elements that were most different, eg the ceilings-roof, floors, foundation, post-beams, and walls. Other equivalent components such as windows, doors, plumbing, and electricity were excluded in the scope of this study. Construction site data including equipment use, electricity use, and labor count were not available for this study. Therefore, an empirical equation provided by the Athena Sustainable Materials Institute and based on building height was used. As with any LCA, additional data on specific processes, eg CLT manufacturing to concrete transportation, will improve the value of the analysis.

CONCLUSION

In this study, a comparative cradle-to-site LCA of a mass timber, tall wood building, and a functionally equivalent concrete building was conducted. This study shows that the mass timber building outperformed the concrete building on a number of environmental impact categories, eg global warming, ozone depletion, and eutrophication, whereas the concrete building showed better performance on smog and acidification, as well as total primary energy demand. The product phase (modules A1-A3) contributed more than 66% of total cradle-to-site (modules A1-A5) impacts in all impact categories for both buildings. The mass timber building was much lighter, 68% of the total weight of the concrete building. Even with the use of concrete and steel in the foundation and CLT floor systems, the mass timber building used 58% of the concrete and 72% of the rebar of the concrete building. Floors and walls were major environmental contributors in building sections. CLT and concrete were the hotspot for the tall wood building, and concrete and rebar were the hotspot for the concrete building. The required use of more gypsum board for mid- to high-rise mass timber buildings to comply with building codes increased global warming, smog, acidification, and eutrophication. The CLT building had lower CO_2 emissions than the concrete building when biogenic carbon and sequestered carbon were included. Sensitivity analysis showed that the environmental impacts for CLT transport distance, including sourcing from European countries, could reverse the advantages of all impact categories for the mass timber building in this study. Further work will focus on environmental impacts at the use and end-of-life phases.

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