UpStream Documentation

ARC 2021-22 Research Report

Biogenic carbon accounting method for upstream forest & end-of-life: A regional approach

06/15/2022

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Project Introduction

The open-source *UpStream Forestry Carbon + LCA Tool* (*UpStream*) that was developed during ARC 2020-21 integrates the impact of different forestry practices and product end-of-life scenarios with current LCA data. In 2021-22, the development team identified three key areas of improvement: specified forest operation and transportation emissions in raw material supply stage, end-of-life research around municipal wood waste data, and investigation of mass timber common bay model designs and their carbon impacts.

The three aspects are closely tied to the UpStream development and contribute to the future version of the tool. Designers and builders should understand the environmental impact of different forest management, and the transportation distance contributes significantly to the wood products LCA. With region-specific municipal waste information, we can achieve a more realistic estimation for a building's end of life. At the design level, understanding the component details, reuse potential and end of life limitations in the common mass timber grid design promotes high deconstructability and reusability which enables longer carbon storage and less raw material consumption. This report will further investigate the impacts in the following chapters.

Research Focuses

Forest Operation and Transportation Carbon Emissions

Pre-commercial thinning has effects on forest growth, yield, and mortality (Suzanne W Simard, et al., 2004). The Consortium for Research on Renewable Industrial Materials (CORRIM) reports the log harvest intensity based on the industry average (table 1).

However, the environmental impacts vary significantly depending on the forest site conditions and thinning operation intensity. It is critical to integrate the carbon impacts with different levels of intensity of the pre-commercial thinning operations into cradle-to-grave life cycle analysis of wood products in buildings.

This chapter will develop the specified life cycle assessments of lumber, and, in particular, focus on different levels of intensity of the forest operations (A1), the process logistics to provide a comparative analysis of lumber production in the PNW, and the transportation distance (A2) from the forest to the sawmill and from the sawmill to manufacture which are integrate into UpStream Carbon Calculation Tool development. The carbon impacts from A1 and A2 are based on CORRIM studies.

Customized forest operation scenarios and project-specific transportation distances enable designers to conduct sensitive studies and model flexibilities to understand the environmental impact of forest management. It is significant for designers and builders understand the carbon footprint of each procurement decision and be intentional about the forest we choose.

Products	**Value**	**Units per m3**	**Allocation, %**
Roundwood sawlogs, softwood, green, at logyard	1.00E+00	m^3	99.4
Roundwood sold off site , softwood, green, at logyard,	5.90E-03	m^3	0.6
Resources			
Water, process, surface	2.24E+00	kg	
Water, process, well	2.02E+00	kg	
Materials/fuels			
Softwood logs with bark, harvested at average intensity site in Pacific Northwest US	1.01E+00	m^3	
Transport, combination truck, diesel powered	9.89E+01	tkm	
Diesel, loaders and haulers	4.00E-01	l	
Gasoline, loaders and haulers	4.36E-03	l	
Propane, loaders and haulers	5.38E-03	l	
Lube oil, in engines of loaders and haulers	2.18E-03	l	
Hydraulic fluid for loaders and haulers	3.30E-03	l	
Antifreeze, 50% solution, loaders and haulers	3.64E-04	l	
Transmission fluid, loaders and haulers	2.80E-04	l	
Other lubes and grease for loaders and haulers	1.30E-03	l	
Hydraulic oil for stationary equipment	1.50E-03	l	
Greases, stationary equipment	4.20E-04	l	
Oils, stationary equipment	4.40E-04	l	
Solvents for cleaning	1.90E-06	kg	
Landfill, woody material	1.57E-03	kg	
Landfill, dirt and rocks	2.42E-03	kg	
Landfill, other organics	7.26E-05	kg	
Landfill, other inorganics	2.91E-04	kg	
Recycle, metals	1.33E-04	kg	
Recycle, used oil	8.84E-05	kg	
Recycle, antifreeze	1.16E-05	kg	
Recycle, bulbs and batteries	1.50E-06	kg	

Table 1, Inputs and outputs for the logyard process. Values are per m3 of wood leaving logyard and delivered to sawmill for PNW of US

This section documents three additional harvest intensity levels (low, medium, and high) on top of the national average harvest intensity which are cited from CORRIM studies and used as inputs for log production logistics in the UpStream. According to CORRIM softwood lumber LCA (2020), timber harvesting activities include four components: felling (severing the standing tree from the stump), processing (bucking, limbing and/or topping) which involves removal of non-merchantable limbs and tops and cutting of the tree into merchantable and transportable log lengths, secondary transportation (called skidding on gentle slopes and yarding on steep slopes),which is a transportation step that moves trees or logs from the point of felling to a loading point near a haul road; and loading (moving logs from the ground to haul vehicles). Hauling logs from the forest to manufacturer emission will be discussed in the transportation section.

Log extraction includes seeding, forest management and logging (figure 1). Table 2 demonstrates the different equipment allocation for thinning and final harvest by level of thinning intensity. The planting density, fertilization application, precommercial thinning, commercial thinning and final harvest volume per unit area varies by the management intensity classes (table 4).

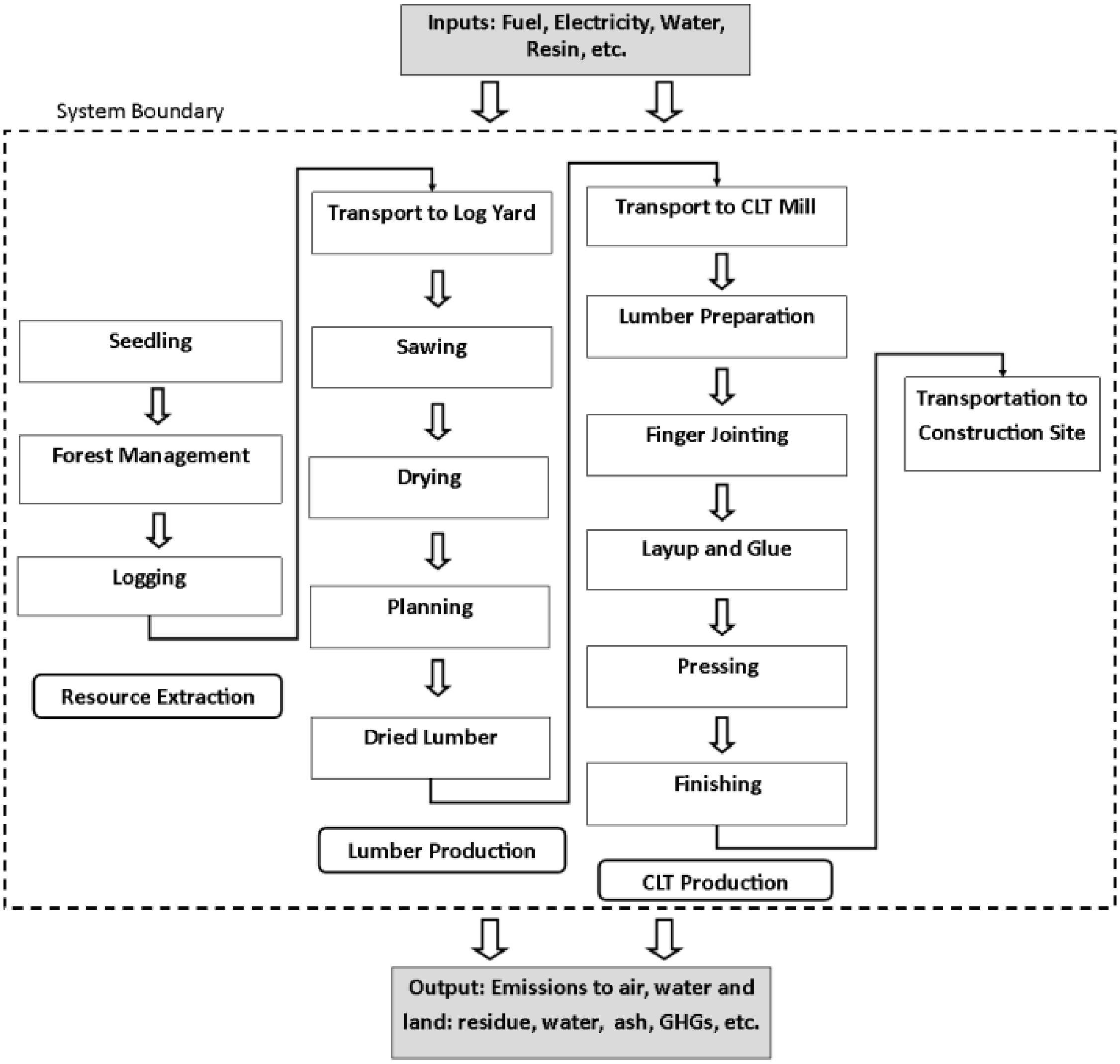

Figure 1, Resource extraction system boundary in the cradle-to-gate LCA for lumber, Chen, C., et al., 2019.

Management Intensity	Thinning	Final Harvest (usage per final volume harvested)
Low intensity site		
Chain saw	NA	100%
Cable yarder, large	NA	100%
Loader	NA	100%
Medium intensity		
Chain saw	19.6%	80.4%
Cable yard, medium	19.6%	
Cable yarder, large		80.4%
Loader	19.6%	80.4%
High intensity		
Chain saw	12.6%	87.5%
Cable yard, medium	12.6%	
Cable yarder, large		87.5%
Loader	12.6%	87.5%

Table 2, Equipment allocation by treatment and management intensity (CORRIM, Softwood lumber PNW LCA 2020).

Management intensity class prescription	Low Intensity	Medium Intensity	High Intensity	Weighted Average
Rotation age (yr)	*45*	*45*	*45*	
Planting density, trees	988	1,482	1,482	1,275
Fertilization	*None*	*None*	*Years 20, 30, 40*	
Pre-commercial thinning	*None*	*Year 15*	*Year 15*	
Final thinned density, trees	NA	740	680	
Commercial thinning, m^3		81	81	47
at year		*30*	*25*	
Final harvest, m^3	433	409	701	454
at year	*45*	*45*	*45*	
Total yield, m^3	433	490	782	501
Percent sawlogs	*100*	*100*	*100*	

Table 3, Input assumptions for three levels of management intensity in the PNW. (A single estimate of the average volume harvested per unit area was developed by weighting three combinations of site productivity and management intensity.) Non italicized values are per hectare (Puettmann et al. 2013).

UpStream documented the CORRIM studies and developed specified A1 carbon impacts by management intensities (table 4). The users can input the management intensity that is specific to customized forest scenarios.

Module A1 Management Intensity	kgCO2e/ per M3 of Lamstock
High	2.437
Medium	2.36389
Low	2.09582
Average	2.26

Table 4, Management Intensity carbon emissions per M3 of Lamstock

The transportation distance can vary significantly among different wood products which impacts its wood product carbon footprint. The industry average is unable to fully capture the specificity of that variance. Thus, granularity and specification of transportation distance can greatly improve the accuracy of wood product environment impacts.

The transportation includes (Module A2) log transportation (from logyard to sawmill) and lamstock transportation (from the sawmill to the manufacturer) and is documented on the basis of diesel truck transportation. According to CORRIM Softwood LCA PNW, the average log transportation distance is 108km which is applied for both Glulam and CLT LCA. Table 5 and table 6 illustrate the regional average lamstock transportation distance by products.

Glulam Production (dry) lamstock transportation distance	KM	Miles
PNW	173	108
SE	234	243

Table 5, Regional average lamstock transportation distance for Glulam production

CLT Production (dry) lamstock transportation distance	KM	Miles
PNW	272	169

Table 6, Regional average lamstock transportation distance for CLT production

UpStream allows the user to create custom scenarios by inputting the truck transportation distance for both log and lamstock transportation in kilometers. For instance, figure 2 represents the custom A1 and A2 output of UpStream and displays the breakdown of the following impacts: 1) the kgCO2e values disaggregated for both logging and lamstock production in module A1, and log transportation and lamstock transportation in module A2, 2) the overall net kgCO2e of the custom impact in A1-A3 modules, 3) the underlying data source/factors which is referenced in the summary chart.

A1		A2		A3	Total (kgCO2e)
31.13		25.32		491.02	547.47
Logging	Lamstock Production	Log Transportation	Lamstock Transportation	Manufacture	Total (kgCO2e)
2.36	28.77	15.25	10.06	Glulam-Glulam US - Industry-Wide EPD-AWC/CWC North American Glued Laminated Timbers 2020-yes	56.45

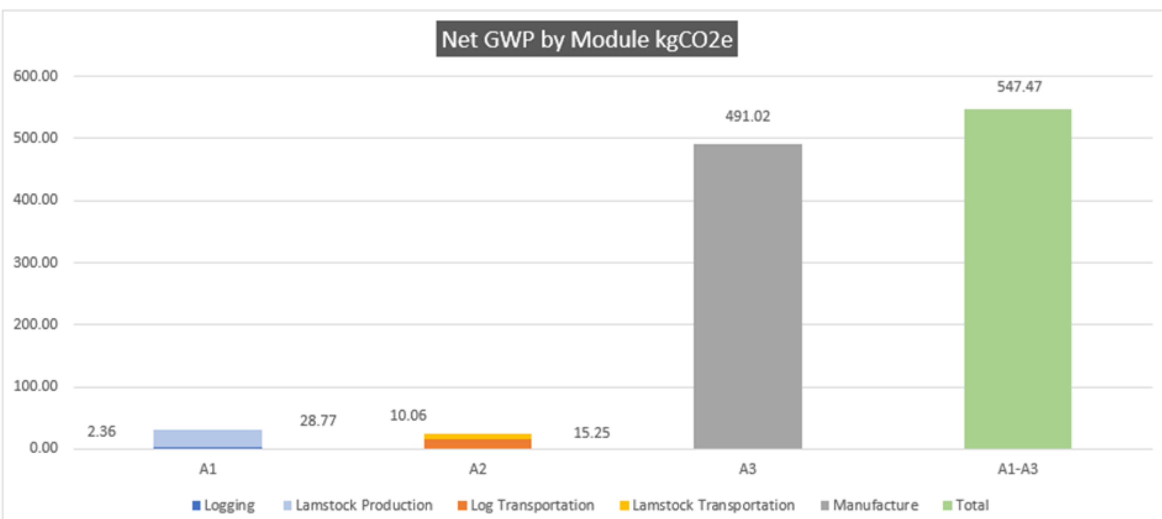

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Figure 2, Carbon Emissions for 1 M3 of Glulam in the Custom A1-A2, UpStream

Regional Municipal Data

To achieve a more realistic and accurate building end of life design, we need to understand the regional waste facility capabilities and waste diversion data. The USDA Southern Research Team states that new residential construction contributes significant wood waste volume to the Construction & Demolition (C&D) landfill sites (Bratkovich S., 2014). To reduce the amount of wood waste being landfilled, we should have a better understanding of the municipal wood waste data and the disposal pathways. It is difficult to track the volume of the wide range of products that generate wood waste and to understand the category they fit in at the municipal level. The wood waste data is dispersed among various government agencies. Lack of transparency and consistency leads to different results (Bratkovich S., 2014). Often there are knowledge gaps around waste disposal pathways definitions, the boundary of different EOL calculation tools and different wood products reuse potential. This section provides an overview of the wood product end of life definitions and the nature of the wood waste management from the municipal perspective. Comparisons are made among different studies and tools.

Wood products contribute a significant portion in MSW and C&D waste stream. The EPA identified MSW as trash or garbage from our homes, schools, hospitals, and businesses, such as product packaging and furniture. C&D is typical waste generation during building construction, renovation, demolition or maintenance activities (EPA). It is important to note that EPA excludes C&D from MSW tracking system which is widely adopted by BioCycle magazine, Columbia University (Shin 2014), and Seattle (2016). Table 6 shows that 35% of wood waste is reused, 16% is combusted, and 16% is landfilled in the MSW wood waste stream.

<table>
<tr><th></th><th>MSW Wood Waste</th><th>C&D Wood Waste</th></tr>
<tr><td>Recovered for products</td><td>35% (12.1 million tons)</td><td rowspan="3">52% (19.1 million tons)</td></tr>
<tr><td>Combusted (e.g., for energy)</td><td>16% (5.5 million tons)</td></tr>
<tr><td>Not Usable Material</td><td>16% (5.5 million tons)</td></tr>
<tr><td>Yet available for recovery</td><td>32% (11.1 million tons)</td><td>48% (17.3 million tons)</td></tr>
</table>

Table 6, Estimates for Wood Waste Recovery in the United States, Bratkovich S., 2014.

Various wood products may have different end of life diversions. Dimensional lumber can be recovered for reuse, sent to a landfill or combusted; MDF can be sent to a landfill or combusted (WARM, 2020). Large volumes of wood with fewer nails and connectors are more likely to be reused or are recycled into particle board. Figure 3 illustrates the general wood products management pathways in EPA Waste Reduction Model (WARM). It is important to know that the WARM model sees wood products as highly reusable materials (instead of recyclable) and models the associated impacts under the recycling management pathway (WARM, 2020).

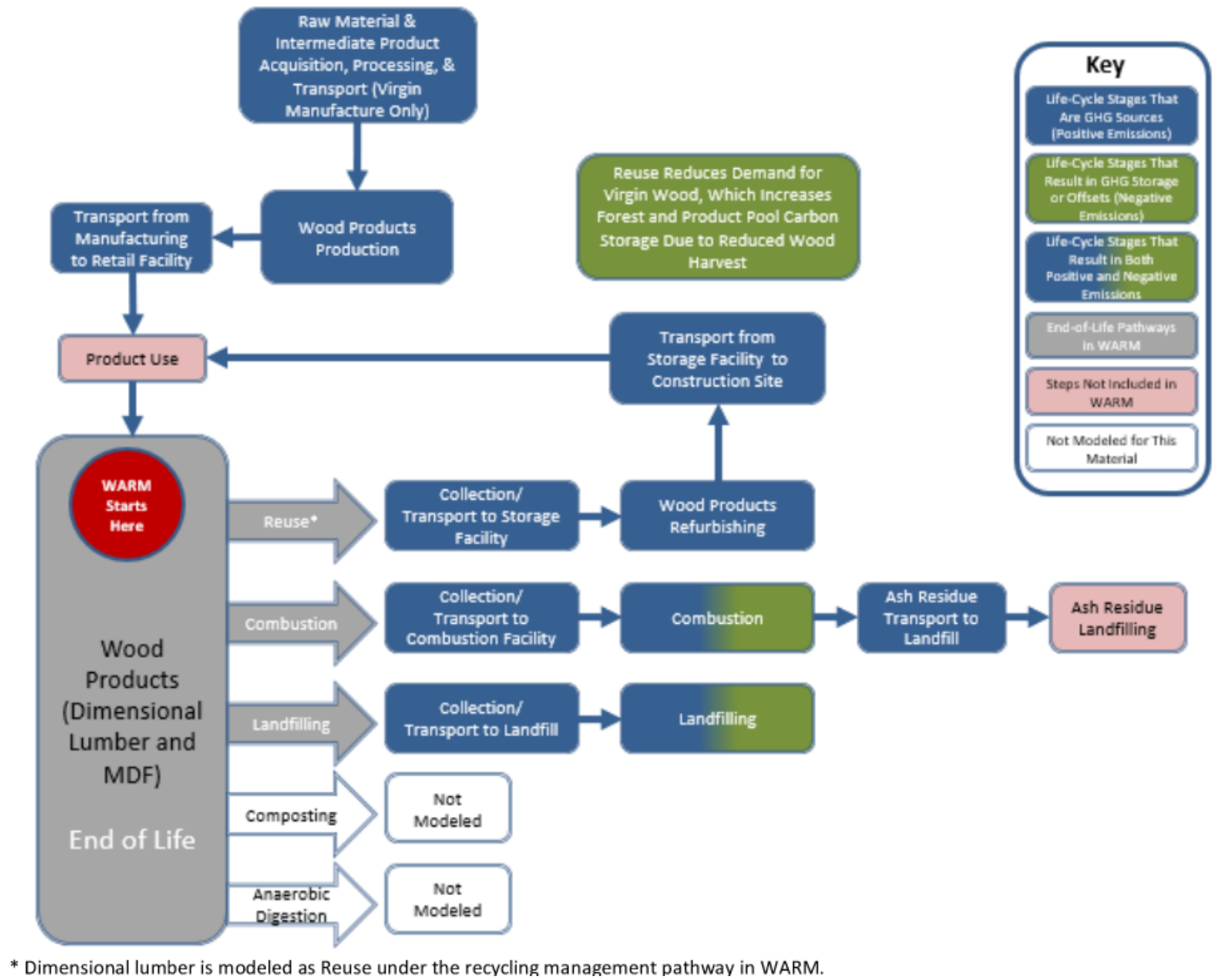


Figure 3, Life cycle of wood product in EPA WARM tool.

Table 7 shows that 17.14% of wood waste is recycled, 15.7% is combusted for energy, and 67.14% is landfilled based on the EPA national wood waste analysis. The wood waste diversions can vary by region. This report aims to understand the regional wood waste policies and analyze the regional wood waste diversion data in county level.

For instance, the City of Seattle landfill ban dictates that unpainted and untreated wood waste is not allowed to be placed in landfill site. Large timber and dimensional lumber are recommended to be used as salvaged building materials (CIWMB 2004).

Management Pathway	1960	1970	1980	1990	2000	2005	2010	2015	2017	2018
Generation	3,030	3,720	7,010	12,210	13,570	14,790	15,710	16,300	18,200	18,090
Recycled	-	-	-	130	1,370	1,830	2,280	2,660	3,030	3,100
Composted	-	-	-	-	-	-	-	-	-	-
Combustion with Energy Recovery	-	10	150	2,080	2,290	2,270	2,310	2,570	2,880	2,840
Landfilled	3,030	3,710	6,860	10,000	9,910	10,690	11,120	11,070	12,290	12,150

Table 7, 1960-2018 Data on Wood in MSW by Weight (in thousands of U.S. tons), EPA, 2018

The wood waste diversion variances among different counties in WA State are shown in table 8. UpStream will document and incorporate county level wood waste diversion data in future versions.

Region	Recycling & Reuse %	Burn for Energy %	Landfill %
King (include Seattle)	5.00%	59.29%	35.71%
Kitsap	0.05%	15.73%	84.22%
Pierce	1.65%	73.29%	25.06%
Snohomish	0.05%	45.91%	54.04%
Spokane	0.06%	69.20%	30.73%
Thurston	67.59%	30.02%	2.39%
Jefferson	0.00%	0.00%	100.00%
Skamania	0.00%	100.00%	0.00%
Walla Walla	0.00%	0.00%	100.00%
Wahkiakum	0.00%	24.49%	75.51%
Whatcom	0.00%	69.51%	30.49%
Whitman	0.00%	76.49%	23.51%

Skagit	0.00%	100.00%	0.00%
San Juan	0.00%	82.68%	17.32%
Pacific	0.00%	90.11%	9.89%
Okanogan	0.00%	25.00%	75.00%
Mason	0.00%	44.67%	55.33%
Lewis	0.00%	23.94%	76.06%
Island	0.00%	22.93%	77.07%
Jefferson	0.00%	18.61%	81.39%
Grays Harbor	0.00%	24.98%	75.02%
Grant	0.00%	73.19%	26.81%
Cowlitz	0.00%	45.77%	54.23%
Clark	0.00%	97.19%	2.81%
Clallam	0.00%	96.92%	3.08%
Yakima	0.00%	0.00%	100.00%
Chelan	0.00%	0.00%	100.00%
Klickitat	0.00%	0.00%	100.00%

Table 8, County level Wood MSW management in WA State, WA DOE, 2018

Mass Timber Bay Model Studies

For designers and builders, it is important to understand the common practice in mass timber design and what design details and components contribute to higher reusability and deconstructability. We should dive into connection and component details to analyze the deconstruction technique and reuse potential. However, it is challenging to quantify the reuse potential and identify the end-of-life distribution. This section investigates the common bay design of mass timber buildings, analyzes the range of possibilities of each end-of-life assumption based on design details, and shows the carbon contribution by each impact modules.

The bay model studies investigate the common mass timber bay design in PNW. Four mass timber bay models are compared with a steel baseline bay model. The generic bay model starts with the following assumptions. Structural engineers were provided with the assumptions to develop suitable size columns, beams, deck components and fasteners to achieve 30' by 30' grid (table 9). The bay types include mass timber, concrete composite, and steel hybrid system. The goal is to understand the common practice in mass timber system design by component and further reduce upstream and downstream carbon emissions.

Bay model assumptions:

- Location: near Seattle
- Code: WA 2018 IBC
- Office B Occupancy
- Type of construction: IV B, fully sprinklered
- Fire rating: 2 HR fire rating, primary structural frame and floor is design with charring
- Grid size: 30' x 30'
- Load:
    - 50 PSF superimposed dead load
    - 100 PSF live load
- Floor height: 10 floors @ 13'-6" height

WA Building Code

We should be aware of the current code requirements and limitations for reusing lumber. The WA 2018 international residential code states that dimensional lumber that identified with a grade mark, in good condition and devoid of areas of decay meet the requirements of Section R602.1.1 shall be used as No.2 grade and shall have structural properties assigned in accordance with current adopted standards.

Design Guidelines

Be more intentional by using alternative design approaches to increase deconstructability and recognize the limitation of the current common practice. There are many key drivers for material connection design, such as fire codes, thermal mass, lateral system, acoustic performance, and span (figure 4). Floor with composite action, also called the wet application, increases deconstruction difficulty and results in landfilling. Dry application (figure 4) contributes a higher recycling rate. The choice of connection hardware can determine the reuse potential. Using through bolts makes deconstruction easier and more effective than using screws. Larger and more durable screws are better than numerous small and brittle screws.

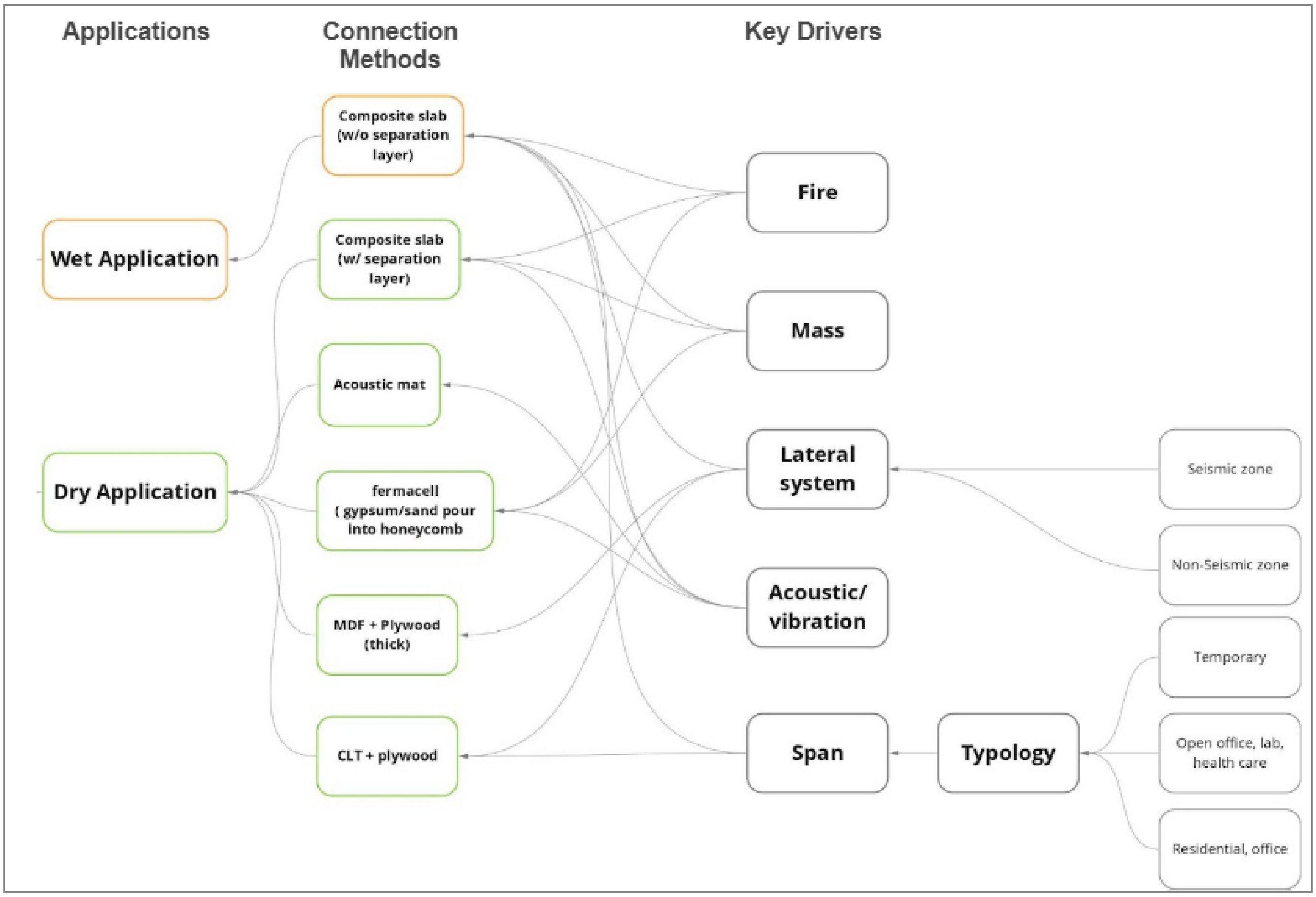


Figure 4, Key design drivers for floor assembly deconstruction design

Process

The ARC research group developed the bay model assumptions with the building criteria stated above. The group hosted workshops to further discuss the mass timber construction details for design for deconstruction. Structural engineers then provided detailed drawings in response to the finalized bay types. The research group collected and summarized the material quantities and connection types and developed 3D models in Revit. Embodied carbon emissions are postprocessed using Tally and UpStream. The conclusion discusses the deconstruction possibility for each bay.

Bay Model Comparisons

This section analyzes the connection details used for gravity, lateral and acoustic systems. Material quantities are specified by components and embodied carbon emissions are calculated using Tally and UpStream.

The following bay model studies are incomplete due to a lack of access to data and will be completed at a future date.

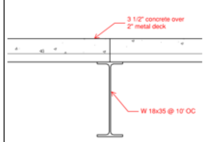
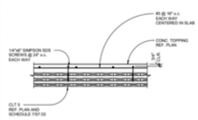
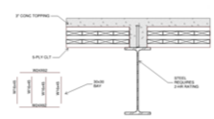
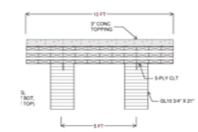
	Steel Baseline	**Bay 1: Typical Concrete Composite**	**Bay 2: Non-Composite**	**Bay 3: Steel & Mass Timber Hybrid**	**Bay 4: Double T Glulam Beams**
Connection Details					
Gravity	Steel beam, column	Glulam beam, column	Glulam beam, column	Steel beam (2-HR rating), 5-ply CLT	Composite double T Glulam & 5-ply CLT, precast concrete girders
Lateral	Concrete topping with metal deck	CLT & topping slab with composite acotion	CLT	Concrete topping coupled to steel beam	Concrete slab /plywood
Acoustic & Vibration	Topping slab	3" Topping slab	3" Topping slab (w/o composite action)	3" Topping slab	3" Topping slab (w/o composite action)

Table 9, Bay model system comparisons with steel baseline

Conclusion and Future Research

This report aims to connect environmental impact to procurement decisions, municipal waste scenarios and design intensions. Understanding the environmental impact of different forest management and the transportation distance is key for the wood product procurement. The common mass timber bay model studies dive into the design details and analyze the carbon impact by component, which helps us to better design for deconstruction. Linking the wood products' end-of-life pathway to the region-specific municipal waste information can generate more realistic and accurate carbon impact assumptions.

In the future research, it is critical to involve the deconstruction contractors in the end-of-life research and develop wood product recovery rates for different design scenarios. Given the wide range wood waste volume from different wood waste studies or tools, probabilistic statistical analysis is needed to present us the range of reuse potential.

In the bay model studies, we explored the design options for the PNW seismic zone. Future investigation would cover panelized acoustic systems in non-seismic zones, such as using dry application for the floor assembly in bay model 3.

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