

An aerial photograph of a dense forest, likely a coniferous stand, with many tall, thin trees visible. The image is dark and serves as a background for the text.

Efficient Product Utilization from Forest Stands

Efficient Product Utilization from Different Stands

By
Ethan Bloom

Graduate Committee Members:
Mikhail Gershfeld, Alison Kwok, Judith Sheine (Chair)

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Mass Timber and Climate Change



The Building Sector and Embodied Carbon

Increased emissions of greenhouse gases (GHGs) to the atmosphere from fossil-fuel based anthropogenic activity over the last couple centuries has stirred environmental concern. The building sector alone is responsible for nearly 40% of global annual carbon dioxide (CO₂) emissions with 23% of those total emissions attributed to building operation and 11% to material production and construction (known as embodied carbon) (Architecture 2030). Significant progress to increase building operational efficiency has been achieved over the years through innovations in renewable energy technologies as well as through well designed structures that take advantage of passive strategies and aim towards net zero design. Given the substantial amount of effort to mitigate the impacts of building operation, attention has recently turned to embodied carbon.

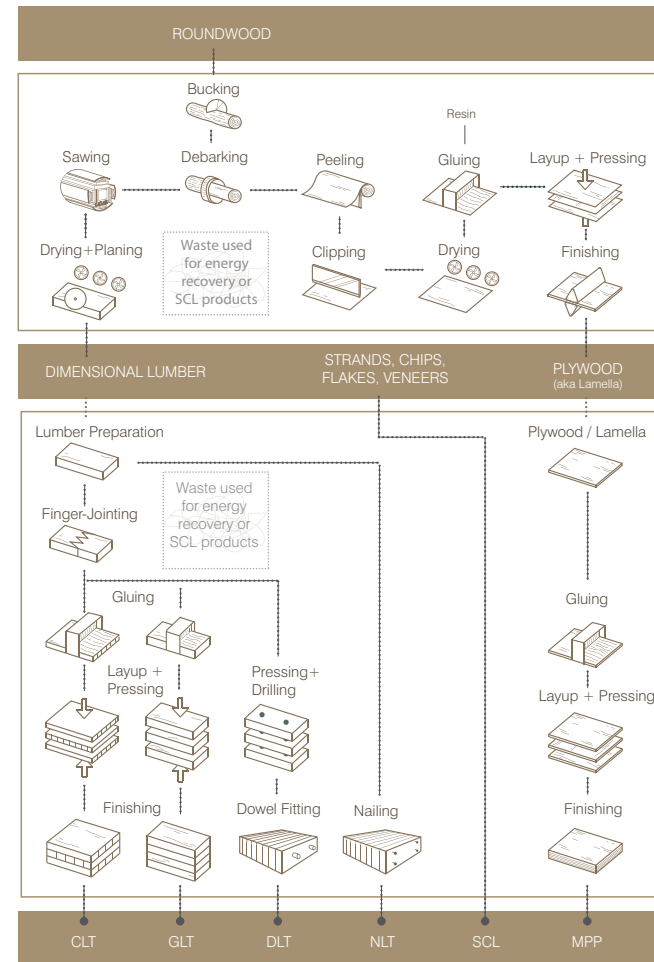
Unlike the impacts connected to building operational energy which can be reduced over time through building upgrades, the impacts of embodied carbon are generally mostly realized by the time a building is constructed. This is of particular concern as global building floor area is expected to double by 2060 (Architecture 2030), emphasizing the need to curtail embodied carbon emissions associated with new construction. To alleviate embodied carbon, innovation of novel building technologies combined with principles of circular economy must be employed. One such strategy that has gained popularity and offers great potential to lower embodied carbon in the building sector is mass timber construction. This study addresses mass timber (cross laminated timber and mass plywood panels) product efficiency from a forestry management and wood utilization perspective.



What is Mass Timber?

Mass timber serves as an umbrella term for a variety of engineered wood products (EWPs), technology that utilizes small, dimensioned lumber to form large composite wood components for structural applications. By combining standard, individual pieces of lumber and veneer into one finished product, EWPs offer greater dimensional stability, strength, and durability. Popular EWPs on the market include cross laminated timber (CLT), glulam, mass plywood panels (MPP), dowel laminated timber (DLT), nail laminated timber (NLT) and other structural composite lumber (SCL) products.

Projects that utilize EWPs as the main material for a building's structural frame are considered mass timber construction. Although wood has been used as a structural material for thousands of years and is well-known in traditional stick frame construction, mass timber adds a new spin on the familiar bio-based material. Mass timber's high strength-to-weight ratio not only allows EWPs to compete with other common structural materials, but also expands their application to a wider range of projects, particularly mid-to-high rise construction (Ramage et al., 2017).

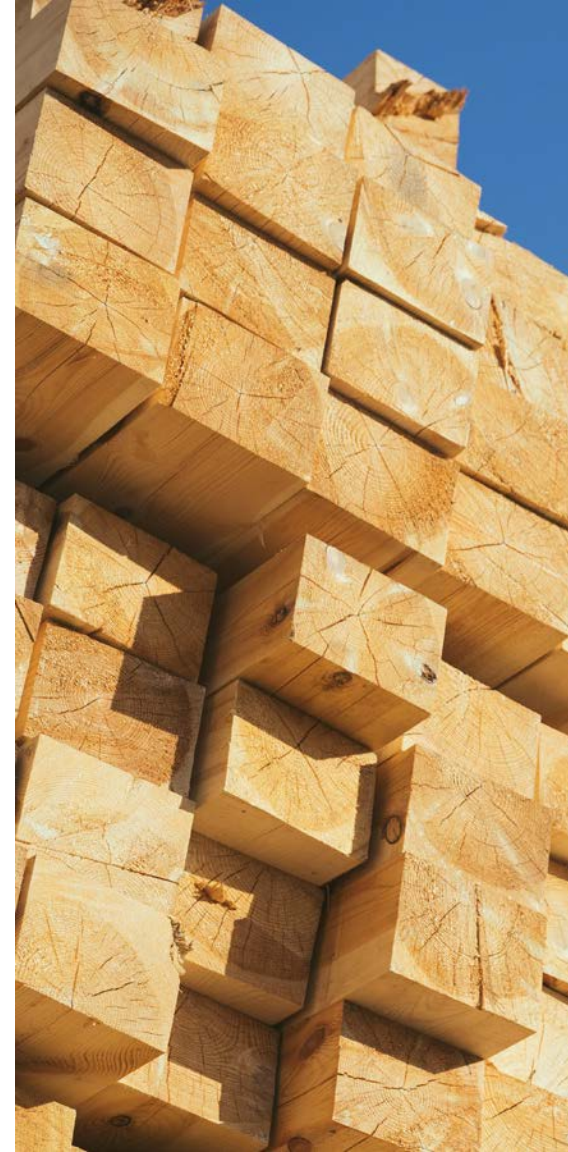


Why Mass Timber? An Environmental Perspective

The structural materials used in constructing primary load resisting systems are steel, concrete and wood. The structural properties and architectural qualities of each material have been exemplified in building projects across the globe. In light of growing effort to reduce building sector embodied carbon, the environmental impact of each material has become important in material selection considerations.

Mineral-based materials such as steel and concrete are highly extractive and energy intensive which result in significant amounts of embodied carbon through their production. Lots of energy, often supplied by fossil fuels, is needed to heat material in steelmaking (e.g., blast furnaces) or in clinker production (e.g., kilns) to achieve necessary ingredients. Since fossil fuels are finite resources, their emissions are considered permanent one-way additions of carbon into the atmosphere, increasing the GHG effect. The acquisition of mineral raw material faces a similar challenge as resources are extracted at a rate far exceeding their renewability. Besides insufficient future supply,

mining these raw resources often leads to degradation of the surrounding environment and ecosystems. Some emissions occur naturally in the production like the calcination of limestone in cement production, which are significant and difficult to avoid. There is room for improvement for steel and concrete with ongoing research looking to reduce each industry's respective embodied carbon.



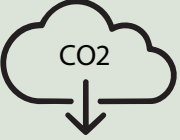
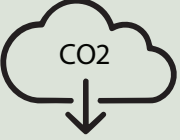
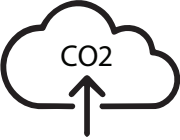
Why Mass Timber? An Environmental Perspective (continued)

Bio-based materials like timber, on the other hand, boast several environmental benefits. Timber is renewable, relatively energy non-intensive, and naturally sequesters carbon. As of late, harvested wood products (HWP) as opposed to conventional mineral-based materials, have been recognized as a potential climate change mitigation strategy to curb building sector embodied carbon by increasing the wood products pool, thereby allowing for greater carbon storage beyond the forest. Arguably the greatest emissions savings from utilizing HWPs, however, are associated with the substitution benefits of high-embodied energy materials for low-embodied energy materials. Replacing steel and concrete for timber can result in known reduced carbon emissions thus reducing the short-term climate impact of material production. Carbon sequestration may further improve the climate benefit over the long term. Lastly, logging and mill residue can constitute as bioenergy and contribute to energy substitution benefits. Emissions from bioenergy are considered temporary two-way emissions into the atmosphere as that carbon is biogenic and a part of the carbon cycle.

Timber

Concrete

Steel

Is it Renewable?	Is it Energy-Intensive?	Does it Store Carbon?
 Trees are renewable	 Comparatively less energy is required to manufacture timber products	 Wood sequesters carbon through photosynthesis
 Raw material such as limestone, shale, clay, marl, sand and other aggregates are finite resources	 A significant amount of energy is required to fuel rotary kilns for clinker production	 Concrete sequesters carbon through carbonation during service life and primarily at end-of-life
 Iron ore is a finite resource	 A significant amount of energy is required to fuel blast furnaces and basic oxygen furnaces in steelmaking	 Steel does not store carbon

Biogenic Carbon

What is Biogenic Carbon?

As trees grow through photosynthesis, they extract carbon dioxide (CO₂) from the atmosphere. Some of that CO₂ is used for growing functions and is released back to the atmosphere through respiration while the rest is stored as sugars and starches in the form of woody biomass. The longer trees grow, the more atmospheric CO₂ is sequestered into new biomass growth highlighting the direct correlation between carbon sequestration and wood yield. When a tree or part of a tree dies because of age or disturbance, carbon is no longer actively sequestered.

As a result, biogenic carbon will eventually move through different pools in the forest ecosystem, specifically from living biomass pools (i.e., aboveground, and belowground biomass like trees and roots respectively) to non-living carbon pools (i.e., soils, deadwood, and litter). Carbon may also be moved out of the forest ecosystem in the form of HWPs and its accumulation in landfill. Ultimately, biogenic carbon will be released back into the

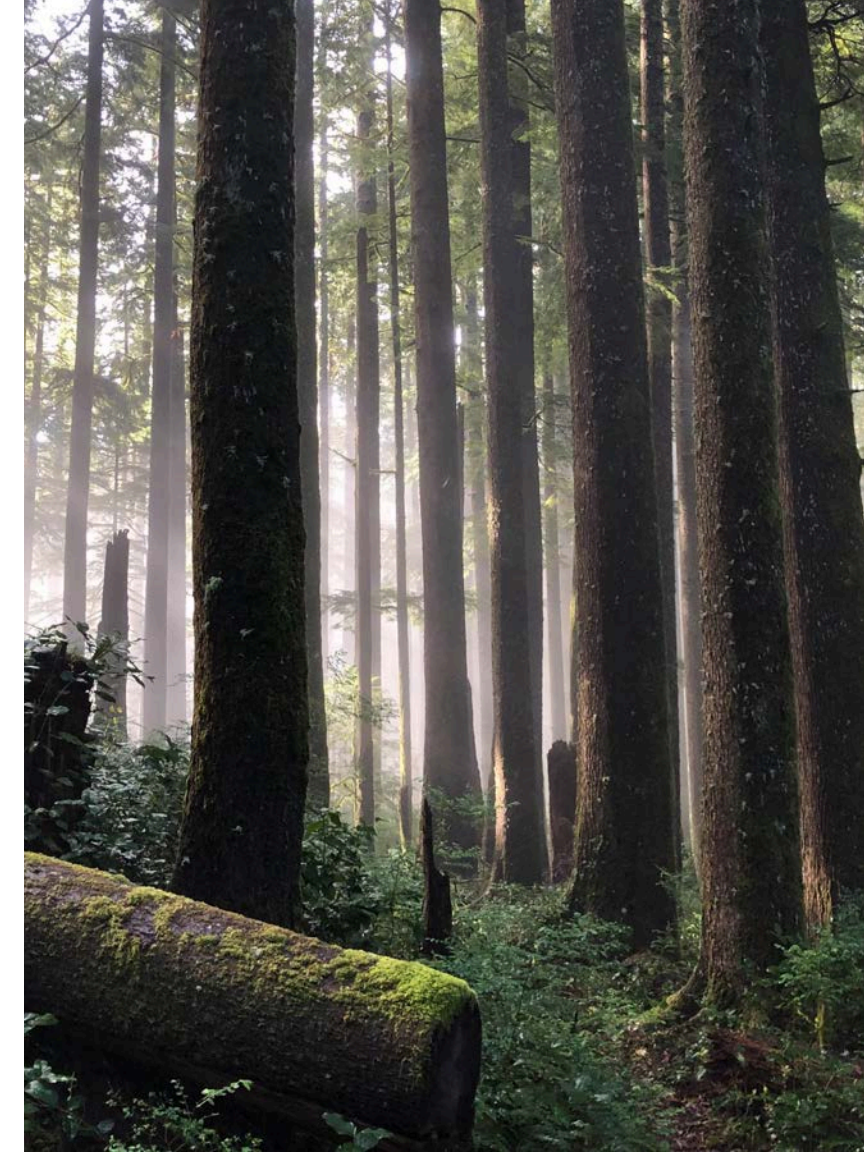
atmosphere, either immediately through incineration (often for bioenergy) or gradually through decay. This release of biogenic carbon into the atmosphere may then be re-sequestered in new plant growth. The process described above illustrates the carbon cycle.

Why is Biogenic Carbon Important?

The climate benefit of forests is well known given their role as large terrestrial carbon sinks. The amount and rate by which carbon is sequestered by forests hugely depends on forest dynamics such as tree species, composition, and climatic conditions. One of the greatest influencing factors over biogenic carbon at the forest scale, however, are disturbances both natural (e.g., fire, storm, insect, disease, etc.) and anthropogenic (e.g., harvest). The intensity and frequency of disturbances greatly influences the quantity and timing of carbon fluxes between forests and the atmosphere. Computer models and simulations may help to give an idea of impending natural disturbances, however such events and their impacts remain largely unpredictable. On the other

hand, the effect of harvest on carbon storage is more direct, with different forest management regimes either informing or inhibiting biogenic carbon storage.

In the case of mass timber, when extending the carbon sink to the built environment, the climate benefit of timber products improves the longer carbon is stored away from the atmosphere, emphasizing the importance of long lived HWP. The greatest influence over biogenic carbon at the product level comes down to end-of-life scenarios.



The Forest Management Debate

The environmental benefits associated with HWP are inextricably tied to the forests from which they are sourced, and so, it is important to consider their carbon implications at the forest scale. Forests, with their ability to sequester atmospheric carbon, make up a considerably large terrestrial carbon sink and are an important component in the carbon cycle (Cook-Patton et al, 2020; Mildrexler et al, 2020). Forests also significantly contribute to land-use patterns, with one third of the US covered by forest land. While great carbon sinks, the success of forests to extract carbon, and the rate at which they do so, depends on several factors including climatic conditions, species composition, and rate/intensity of disturbances.

Forests in the Pacific Northwest, particularly those with high concentrations of Douglas-fir, have some of the greatest carbon storage potential in North America (Hudiburg et al., 2009; Smithwick et al., 2002, Oswalt, et. al. 2019, William and Powers 2019). These forests act as large net sinks not only because of their sheer size, but also because they sequester more carbon than is lost from harvest or wildfires (Hudiburg et al. 2019).

Though carbon storage in wood products has received interest, Pacific Northwest forests can store carbon for many hundreds of years unlike buildings which temporarily store carbon only over the lifespan of the building (Law et al., 2018). As such, some believe that climate change mitigation through terrestrial carbon storage can be best achieved by letting forests grow as old-growth forests, or at the very least by extending harvest rotations and reducing harvest intensity (Law et al., 2018).

Meanwhile, the Pacific Northwest has become an epicenter for the utilization of mass timber construction in North America. The inherent mechanical properties of Douglas-fir as a structural material, and the species' large presence in the region, has gained the interest of the AEC community to build bigger and taller with it. Naturally, a debate exists regarding how to best manage these forests, and more broadly, how forests should serve to mitigate climate change.



The Forest Management Debate (continued)

While maximizing forest growth will provide more wood and greater forest carbon storage, proponents of HWP argue that the greatest source for carbon mitigation comes from displacing fossil fuels as carbon stored in forests is a one-time creation and cannot contribute to continued reduced emissions without harvest (Lippke et al., 2011). It was observed that the long-term carbon stock of unmanaged forests eventually reached a point of equilibrium as increases in carbon storage from tree growth are balanced by decreases through respiration and decomposition. In such a scenario, the absence of using HWP and the continued use of fossil fuels increases net carbon emissions. (Erikson et al., 2007).

Mass timber offers several benefits although its impact on forest and carbon dynamics is highly complex making efficient use of this resource crucial. Forest management regimes lend a role in forest carbon dynamics, with different management strategies prioritizing different end goals and therefore producing different outcomes. How to best manage forests in terms of climate change mitigation remains a controversial issue.



Forest Management Under Climate Change

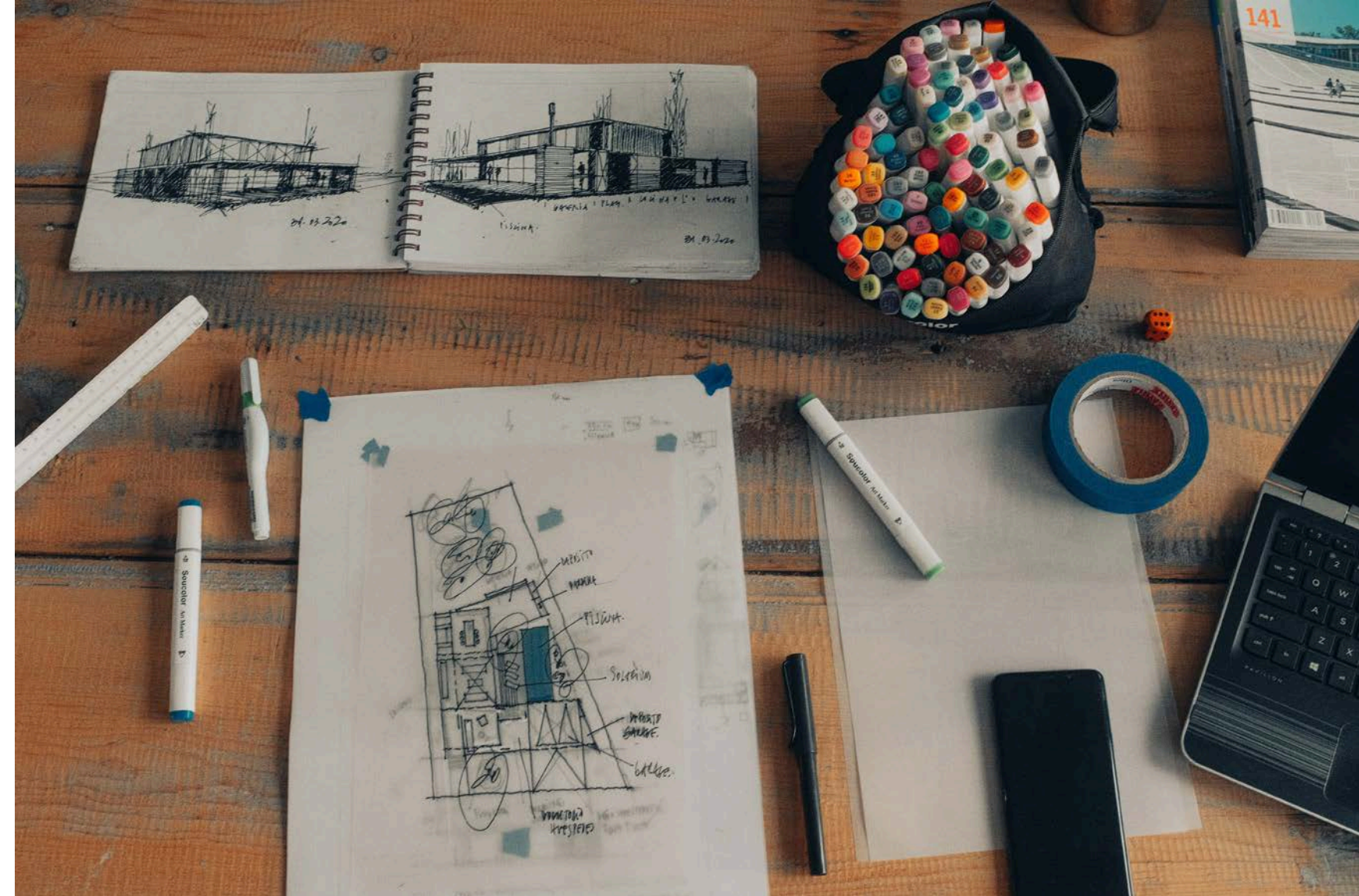
A warming climate poses considerable concern for forest resilience and the potential for future forest carbon storage. Forest resiliency, a forest's capacity to recover from a disturbance, is dependent on sufficient tree regeneration (Johnstone et al. 2016). Direct impacts on forests manifest through climate and can induce drought-stress, phenological changes, productivity changes, unsuccessful seedling establishment, insects and disease, increased wildfire severity and ultimately mortality, all of which hinder the ability of forests to store and sequester carbon. Indirect impacts under climate change threaten to amplify risks from changes in the occurrence and severity of natural disturbances such as wildfires, insects, and disease outbreaks (Case et al. 2021). These disturbances may lead to increased levels of tree mortality and ultimately have the potential to turn forests from carbon sinks into carbon sources (Peterson et al. 2014).

As summers grow hotter and drier, forests are victim to reduced moisture availability which leads to drought and can in turn set the stage for wildfire. Even drought tolerant species like Douglas-fir are vulnerable to summer water deficits which in turn increase their susceptibility to natural disturbances (Littel et al., 2008; Restaino et al., 2016). This is of particular concern for consumers of wood products that depend on the vitality of certain species. As dry regions will likely become drier, another possible concern may be a decrease in the availability of quality harvestable stands (Brecka et al. 2018). Declines in wood supply will have implications for the availability of sustainably harvested wood products. It therefore may be important to reduce long-term harvest targets to ensure a sustainable wood supply during the multiple threats on forest resilience imposed by climate change. Under these circumstances, efficient utilization of wood fiber becomes a priority.



AEC Industry Involvement

The architecture, engineering, construction (AEC) industry is a large consumer of wood products with the growing popularity of mass timber construction projected to further increase the industry's wood consumption. As such, the AEC industry is a large driver of the forest products market which invariably affects forest management and ultimately forest dynamics. Eco-conscious designers looking to reduce their carbon footprint should be aware of their influence over wood consumption since designing wood buildings inherently also means designing forests themselves. Architects are encouraged to work with forest managers to develop context-appropriate supply chain relations that enhance ecological, social, and economic benefits. Product innovation that maximizes wood fiber efficiency coupled with thoughtful design and integration of such technologies in architectural applications can further take advantage of wood volume available post-harvest. Designers hold a great deal of sway over forest carbon dynamics. A couple ways by which they do so include their choice of material selection and the optimization of timber structural systems for wood fiber efficiency.



At what scale do decisions made by designers impact efficient utilization of available wood volume and carbon?

Project Background

With the recent development of the mass timber manufacturing, design and construction industries in the United States, there has been attention focused on mass timber as a viable climate change mitigation strategy to reduce embodied carbon emissions within the building sector as wood sequesters biogenic carbon. Given that forests and the implications of varied management and harvesting strategies are complex, agreement on the best approach to manage forests sustainably remains a point of contention. While an increasing number of architects in the U.S. are interested in employing mass timber as the primary structural system in their designs, they are asking questions about the relative sustainability of the forests from which the wood in mass timber products is sourced. Furthermore, the scale of impact that architects might have on driving forest and carbon dynamics by their choices of timber products seems to be little understood by designers themselves.

The purpose of this study is to:

1. Demonstrate the impact different forest management strategies have on available wood harvest and biogenic carbon.
2. Measure available wood volume and biogenic carbon associated with two different types of harvest strategies.
3. Visualize possible end results of those timber harvests through building design based on available resources in conjunction with product efficiency.



Statement of Problem and Research Questions

Forest management has been a long-debated topic as there is no consensus on the best strategy to sustainably manage a forest for both timber production and climate change mitigation. While some argue that forests are better managed with a less hands-on approach (Hudiburg et al., 2019) and should be left alone, others advocate for forests as an opportunity to better meet future infrastructure demand as opposed to less environmentally friendly alternatives (Churkina et al., 2020). In this light, members of the AEC community working with engineered wood products have a valuable role to play not only in driving the forest products market, but also in making impactful climate change mitigation benefits within the building sector. Effective sourcing of wood, however, depends on wood availability within the limits of sustainable forest management, all of which is subject to different forest management styles. The following questions, which serve as the main points of investigation, seek to understand the scale at which certain decisions made by architects working with mass timber have on forest and carbon dynamics.

1. At what scale do differing forest management regimes impact available wood volume post-harvest? On storing biogenic carbon?
2. In terms of efficient fiber use, at what scale does building with MPP versus CLT better utilize available wood volume post-harvest? In terms of efficient fiber use, it is known that MPP can utilize more of a log than CLT but it is not clear what the scale of that difference translates to in terms of what is able to be built.



Methodology and Assumptions

Literature Review

Investigation first began with a literature review of relevant research material. Resources include academic papers, journals, and articles. This literature review helped to build background knowledge and a deeper understanding of the context at hand.

Establishing Wood Volume

Looking at the McDonald-Dunn Research Forest located at Oregon State University in Corvallis, OR, two types of forest management regimes were chosen, specifically a 40yr and 60yr rotation of Douglas-fir. The purpose for selecting two different stand ages is to compare total wood volume available post-harvest. Stands of Douglas-fir were chosen because this predominant species is commercially grown in the PNW region and is highly sought after for manufacturing wood products. Douglas-fir reaches maximum biological output in terms of carbon sequestration (greatest rate ...

of carbon sequestration) at 70-80 years, by which the rate of sequestration then begins to decline. Typical production for commercial Douglas-fir however, often operates on 40-year rotations. To demonstrate potential differences in wood yield and carbon sequestration of forest practices that are not business-as-usual, Douglas-fir grown at a 60-year rotation was chosen as a compromise for reaching closer to the species' maximum biological output while remaining economically feasible. Although some companies like Port Blakely prove that growing Douglas-fir on 60 year cycles can be profitable, other commercial producers have found equal success growing Douglas-fir on 40 year cycles with a quicker return on investment. Wood volume post-harvest are then to be calculated in board feet for both inventories.

Images on the left show several different stands of Douglas-fir at the McDonald-Dunn Research Forest under different management strategies. Picture A shows an example of variable retention harvest, a form of uneven-aged management where stand structure and age class are left non-uniform



through clear-cutting and thinning operations. Picture B showcases uneven-aged management through thinning operations where some trees are left to grow larger for longer, like the variable retention method. Picture C represents typical commercial production under even-aged management, with some intermittent thinning operations. Lastly, Picture D again shows uneven-aged management of Douglas-fir, although management is relatively light-touch and closely resembles unmanaged forests incorporating lots of deadwood and litter. To compare “apples to apples” between stands of 40yr old and 60 yr old Douglas-fir, it is necessary to evaluate even-aged stands since uneven-aged stands remain highly variable and therefore difficult to calculate.

Regarding the specific age classes chosen, Picture C showcases an even-aged stand of Douglas-fir at 40 years while Picture D showcases an uneven-aged stand of Douglas-fir at 60 years. Although different management strategies are employed it is still worthwhile noting the difference in diameter of trees between stands, with the 60yr trees having larger diameters at breast height.

Originally, when tracts of 40yr and 60yr Douglas-fir stands in the McDonald Research Forest were to be

established, the retrieval of point-cloud lidar data (like shown on the left) with the heights of individual trees would be used to calculate tree volume. This work would have been carried out in consultation with Oregon State University College of Forestry faculty members Professor Stephen Fitzgerald, Director of College of Forestry Research Forests and Associate Professor Bogdan Strimbu of the Department of Forest Engineering, Resources & Management. Once tree heights derived from lidar scans would be available, the following equations would have been used in Microsoft excel to calculate tree volume.

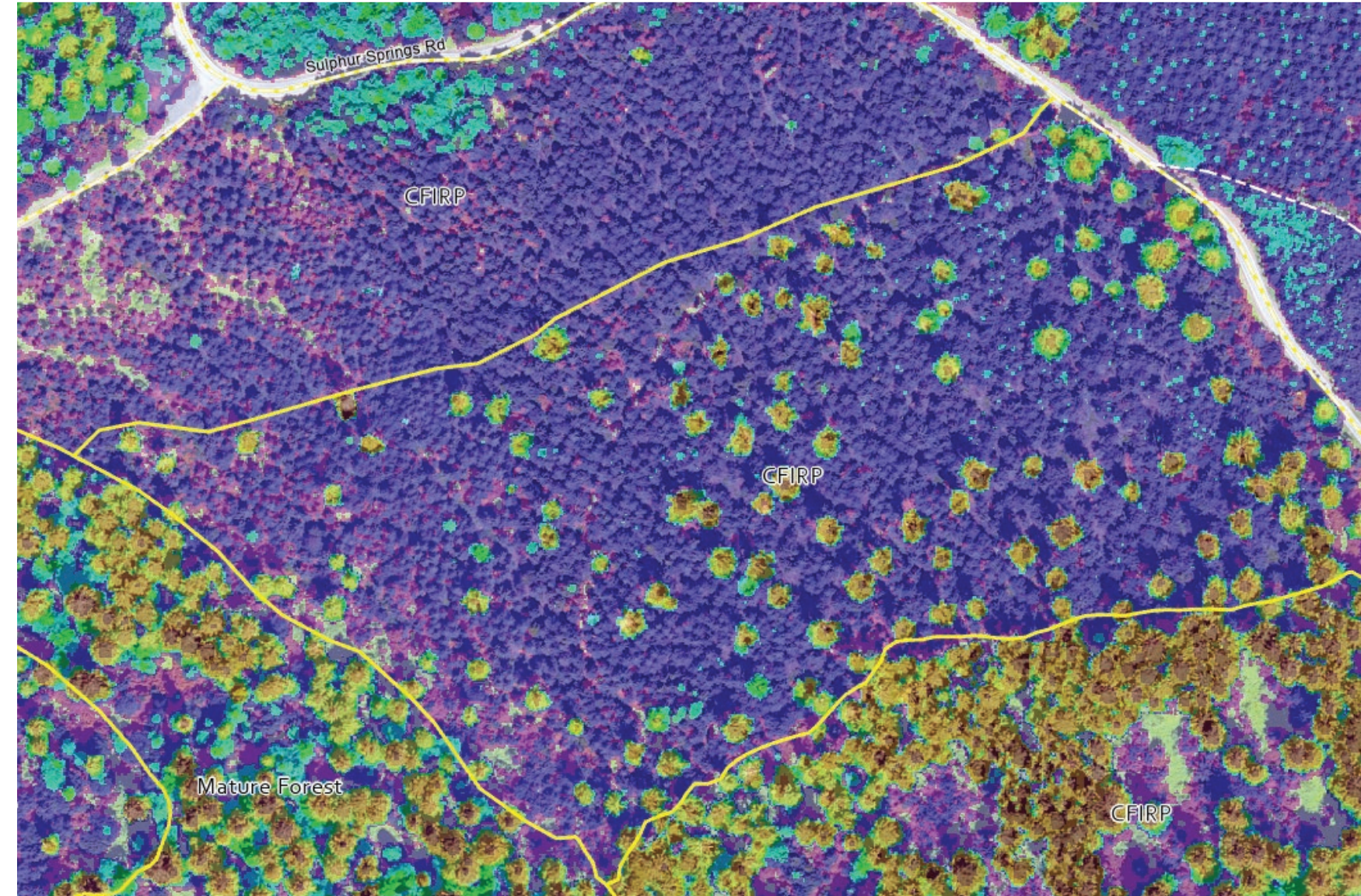
1. Given the heights of individual trees from lidar, the inverse of the equation below, along with the provided coefficients (Eng 2012), will be used to determine tree diameter at breast height (DBH).

$$\text{Height} = 4.5 + \exp(a + b\text{DBH}^c)$$

Species	Eq.	Coefficients			MSE	R ²
		a	b	c		
Redwood	1	5.6911 (0.087)	-7.3644 (0.582)	-0.6294 (0.052)	20.1	0.969
Douglas-fir	1	5.9429 (0.125)	-6.2041 (0.450)	-0.5531 (0.059)	22.6	0.972
Grand fir	1	5.8095 (0.281)	-6.3265 (1.290)	-0.6015 (0.159)	20.9	0.974

2. Next would be to solve for tree volume using the following equation (Poudel and Hailemariam 2016):

$$\begin{aligned} CVTSL = & -3.21809 + 0.04948 \times \log(HT) \times \log(DBH) - 0.15664 \times (\log(DBH))^2 \\ & + 2.02132 \times \log(DBH) + 1.63408 \times \log(HT) - 0.1685 \times (\log(HT))^2 \\ CVTS = & 10^{CVTSL} \end{aligned}$$



From these equations, total stand biomass can be calculated. Unfortunately, retrieval of the point-cloud lidar scans became unavailable. Consequently, estimates of wood volume post-harvest were derived from literature as well as from estimates given by Hampton Lumber and Professor Stephen Fitzgerald.

According to Hampton Lumber, 22,000 bd.ft. of lumber can be expected from one acre of Douglas-fir at 40 years. This was also confirmed by Stephen Fitzgerald to be a reasonable estimate for lumber coming from similar stands in the McDonald research forest.

As shown in the yield table below, this estimate matches findings for stands categorized by Class 3 site indexes. Since a majority of stands in the research forest are categorized with Class 3 site productivity, it can be assumed that a 60-year-old stand of Douglas-fir will provide 52,000 bd.ft. of lumber.

The estimated total for bd.ft. derived thus far applies to dimensional lumber available post-harvest. Based off aggregate data, about 50% of a log is utilized and converted into dimensional lumber. These estimates are helpful to gauge how much wood volume is

available post-harvest for lumber-based EWP's like CLT and glulam, but do not reflect different wood fiber utilization efficiencies of other products such as MPP, a veneer-based product.

According to Freres Lumber, the sole producer of MPP, approximately 70% of a log is utilized and converted into veneer. A higher log utilization percentage for veneer can be explained by the log peeling process as opposed to cutting rectangular shapes from a circular cross section in lumber production. Furthermore, roughly 20% less wood fiber is required for MPP to achieve the same structural capabilities as a CLT equivalent given the products greater density. MPP is therefore about 40% more efficient with wood fiber than CLT. Multiplying the previous estimates for dimensional lumber by 1.4, total estimated bd.ft. of veneer for both stands can be calculated. Accordingly, a 40-year-old stand of Douglas-fir can be assumed to provide 30,800 bd.ft. of veneer while a 60-year-old stand of Douglas-fir can be assumed to provide 72,800 bd.ft. of veneer.

Total Board Feet Estimates

Lumber from 40-year-old stand: 22,000 bd.ft.
Veneer from 40-year-old stand: 30,800 bd.ft.

Lumber from 60-year-old stand: 52,000 bd.ft.
Veneer from 60-year-old stand: 72,800 bd.ft.

It is important to note that these estimates reflect fully stocked acres with no thinning interventions. Typically, thinning is involved in forest management plans to prevent overcrowding, allow for enhanced growth rates in younger stands, and avoid competition for sunlight, water, and nutrients. The impact of thinning on total stand biomass is highly variable as the amount of biomass subtracted from thinning depends on the age of trees at the time of thinning as well as the intensity of the thinning. Thinning will usually produce less standing biomass at the end of a rotation than will a fully stocked acre, although depending on the nature of thinning operations, trees removed may be large enough to be considered marketable logs.

YIELD IN BOARD FEET, INTERNATIONAL RULE (3/4-INCH KERF)

Age (years)	Site Class V		Site Class IV			Site Class III			Site Class II			Site Class I		
	Site index	Site index	Site index	Site index	Site index	Site index	Site index	Site index	Site index	Site index	Site index	Site index	Site index	Site index
	80	90	100	110	120	130	140	150	160	170	180	190	200	210
	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.
20	0	0	0	0	0	0	200	800	1,500	2,100	2,800	3,900	4,900	6,000
30	0	0	1,000	2,400	4,300	6,200	8,400	10,700	13,300	16,000	18,800	21,400	24,400	27,000
40	1,500	3,800	6,400	9,200	13,400	17,400	22,000	26,000	30,500	34,900	39,000	43,000	47,000	51,500
50	5,900	9,500	13,600	19,000	25,100	31,400	37,100	43,300	49,200	55,000	60,000	65,200	70,500	75,300
60	10,500	15,900	21,700	28,900	37,000	44,500	52,000	59,500	66,200	72,800	79,000	85,100	90,800	96,200
70	15,400	22,100	29,500	37,900	47,200	56,500	65,600	74,300	82,000	89,000	96,000	102,400	108,500	114,500
80	20,300	27,800	36,300	45,700	56,300	66,800	77,200	86,800	95,200	103,200	110,900	118,100	124,700	131,100
90	24,900	32,700	41,900	52,200	63,900	75,700	86,700	96,800	106,100	114,700	123,000	130,800	137,700	144,000
100	28,800	37,200	46,700	58,100	70,600	83,000	94,700	105,600	115,100	124,400	133,500	141,500	148,900	155,400
110	32,000	41,000	51,300	63,200	76,300	89,500	101,500	113,000	123,400	133,000	142,000	150,100	157,900	164,900
120	34,700	44,000	55,100	67,500	81,400	94,700	107,200	119,200	130,100	140,300	149,400	157,500	165,500	172,700
130	37,000	46,900	58,600	71,000	85,800	99,300	112,200	124,700	136,200	146,500	155,700	164,000	172,000	179,500
140	39,200	49,500	61,400	74,300	89,700	103,500	116,900	129,900	141,400	152,000	161,300	169,900	178,000	185,400
150	41,300	51,700	63,900	77,500	93,000	107,800	121,100	134,500	146,100	156,700	166,500	175,200	183,300	190,900
160	43,300	54,000	66,200	80,100	96,000	110,900	125,000	138,900	150,400	161,100	171,400	180,300	188,100	196,000

Visualizing Wood Volume

Once wood volume in terms of board feet for lumber and veneer coming from both stands were established, the next step was to visualize it. A couple of exercises were performed to accomplish just that. The first exercise, titled “How much wood?” looked to compare total merchantable volume coming from each scenario. The second exercise, titled “Wood and Structure, CLT and MPP” went a step further and looked at comparing differences in wood volume for both products as it applies to different structures. An average of the difference in wood volumes calculated for building totals in each scenario will provide a general margin of wood fiber reduction between CLT and MPP. A more detailed description of “How Much Wood?” can be found on page (39). Similarly, a more detailed description of “Wood and Structure, CLT and MPP” can be found on page (45).

Peavy Forest Education Center

The final demonstration builds on the last two exercises to showcase wood fiber utilization as it applies to a building design. Peavy lodge, shown

right, is in Peavy Arboretum within the McDonald Research Forest at Oregon State University. Situated on 10,000 sq.ft within the arboretum, Peavy Lodge is surrounded by various protected tree species. However, the lodge is slated for demolition and replacement.

Five redesigns of Peavy Lodge, in consultation with Judith Sheine and structural engineer Mikhail Gershfeld, along with reference to the Fast+Epp timber bay calculator will account for differences in wood fiber usage between CLT and MPP. The percentage of wood fiber reduction from CLT to MPP will be determined by the average deviation in wood volume differences calculated from the matrix of scenarios in exercise 2. Each design utilizes the same program, organization, and internal structure (post and beam). Designs defer in terms of envelope structure enclosing the entire volume. A standard scenario using simple post and beam construction with shear walls will serve as a base case scenario. Four separate designs will look to enclose the same space through different structural approaches. Finally, carbon storage associated with each design is assessed through the Woodworks calculator.



How Much Wood?

To comprehend what the calculated amount of board feet coming from both the 40-year and 60-year stands of Douglas-fir looks like, this first exercise looks to visualize these wood volumes through 10' x 12' panels of both CLT and MPP. Representing volume as panels not only establishes a recognizable unit to better understand total volumes, but it also allows for the comparison of wood fiber usage in a realistic application through similar structural equivalence. Using an APA product report for DR Johnson CLT and Freres Lumber's MPP panel design guide, panels of the same structural performance were determined. According to the Freres Lumber Design Guide, "E2 CLT is the most comparable grade of CLT in terms of engineering and species that we have to compare to Mass Ply. 5.10" F-16 Mass Ply can achieve the same spans as 6.875" 5-ply E-2 CLT." In terms of structural equivalence, these panels perform similarly under the same load conditions for roof and floor spans.

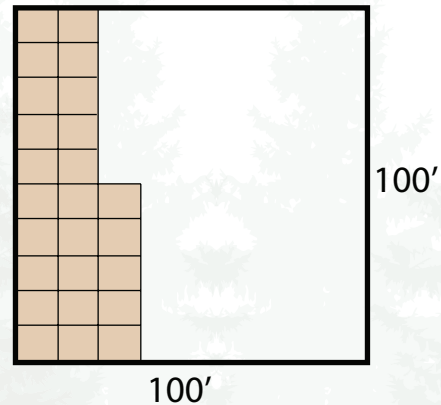
The number of panels represented are derivative of total wood volume post-harvest over one acre and twenty acres of harvest. Twenty acres is represented because that is the minimum amount of acreage considered worthwhile for entry into the forest with harvest equipment. Lastly, wood volumes in both the one-acre and twenty-acre demonstrations are referenced to a square 10,000 sq.ft. base representing the Peavy Forest Education Center site area. Doing so ties wood volume available post-harvest from stands in the research forest to the project site area.

E-2 5-Ply CLT

From Douglas-fir stand
at 40 year harvest

E-2 CLT, 5-ply thickness = 6.875"
1 panel = 10' x 12' x 6.875"
1 bd.ft. = 1' x 1' x 1"
1 panel = 835 bd.ft.

If one acre at 40yrs produces approx. 22,000
bd.ft. of lumber, then one acre can produce:
25 panels

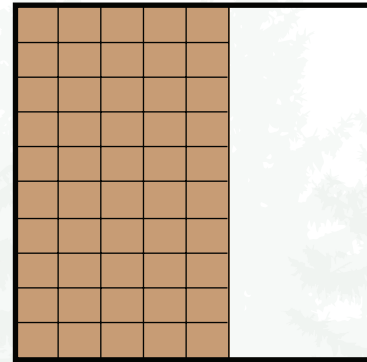


F-16 5-ply MPP

From Douglas-fir stand
at 40 year harvest

F-16 MPP, 5-ply thickness = 5.10"
1 panel = 10' x 12' x 5.10"
1 bd.ft. = 1' x 1' x 1"
1 panel = 612 bd.ft.

If one acre at 40yrs produces approx. 30,800
bd.ft. of veneer, then one acre can produce:
50 panels

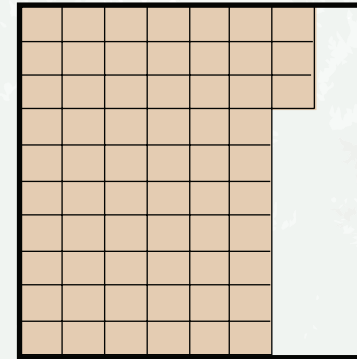


E-2 5-Ply CLT

From Douglas-fir stand
at 60 year harvest

E-2 CLT, 5-ply thickness = 5.10"
1 panel = 10' x 12' x 5.10"
1 bd.ft. = 1' x 1' x 1"
1 panel = 835 bd.ft.

If one acre at 60yrs produces approx. 52,000
bd.ft. of lumber, then one acre can produce:
63 panels

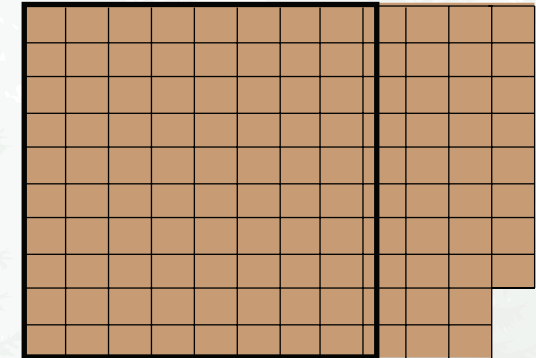


F-16 5-ply MPP

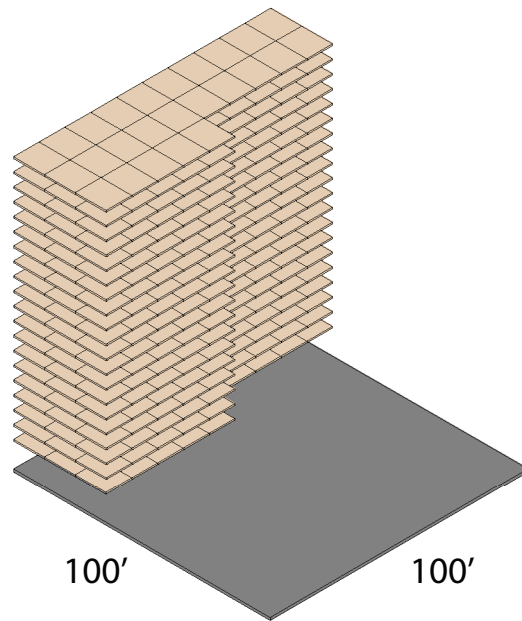
From Douglas-fir stand
at 60 year harvest

F-16 MPP, 5-ply thickness = 5.10"
1 panel = 10' x 12' x 5.10"
1 bd.ft. = 1' x 1' x 1"
1 panel = 612 bd.ft.

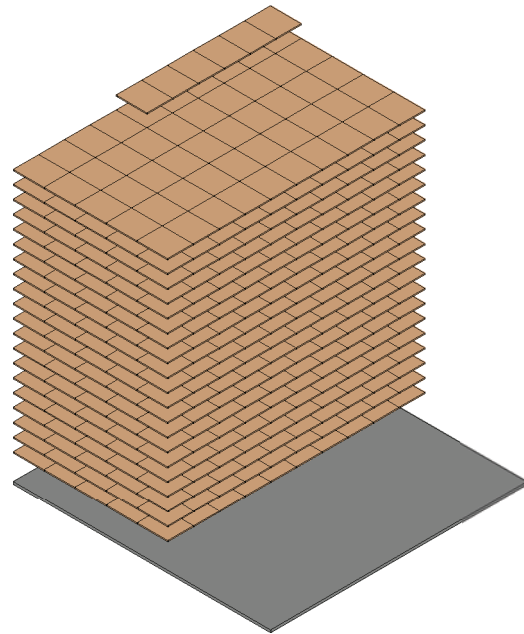
If one acre at 60yrs produces approx. 72,800
bd.ft. of veneer, then one acre can produce:
118 panels



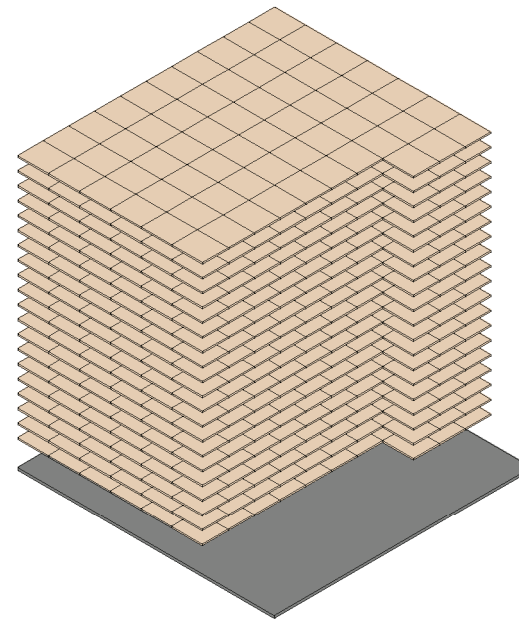
If twenty acres at 40yrs produces approx.
440,000 bd.ft. of lumber, then twenty acres can
produce:
533 panels



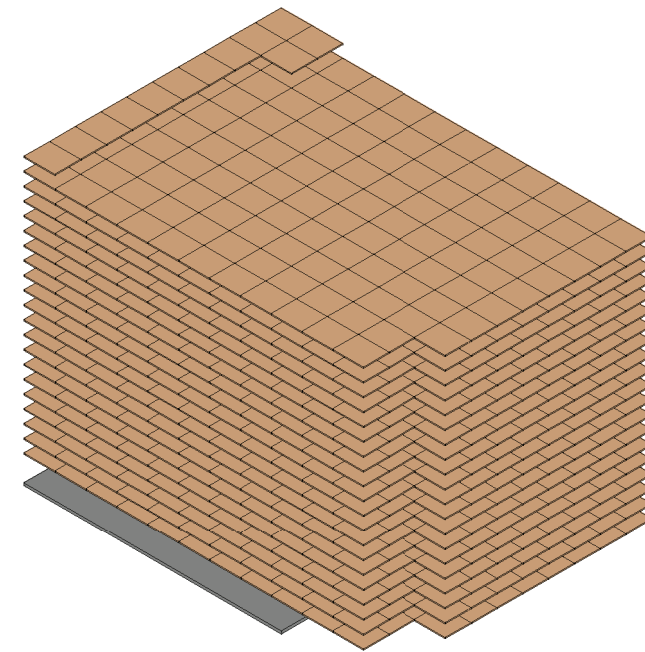
If twenty acres at 40yrs produces approx.
616,000 bd.ft. of veneer, then twenty acres can
produce:
1,006 panels



If twenty acres at 60yrs produces approx.
1,040,000 bd.ft. of lumber, then twenty acres can
produce:
1,260 panels



If twenty acres at 60yrs produces approx.
1,456,000 bd.ft. of veneer, then twenty acres can
produce:
2,379 panels



Wood and Structure, CLT and MPP

The purpose of this second exercise is to demonstrate differences in wood volume between CLT and MPP as it relates to structure. A variety of structural scenarios are applied to a rectangular volume of 27,000 cu.ft. Each scenario varies by a different structural approach to enclose the rectangular volume, highlighting differences in wood fiber efficiency through structural design. Furthermore, each scenario is assessed through construction with CLT/glulam and with MPP panels, columns and beams, highlighting wood fiber efficiency between products.

Member sizing was calculated with Fast+Epp's timber bay calculator, Structurlam and Freres Lumber design guides, and guidance by committer members. Wood volume required to construct the building total in each scenario is then calculated in board feet. Total board feet required to construct the building total in each CLT and MPP scenario is then compared to determine percentages of wood volume reduction when using MPP. An average of these wood volume reduction percentages shows that MPP structures are generally 19% more efficient in terms of wood volume compared to CLT. This average allows for quick comparisons in wood fiber efficiency between CLT and MPP iterations for designs of the Peavy Forest Education Center.

Building totals between CLT and MPP for each scenario are also compared in terms of log utilization (i.e. the number of trees (logs) needed for harvest to construct each scenario). This was achieved by comparing wood consumption of one acre needed for each CLT and MPP volume in all scenarios. These comparisons between CLT and MPP log utilization were done between 40yr stands and 60yr stands. Doing so allows for better understanding of how much less trees (log), are needed for extraction when using MPP instead of CLT.

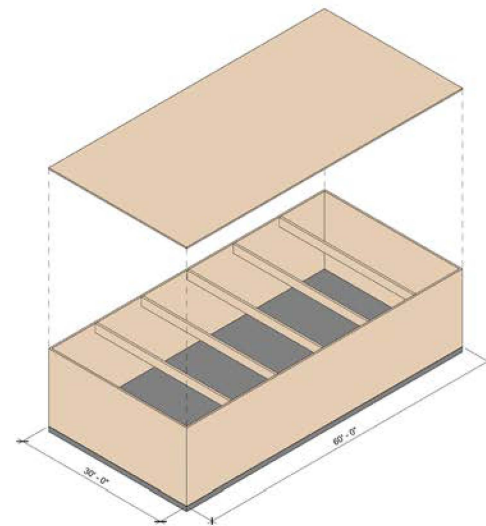
CLT from Douglas-fir Stand

Load-bearing CLT walls, Beams 10 ft o.c.

Roof: 87V (3ply) CLT
 $30' \times 60' \times 3.43" = 6,174 \text{ bd.ft.}$

Walls: 105V (3ply CLT)
 $15' \times 60' \times 4.14" = 3,726 \text{ bd.ft. (2)} = 7,452 \text{ bd.ft.}$
 $15' \times 29.31' \times 4.14" = 1,820 \text{ bd.ft. (2)} = 3,640 \text{ bd.ft.}$
 Total = 11,092 bd.ft.

Glulams: Width: 5.12", Depth: 21"
 $5.12" \times 21" \times 29.31' = 31,820.16 \text{ cu.in.} = 21.89 \text{ cu.ft.} = 263 \text{ bd.ft. (5)}$
 Total = 1,315 bd.ft.

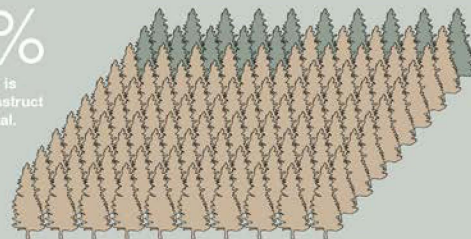


Building Total = 18,581 bd.ft

40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

85%

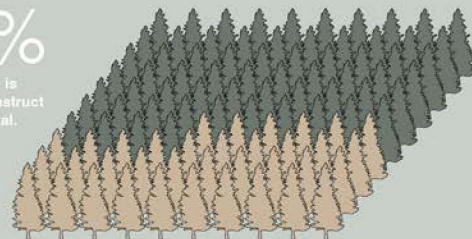
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

36%

of one acre is required to construct building total.



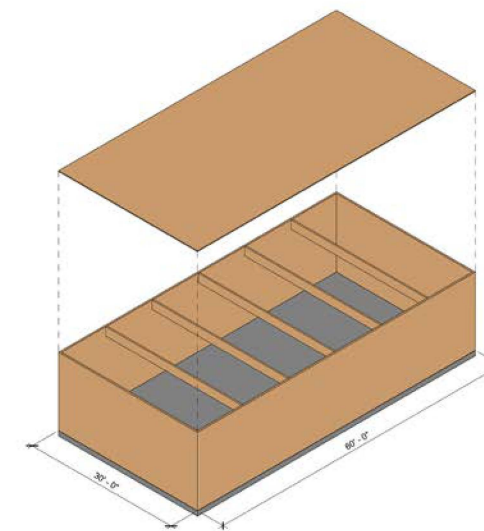
MPP from Douglas-fir Stand

Load-bearing MPP walls, Beams 10 ft o.c.

Roof: 2-ply MPP
 $30' \times 60' \times 2.04" = 3,672 \text{ bd.ft.}$

Walls: 4-ply MPP
 $15' \times 60' \times 4.08" = 3,672 \text{ bd.ft. (2)} = 7,344 \text{ bd.ft.}$
 $15' \times 29.33' \times 4.08" = 1,795 \text{ bd.ft. (2)} = 3,590 \text{ bd.ft.}$
 Total = 10,934 bd.ft.

MPP Beams: Width: 3.06", Depth: 21"
 $3.06" \times 21" \times 29.33' = 19,216.95 \text{ cu.in.} = 13.09 \text{ cu.ft.}$
 $= 157 \text{ bd.ft. (5)}$
 Total = 785 bd.ft.

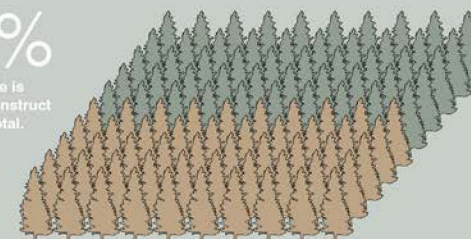


Building Total = 15,391 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

50%

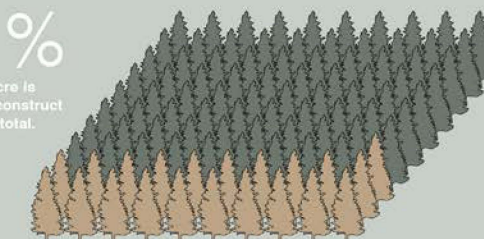
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

21%

of one acre is required to construct building total.



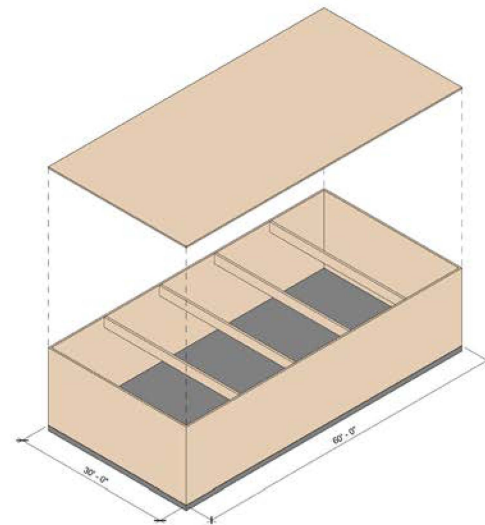
CLT from Douglas-fir Stand

Load-bearing CLT walls, Beams 12 ft o.c.

Roof: 87V (3ply) CLT
 $30' \times 60' \times 3.43" = 6,174 \text{ bd.ft.}$

Walls: 105V (3ply) CLT
 $15' \times 60' \times 4.14" = 3,726 \text{ bd.ft. (2)} = 7,452 \text{ bd.ft.}$
 $15' \times 29.31' \times 4.14" = 1,820 \text{ bd.ft. (2)} = 3,640 \text{ bd.ft.}$
 Total = 11,092 bd.ft.

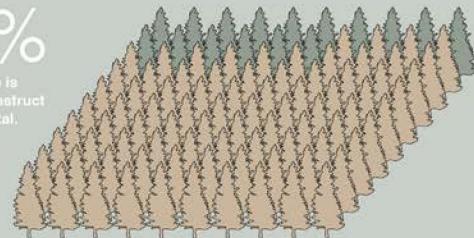
Glulams: Width: 5.12", Depth: 23"
 $5.12" \times 23" \times 29.31' = 41,422.08 \text{ cu.in.} = 23.97 \text{ cu.ft.} = 288 \text{ bd.ft. (4)}$
 Total = 1,152 bd.ft.



Building Total = 18,418 bd.ft.

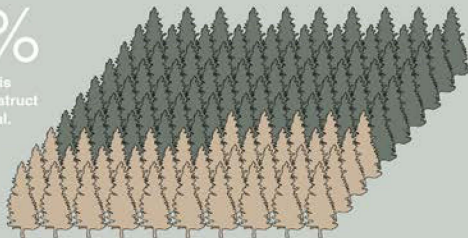
40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

84%
 of one acre is
 required to construct
 building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

35%
 of one acre is
 required to construct
 building total.



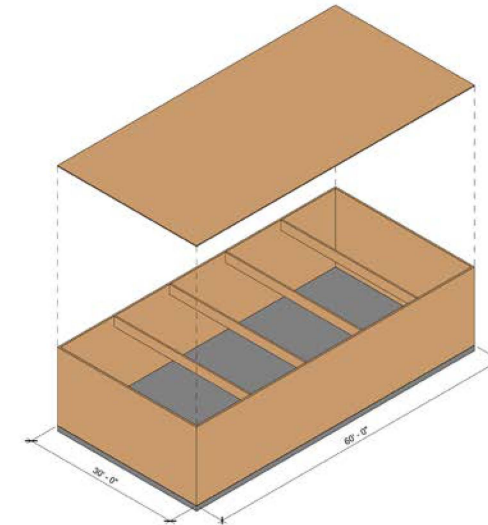
MPP from Douglas-fir Stand

Load-bearing MPP walls, Beams 12 ft o.c.

Roof: 3-ply MPP
 $30' \times 60' \times 3.06" = 5,508 \text{ bd.ft.}$

Walls: 4-ply MPP
 $15' \times 60' \times 4.08" = 3,672 \text{ bd.ft. (2)} = 7,344 \text{ bd.ft.}$
 $15' \times 29.33' \times 4.08" = 1,795 \text{ bd.ft. (2)} = 3,590 \text{ bd.ft.}$
 Total = 10,934 bd.ft.

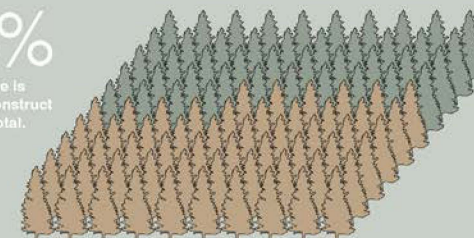
MPP Beams: Width: 3.06", Depth: 23"
 $3.06" \times 23" \times 29.33' = 3,060 \text{ cu.in.} = 14.34 \text{ cu.ft.}$
 $3.06" \times 23" \times 351.96" = 24,770.94 \text{ cu.in.} = 14.34 \text{ cu.ft.}$
 = 172 bd.ft. (4)
 Total = 688 bd.ft.



Building Total = 17,130 bd.ft.

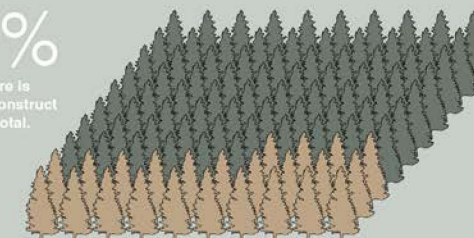
40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

56%
 of one acre is
 required to construct
 building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

24%
 of one acre is
 required to construct
 building total.



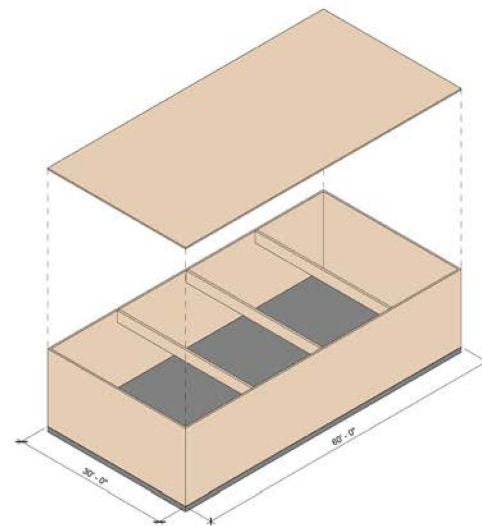
CLT from Douglas-fir Stand

Load-bearing CLT walls, Beams 15 ft o.c.

Roof: 87V (3ply) CLT
 $30' \times 60' \times 3.43" = 6,174 \text{ bd.ft.}$

Walls: 105V (3ply) CLT
 $15' \times 60' \times 4.14" = 3,726 \text{ bd.ft. (2)} = 7,452 \text{ bd.ft.}$
 $15' \times 29.31' \times 4.14" = 1,820 \text{ bd.ft. (2)} = 3,640 \text{ bd.ft.}$
 Total = 11,092 bd.ft.

Glulams: Width: 5.12", Depth: 27"
 $5.12" \times 27" \times 29.31' = 48,625.92 \text{ cu.in.} = 28.14 \text{ cu.ft.} = 338 \text{ bd.ft. (3)}$
 Total = 1,014 bd.ft.

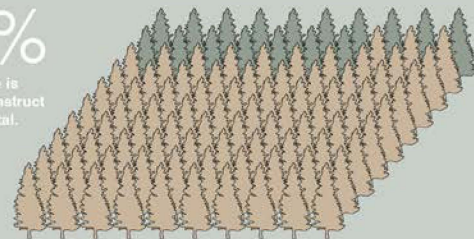


Building Total = 18,280 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

83%

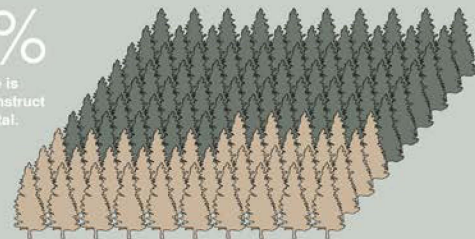
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

35%

of one acre is required to construct building total.



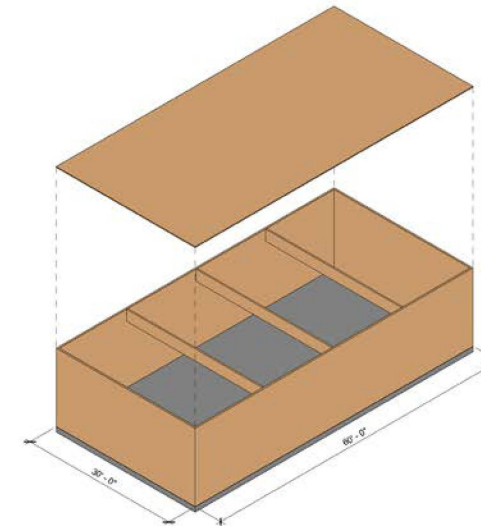
MPP from Douglas-fir Stand

Load-bearing MPP walls, Beams 15 ft o.c.

Roof: 3-ply MPP
 $30' \times 60' \times 3.06" = 5,508 \text{ bd.ft.}$

Walls: 4-ply MPP
 $15' \times 60' \times 4.08" = 3,672 \text{ bd.ft. (2)} = 7,344 \text{ bd.ft.}$
 $15' \times 29.33' \times 4.08" = 1,795 \text{ bd.ft. (2)} = 3,590 \text{ bd.ft.}$
 Total = 10,934 bd.ft.

MPP Beams: Width: 3.06", Depth: 27"
 $3.06" \times 27" \times 29.33' = 29,078.94 \text{ cu.in.} = 16.83 \text{ cu.ft.}$
 $= 202 \text{ bd.ft. (3)}$
 Total = 606 bd.ft.

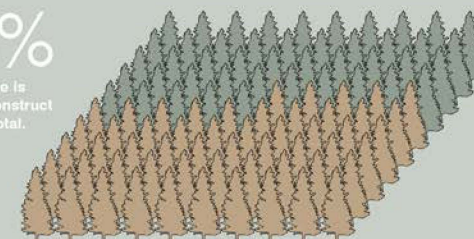


Building Total = 17,048 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

55%

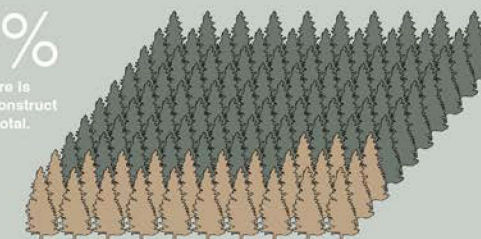
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

23%

of one acre is required to construct building total.



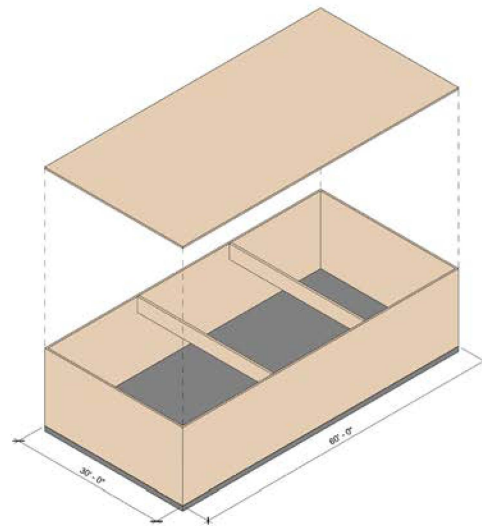
CLT from Douglas-fir Stand

Load-bearing CLT walls, Beams 20 ft o.c.

Roof: 105V (3ply) CLT
 $30' \times 60' \times 4.14" = 7,452 \text{ bd.ft.}$

Walls: 105V (3ply) CLT
 $15' \times 60' \times 4.14" = 3,726 \text{ bd.ft. (2)} = 7,452 \text{ bd.ft.}$
 $15' \times 29.31' \times 4.14" = 1,820 \text{ bd.ft. (2)} = 3,640 \text{ bd.ft.}$
 Total = 11,092 bd.ft.

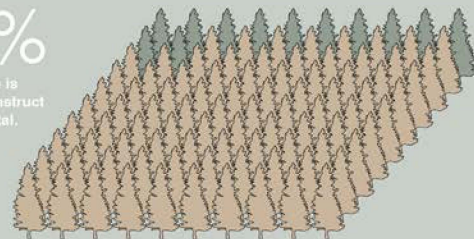
Glulams: Width: 5.12", Depth: 36"
 $5.12" \times 36" \times 29.31' = 54,834.56 \text{ cu.in.} = 37.52 \text{ cu.ft.} = 450 \text{ bd.ft. (2)}$
 Total = 900



Building Total = 19,444 bd.ft.

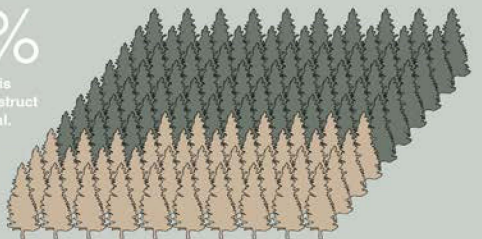
40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

88%
 of one acre is
 required to construct
 building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

37%
 of one acre is
 required to construct
 building total.



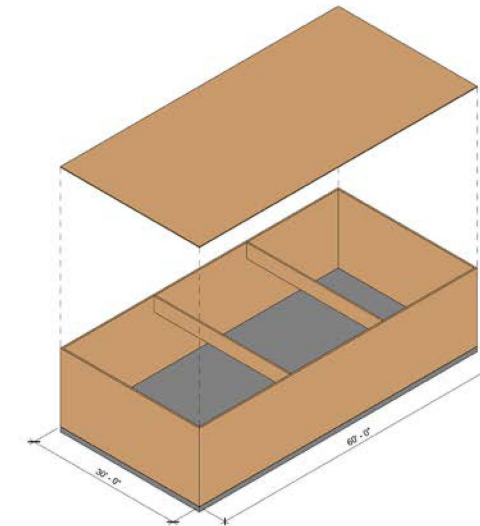
MPP from Douglas-fir Stand

Load-bearing MPP walls, Beams 20 ft o.c.

Roof: 4-ply MPP
 $30' \times 60' \times 4.08" = 7,344 \text{ bd.ft.}$

Walls: 4-ply MPP
 $15' \times 60' \times 4.08" = 3,672 \text{ bd.ft. (2)} = 7,344 \text{ bd.ft.}$
 $15' \times 29.33' \times 4.08" = 1,795 \text{ bd.ft. (2)} = 3,590 \text{ bd.ft.}$
 Total = 10,934 bd.ft.

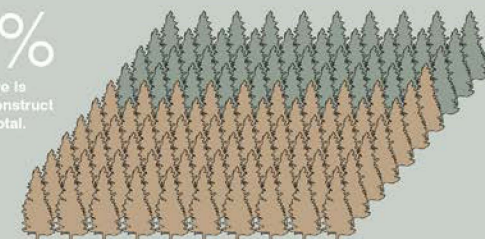
MPP Beams: Width: 3.06", Depth: 36"
 $3.06" \times 36" \times 29.33' = 32,771.91 \text{ cu.in.} = 22.44 \text{ cu.ft.}$
 $= 269 \text{ bd.ft. (2)}$
 Total = 538 bd.ft.



Building Total = 18,816 bd.ft.

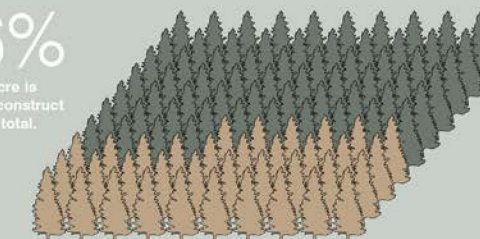
40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

61%
 of one acre is
 required to construct
 building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

26%
 of one acre is
 required to construct
 building total.



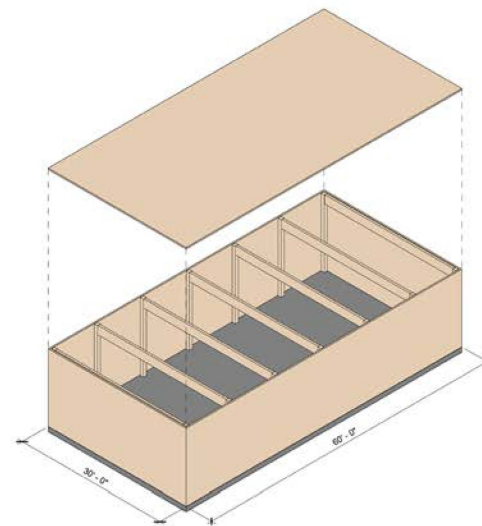
CLT from Douglas-fir Stand Post and Beam w Shear Walls, Frames 10ft o.c.

Roof: 87V (3ply) CLT
30' x 60' x 3.43" = 6,174 bd.ft.

Walls: 87V (3ply CLT)
15' x 60' x 3.43" = 3,087 bd.ft. (2) = 6,174 bd.ft.
15' x 29.31' x 3.43" = 1,508 bd.ft. (2) = 3,016 bd.ft.
Total = 9,190 bd.ft.

Glulams: Width: 5.12", Depth: 21"
5.12" x 21" x 27.98' = 36,101 cu.in. = 20.89 cu.ft.
= 252 bd.ft. (7)
Total = 1,764 bd.ft.

Columns: 8" x 8"
8" x 8" x 15' = 11,520 cu.in.
= 7 cu.ft. = 84 bd.ft. (14)
Total = 1,176 bd.ft.

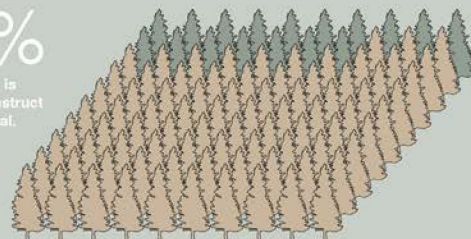


Building Total = 18,304 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

83%

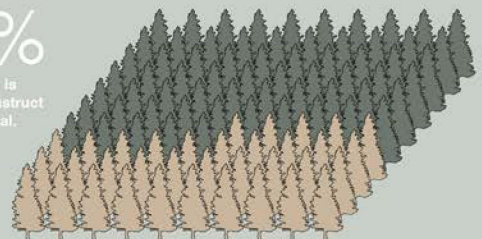
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

35%

of one acre is required to construct building total.



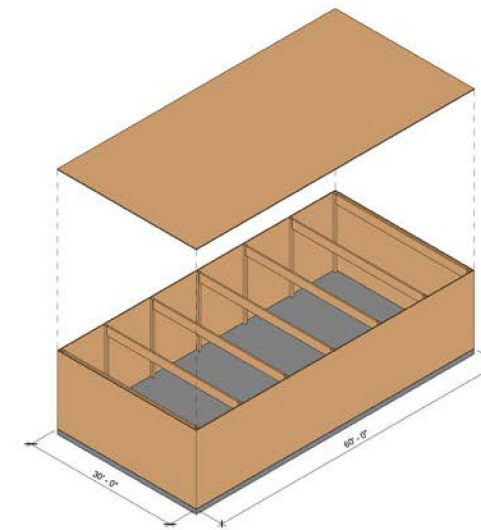
MPP from Douglas-fir Stand Post and Beam w Shear Walls, Frames 10ft o.c.

Roof: 2-ply MPP
30' x 60' x 2.04" = 3,672 bd.ft.

Walls: 2-ply MPP
15' x 60' x 2.04" = 1,836 bd.ft. (2) = 3,672 bd.ft.
15' x 29.66' x 2.04" = 907.6 bd.ft. (2) = 1,815 bd.ft.
Total = 5,487 bd.ft.

Glulams: Width: 3.06", Depth: 21"
3.06" x 21" x 28.81' = 22,215.97 cu.in. = 12.86 cu.ft.
= 154 bd.ft. (7)
Total = 1,078 bd.ft.

Columns: 5.1" x 5.1"
5.1" x 5.1" x 15' = 4,681.8 cu.in. = 2.71 cu.ft.
= 33 bd.ft. (14)
Total = 462 bd.ft.

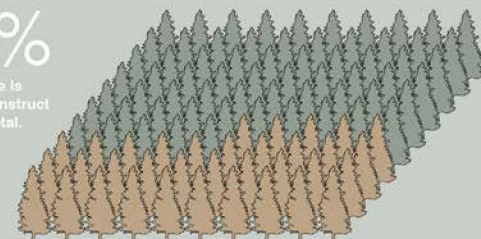


Building Total = 10,699 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

35%

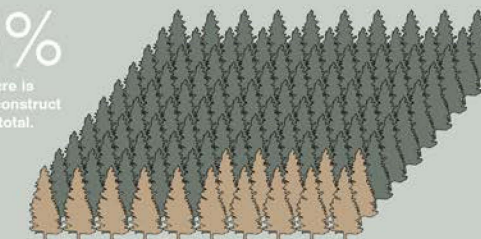
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

15%

of one acre is required to construct building total.



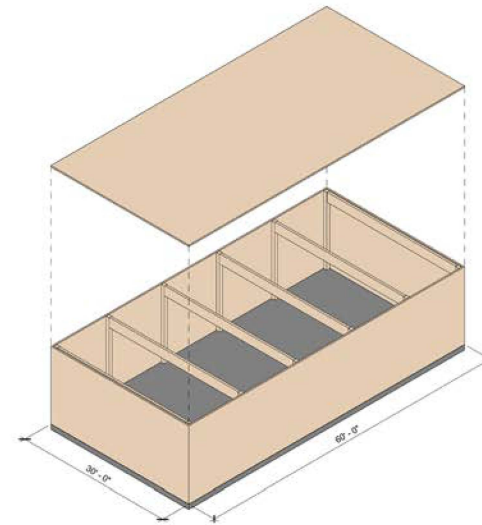
CLT from Douglas-fir Stand Post and Beam w Shear Walls, Frames 12ft o.c.

Roof: 87V (3ply) CLT
30' x 60' x 3.43" = 6,174 bd.ft.

Walls: 87V (3ply) CLT
15' x 60' x 3.43" = 3,087 bd.ft. (2) = 6,174 bd.ft.
15' x 29.31' x 3.43" = 1,508 bd.ft. (2) = 3,016 bd.ft.
Total = 9,190 bd.ft.

Glulams: Width: 5.12", Depth: 23"
5.12" x 23" x 27.98' = 39,535 cu.in. = 22.88 cu.ft.
= 275 bd.ft. (6)
Total = 1,650 bd.ft.

Columns: 8" x 8"
8" x 8" x 15'
= 6.67 cu.ft.
= 80 bd.ft. (12)
Total = 960 bd.ft.

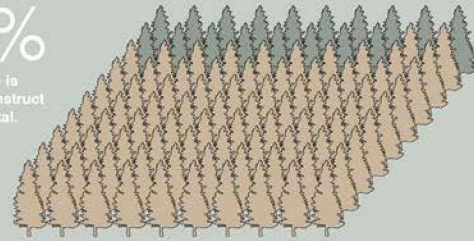


Building Total = 17,974 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

82%

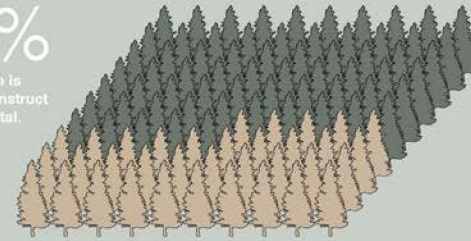
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

35%

of one acre is required to construct building total.



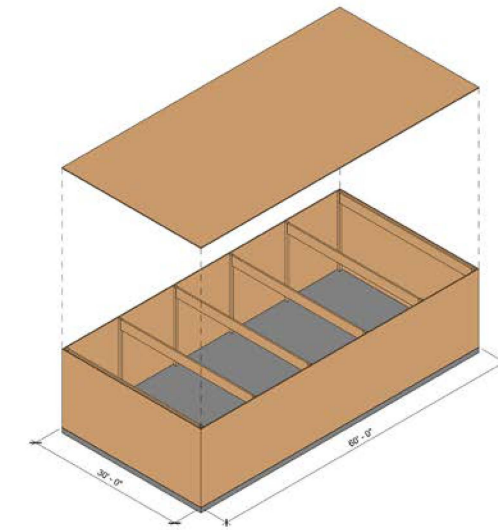
MPP from Douglas-fir Stand Post and Beam w Shear Walls, Frames 12ft o.c.

Roof: 3-ply MPP
30' x 60' x 3.06" = 5,508 bd.ft.

Walls: 2-ply MPP
15' x 60' x 2.04" = 1,836 bd.ft. (2) = 3,672 bd.ft.
15' x 29.66' x 2.04" = 907.6 bd.ft. (2) = 1,815 bd.ft.
Total = 5,487 bd.ft.

Glulams: Width: 3.06", Depth: 23"
3.06" x 23" x 28.64' = 24,188.2 cu.in. = 14 cu.ft.
= 168 bd.ft. (6)
Total = 1,008 bd.ft.

Columns: 5.1" x 5.1"
5.1" x 5.1" x 15'
= 4,681.8 cu.in. = 2.71 cu.ft.
= 33 bd.ft. (12)
Total = 396 bd.ft.

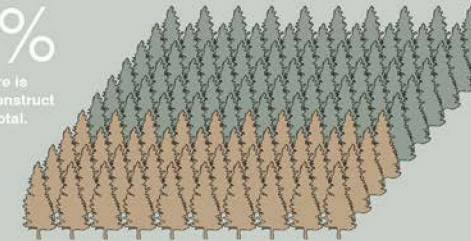


Building Total = 12,399 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

40%

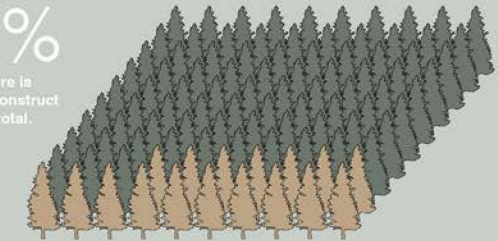
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

17%

of one acre is required to construct building total.



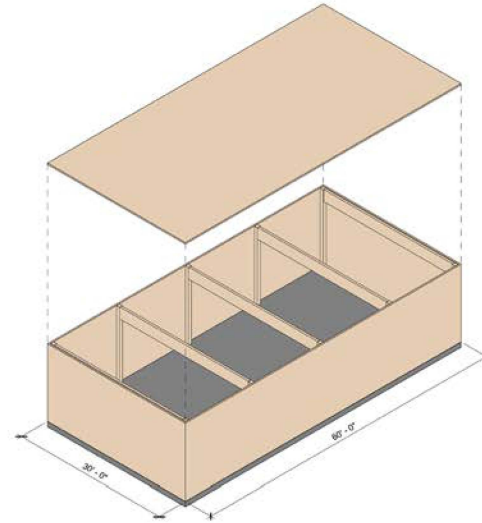
CLT from Douglas-fir Stand Post and Beam w Shear Walls, Frames 15ft o.c.

Roof: 87V (3ply) CLT
30' x 60' x 3.43" = 6,174 bd.ft.

Walls: 87V (3ply CLT)
15' x 60' x 3.43" = 3,087 bd.ft. (2) = 6,174 bd.ft.
15' x 29.31' x 3.43" = 1,508 bd.ft. (2) = 3,016 bd.ft.
Total = 9,190 bd.ft.

Glulams: Width: 5.12", Depth: 27"
5.12" x 27" x 27.98' = 38.67 cu.ft.
5.12" x 27" x 335.76" = 46,415 cu.in. = 26.86 cu.ft.
= 322 bd.ft. (5)
Total = 1,610 bd.ft.

Columns: 8" x 8"
8" x 8" x 15'
8" x 8" x 180" = 11,520 cu. in.
= 6.67 cu. ft.
= 80 bd.ft. (10)
Total = 800 bd.ft.

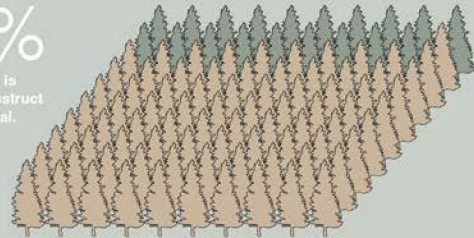


Building Total = 17,774 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

81%

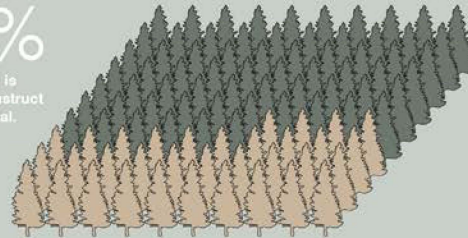
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

34%

of one acre is required to construct building total.



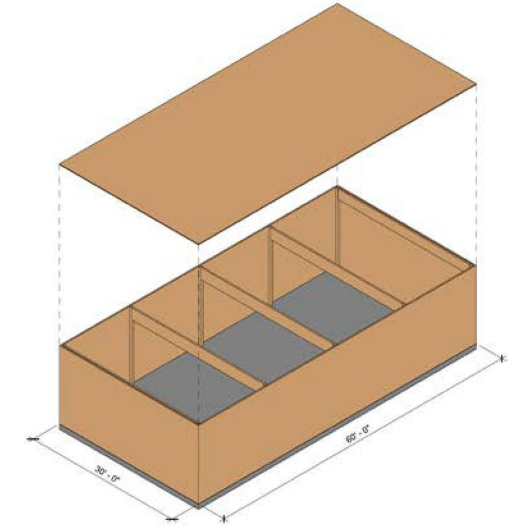
MPP from Douglas-fir Stand Post and Beam w Shear Walls, Frames 15ft o.c.

Roof: 3-ply MPP
30' x 60' x 3.06" = 5,508 bd.ft.

Walls: 3-ply MPP
15' x 60' x 3.06" = 2,700 bd.ft. (2) = 5,508 bd.ft.
15' x 29.49' x 3.06" = 1,353.6 bd.ft. (2) = 2,707 bd.ft.
Total = 8,215 bd.ft.

Glulams: Width: 3.06", Depth: 27"
3.06" x 27" x 28.64' = 23.84 cu.ft.
3.06" x 27" x 343.68" = 28,394.84 cu.in. = 16.43 cu.ft.
= 197 bd.ft. (5)
Total = 985 bd.ft.

Columns: 5.1" x 5.1"
5.1" x 5.1" x 15'
5.1" x 5.1" x 180" = 4,681.8 cu.in. = 2.71 cu.ft.
= 33 bd.ft. (10)
Total = 330 bd.ft.

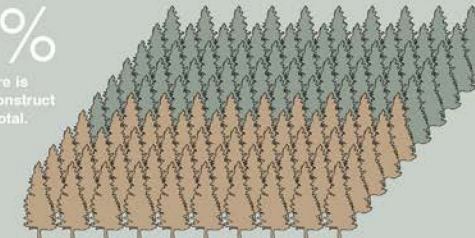


Building Total = 15,038 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

49%

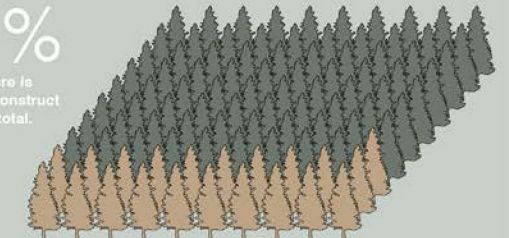
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

21%

of one acre is required to construct building total.



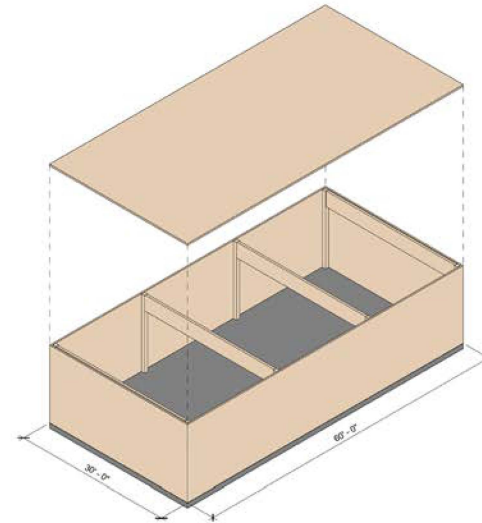
CLT from Douglas-fir Stand Post and Beam w Shear Walls, Frames 20ft o.c.

Roof: 105V (3ply) CLT
30' x 60' x 4.14" = 7,452 bd.ft.

Walls: 87V (3ply CLT)
15' x 60' x 3.43" = 3,087 bd.ft. (2) = 6,174 bd.ft.
15' x 29.31' x 3.43" = 1,508 bd.ft. (2) = 3,016 bd.ft.
Total = 9,190 bd.ft.

Glulams: Width: 5.12", Depth: 36"
5.12" x 36" x 27.98' = 51,887 cu.in. = 35.81 cu.ft.
= 430 bd.ft. (4)
Total = 1,720 bd.ft.

Columns:
8" x 8" x 15'
8" x 8" x 180" = 11,520 cu.in.
= 6.67 cu.ft.
= 80 bd.ft. (8)
Total = 640 bd.ft.

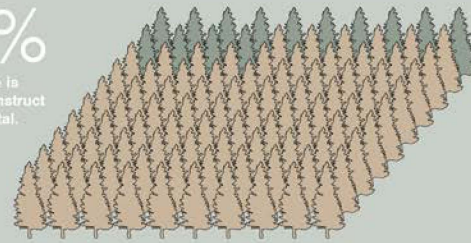


Building Total = 19,002 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

86%

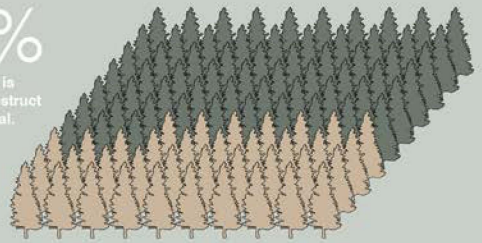
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

37%

of one acre is required to construct building total.



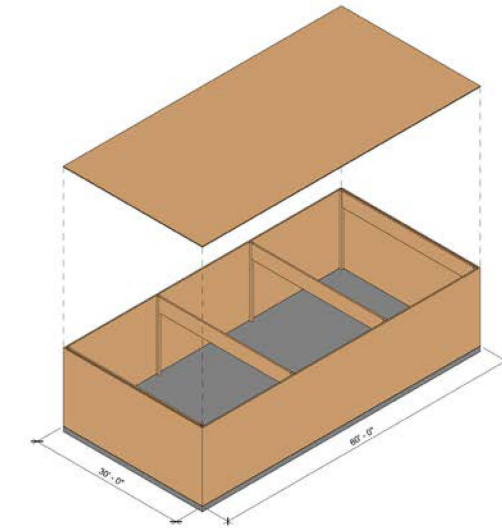
MPP from Douglas-fir Stand Post and Beam w Shear Walls, Frames 20ft o.c.

Roof: 4-ply MPP
30' x 60' x 4.08" = 7,344 bd.ft.

Walls: 3-ply MPP
15' x 60' x 3.06" = 2,700 bd.ft. (2) = 5,508 bd.ft.
15' x 29.49' x 3.06" = 1,353.6 bd.ft. (2) = 2,707 bd.ft.
Total = 8,215 bd.ft.

Glulams: Width: 3.06", Depth: 36"
3.06" x 36" x 28.64' = 31,859.79 cu.in. = 21.91 cu.ft.
= 263 bd.ft. (4)
Total = 1,052 bd.ft.

Columns: 5.1" x 5.1"
5.1" x 5.1" x 15'
5.1" x 5.1" x 180" =
4,681.8 cu.in. = 2.71 cu.ft.
= 33 bd.ft. (8)
Total = 264 bd.ft.

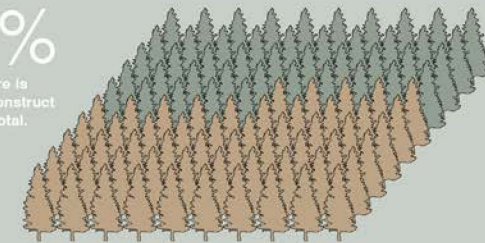


Building Total = 16,875 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

55%

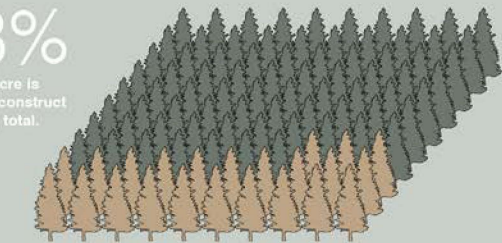
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

23%

of one acre is required to construct building total.

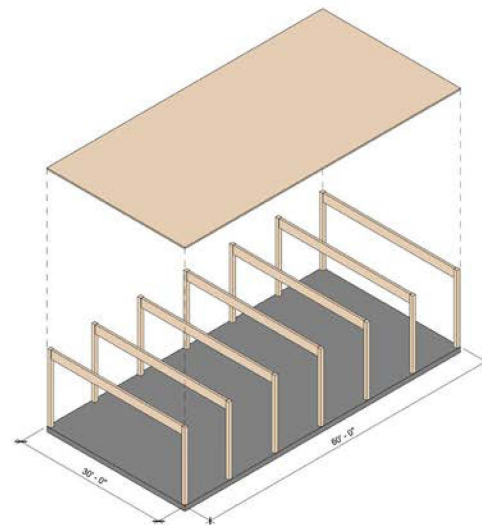


CLT from Douglas-fir Stand Post and Beam Frames 10ft o.c.

Roof: 87V (3ply) CLT
30' x 60' x 3.43" = 6,174 bd.ft.

Glulams: Width: 5.12", Depth: 21"
5.12" x 21" x 28.67'
5.12" x 21" x 344" = 36,987 cu.in. = 21.40 cu.ft.
= 257 bd.ft. (7)
Total = 1,799 bd.ft.

Columns: 8" x 8"
8" x 8" x 15'
8" x 8" x 180" = 11,520 cu. in. = 6.67 cu. ft. = 80 bd.ft. (14)
Total = 1,120 bd.ft.

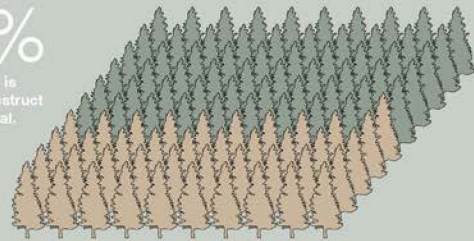


Building Total = 9,093 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

41%

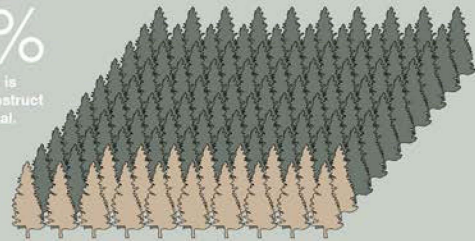
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

18%

of one acre is required to construct building total.

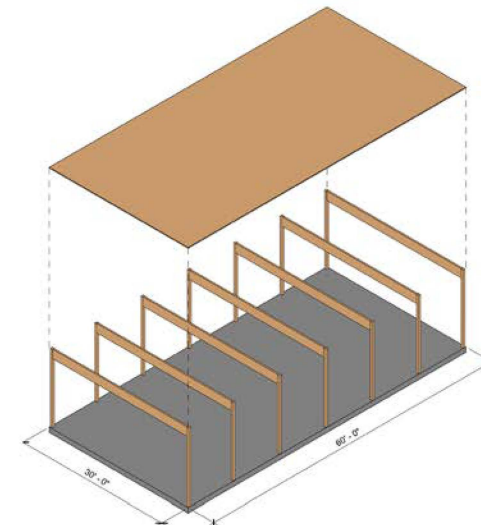


MPP from Douglas-fir Stand Post and Beam Frames 10ft o.c.

Roof: 2-ply MPP
30' x 60' x 2.04" = 3,672 bd.ft.

Glulams: Width: 3.06", Depth: 21"
3.06" x 21" x 29.15'
3.06" x 21" x 349.8" = 22,478.15 cu.in. = 13 cu.ft.
= 156 bd.ft. (7)
Total = 1,092 bd.ft.

Columns: 5.1" x 5.1"
5.1" x 5.1" x 15'
5.1" x 5.1" x 180" =
4,681.8 cu.in. = 2.71 cu.ft. = 33 bd.ft. (14)
Total = 462 bd.ft.

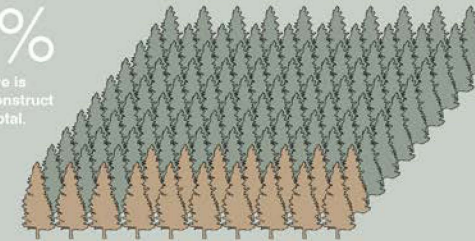


Building Total = 5,226 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

17%

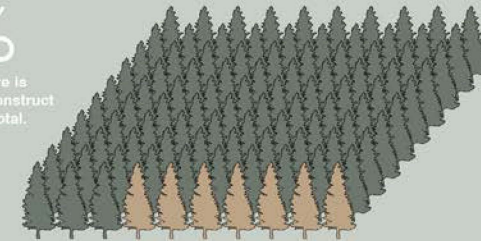
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

7%

of one acre is required to construct building total.



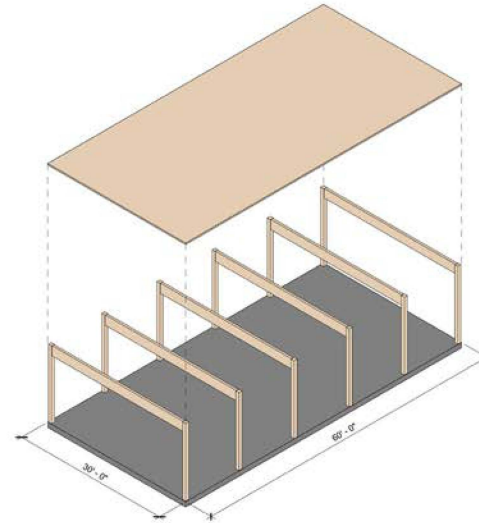
CLT from Douglas-fir Stand Post and Beam Frames 12ft o.c.

Roof: 87V (3ply) CLT
 $30' \times 60' \times 3.43" = 6,174 \text{ bd.ft.}$

Glulams: Width: 5.12", Depth: 23"
 $5.12" \times 23" \times 28.67' = 40,509 \text{ cu.in.} = 23.44 \text{ cu.ft.}$
 $= 281 \text{ bd.ft. (6)}$
 Total = 1,686 bd.ft.

Columns: 8" x 8"
 $8" \times 8" \times 15' = 11,520 \text{ cu. in.} = 6.67 \text{ cu. ft.}$
 $= 80 \text{ bd.ft. (12)}$
 Total = 960 bd.ft.

Building Total = 8,820 bd.ft.



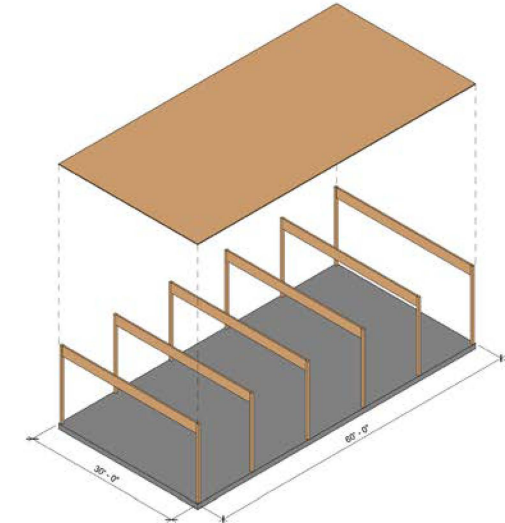
MPP from Douglas-fir Stand Post and Beam Frames 12ft o.c.

Roof: 3-ply MPP
 $30' \times 60' \times 3.06" = 5,508 \text{ bd.ft.}$

Glulams: Width: 3.06", Depth: 23"
 $3.06" \times 23" \times 29.15' = 24,618.92 \text{ cu.in.} = 14.25 \text{ cu.ft.}$
 $= 171 \text{ bd.ft. (6)}$
 Total = 1,026 bd.ft.

Columns: 5.1" x 5.1"
 $5.1" \times 5.1" \times 15' = 4,681.8 \text{ cu.in.} = 2.71 \text{ cu.ft.} = 33 \text{ bd.ft. (12)}$
 Total = 396 bd.ft.

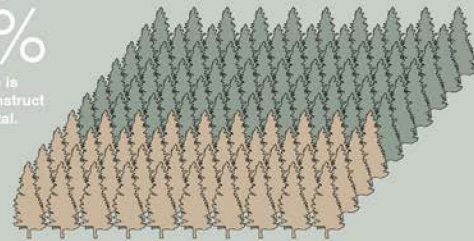
Building Total = 6,930 bd.ft.



40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

40%

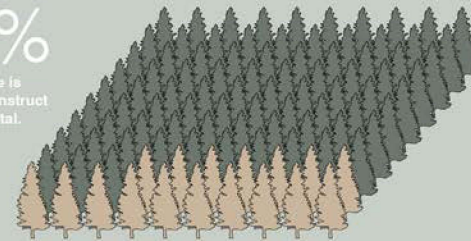
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

17%

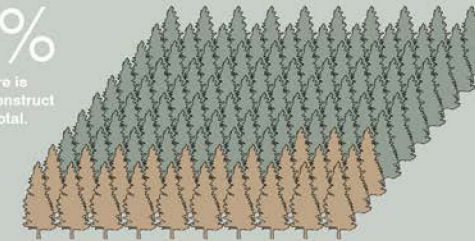
of one acre is required to construct building total.



40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

23%

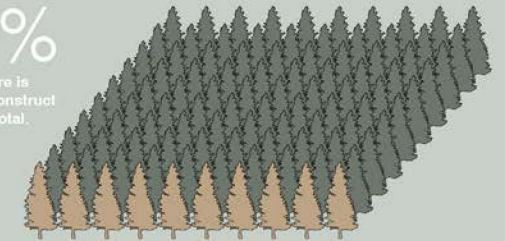
of one acre is required to construct building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

10%

of one acre is required to construct building total.

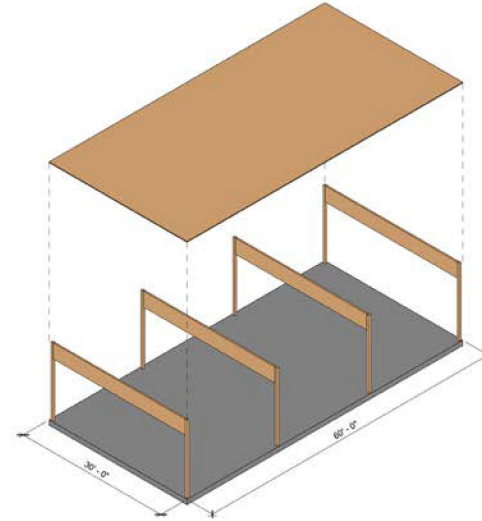


MPP from Douglas-fir Stand Post and Beam Frames 20ft o.c.

Roof: 4-ply MPP
 $30' \times 60' \times 4.08" = 7,344 \text{ bd.ft.}$

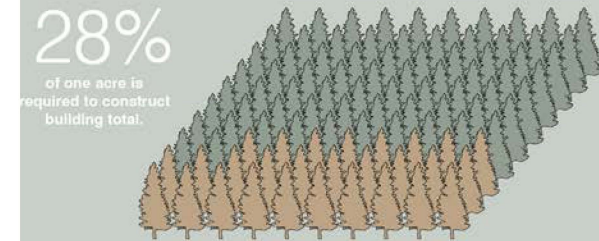
Glulams: Width: 3.06", Depth: 36"
 $3.06" \times 36" \times 29.15' = 38,533.97 \text{ cu.in.} = 22.3 \text{ cu.ft.}$
 $= 268 \text{ bd.ft. (4)}$
 Total = 1,072 bd.ft.

Columns: 5.1" x 5.1"
 $5.1" \times 5.1" \times 15' = 38,533.97 \text{ cu.in.} = 22.3 \text{ cu.ft.}$
 $5.1" \times 5.1" \times 180" = 4,681.8 \text{ cu.in.} = 2.71 \text{ cu.ft.} = 33 \text{ bd.ft. (8)}$
 Total = 264 bd.ft.

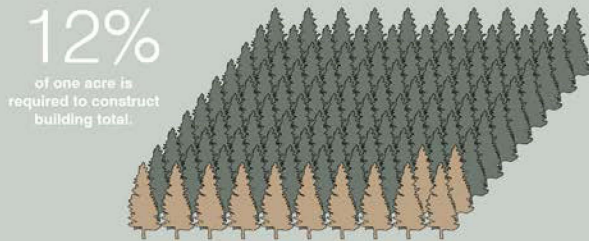


Building Total = 8,680 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

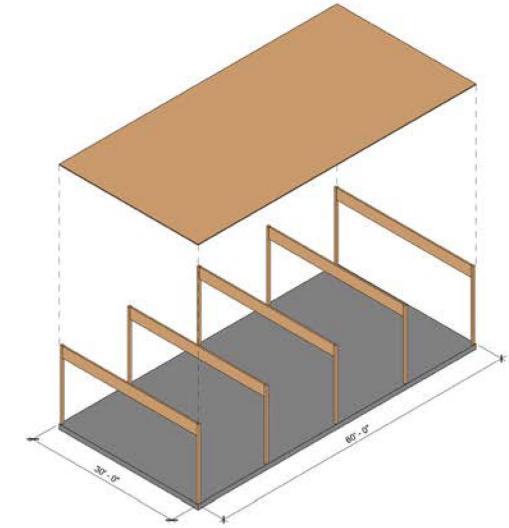


MPP from Douglas-fir Stand Post and Beam Frames 15ft o.c.

Roof: 3-ply MPP
 $30' \times 60' \times 3.06" = 5,508 \text{ bd.ft.}$

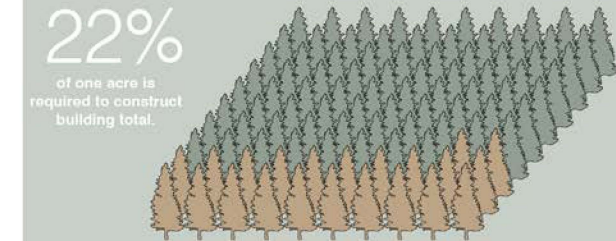
Glulams: Width: 3.06", Depth: 27"
 $3.06" \times 27" \times 29.15' = 28,900.78 \text{ cu.in.} = 16.72 \text{ cu.ft.}$
 $= 201 \text{ bd.ft. (5)}$
 Total = 1,005 bd.ft.

Columns: 5.1" x 5.1"
 $5.1" \times 5.1" \times 15' = 38,533.97 \text{ cu.in.} = 22.3 \text{ cu.ft.}$
 $5.1" \times 5.1" \times 180" = 4,681.8 \text{ cu.in.} = 2.71 \text{ cu.ft.} = 33 \text{ bd.ft. (10)}$
 Total = 330 bd.ft.

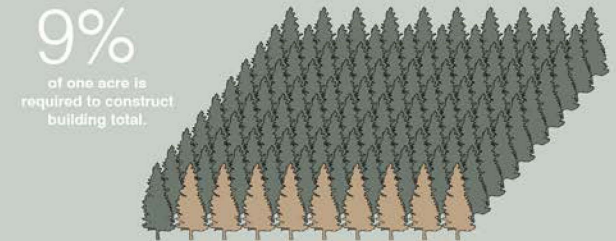


Building Total = 6,843 bd.ft.

40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.



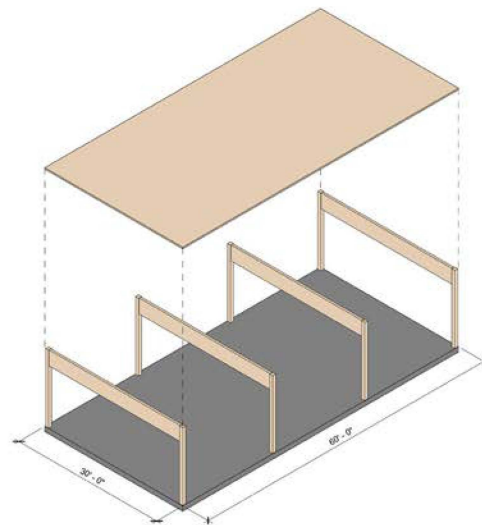
CLT from Douglas-fir Stand Post and Beam Frames 20ft o.c.

Roof: 105V (3ply) CLT
30' x 60' x 4.14" = 7,452 bd.ft.

Glulams:
5.12" x 36" x 28.67'
5.12" x 36" x 344" = 63,406 cu.in. = 36.69 cu.ft.
= 440 bd.ft. (4)
Total = 1,760 bd.ft.

Columns:
8" x 8" x 15'
8" x 8" x 180" = 11,520 cu. in. = 6.67 cu. ft.
= 80 bd.ft. (8)
Total = 640 bd.ft.

Building Total = 9,852 bd.ft.



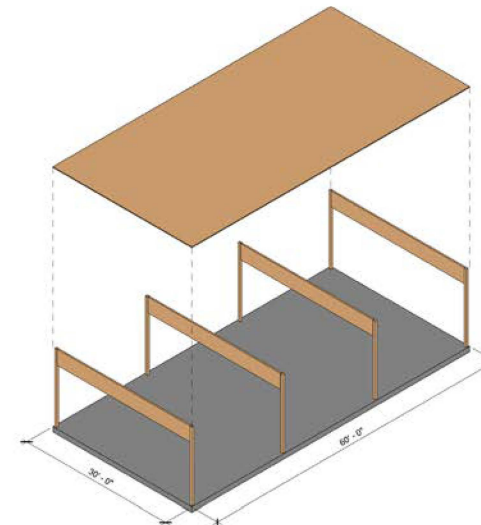
MPP from Douglas-fir Stand Post and Beam Frames 20ft o.c.

Roof: 4-ply MPP
30' x 60' x 4.08" = 7,344 bd.ft.

Glulams: Width: 3.06", Depth: 36"
3.06" x 36" x 29.15'
3.06" x 36" x 349.8" = 38,533.97 cu.in. = 22.3 cu.ft.
= 268 bd.ft. (4)
Total = 1,072 bd.ft.

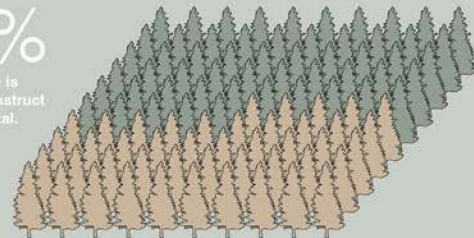
Columns: 5.1" x 5.1"
5.1" x 5.1" x 15'
5.1" x 5.1" x 180" =
4,681.8 cu.in. = 2.71 cu.ft. = 33 bd.ft. (8)
Total = 264 bd.ft.

Building Total = 8,680 bd.ft.



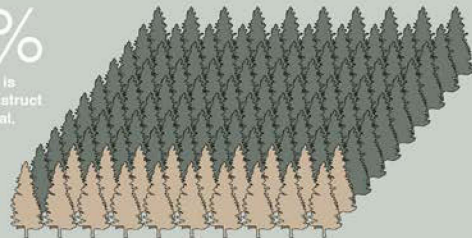
40 yrs: If once acre of Douglas-fir produces approximately: = 22,000 bd.ft.

45%
of one acre is
required to construct
building total.



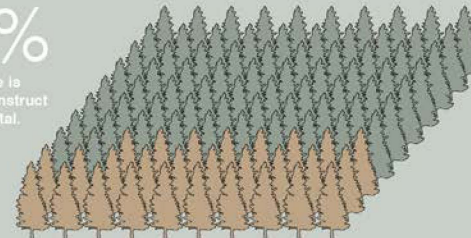
60 yrs: If once acre of Douglas-fir produces approximately: = 52,000 bd.ft.

19%
of one acre is
required to construct
building total.



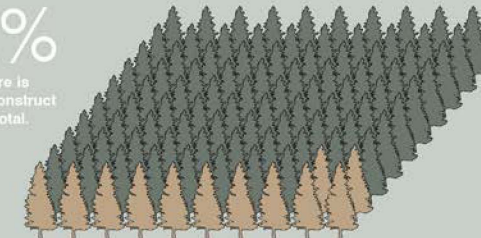
40 yrs: If once acre of Douglas-fir produces approximately: = 30,800 bd.ft.

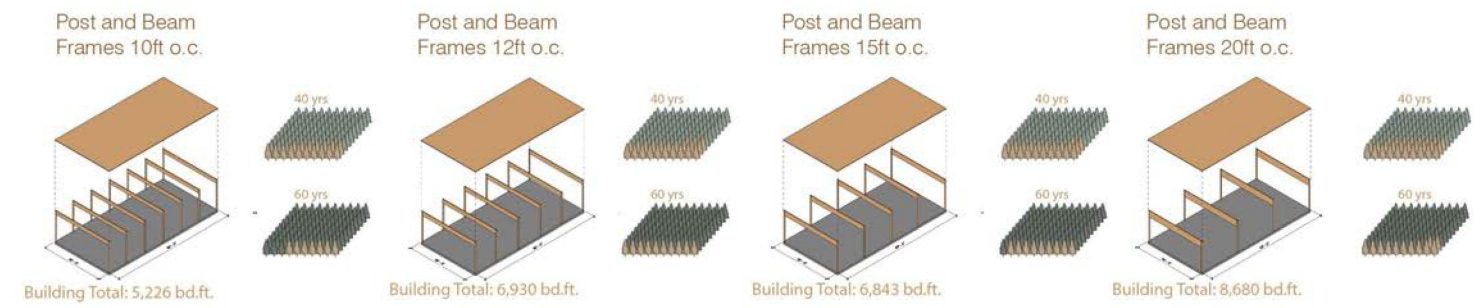
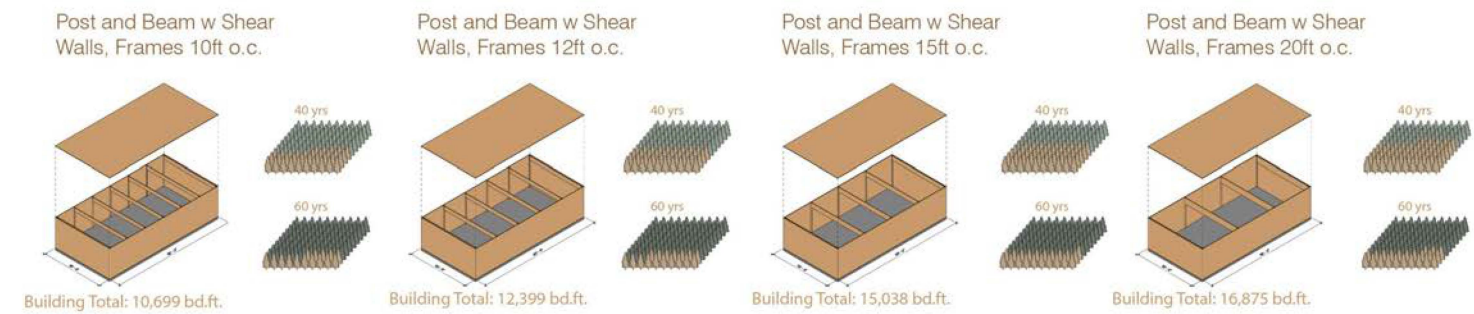
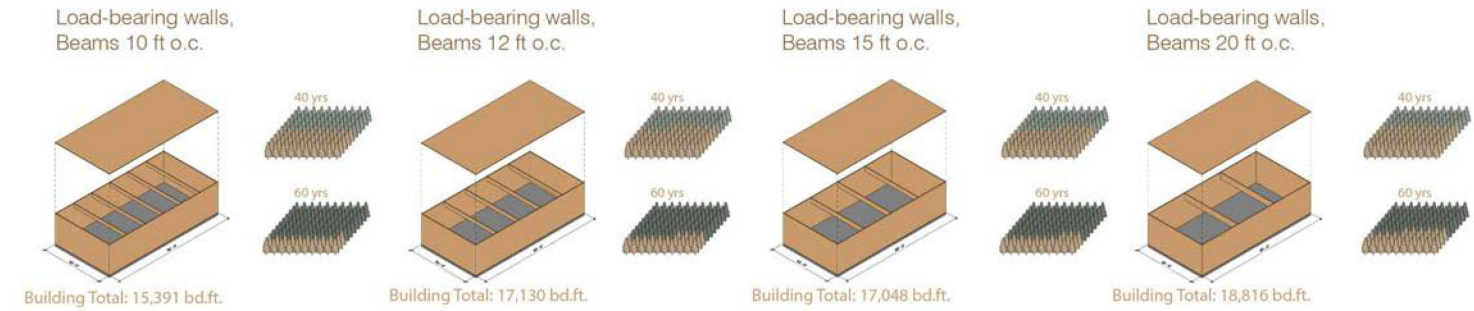
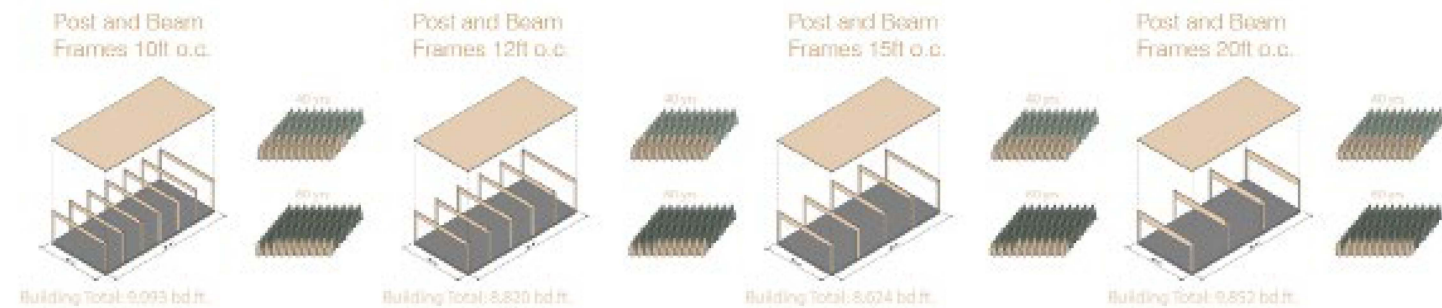
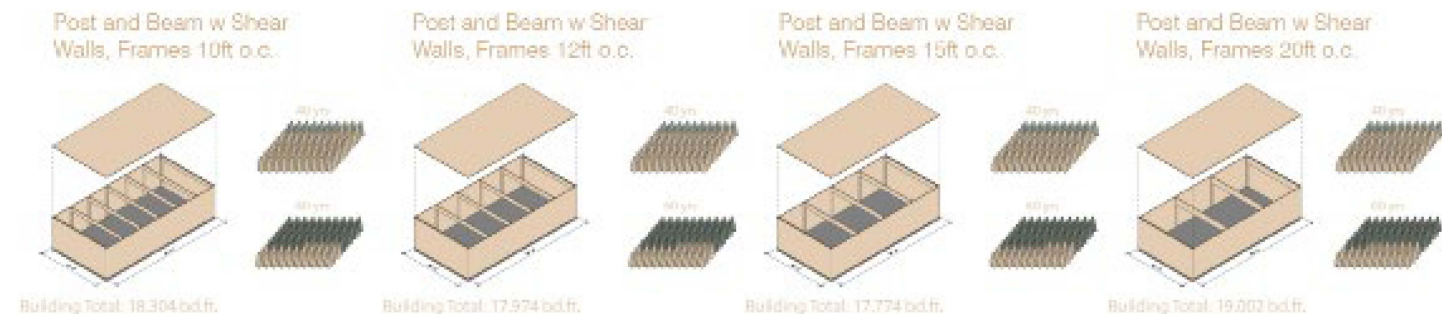
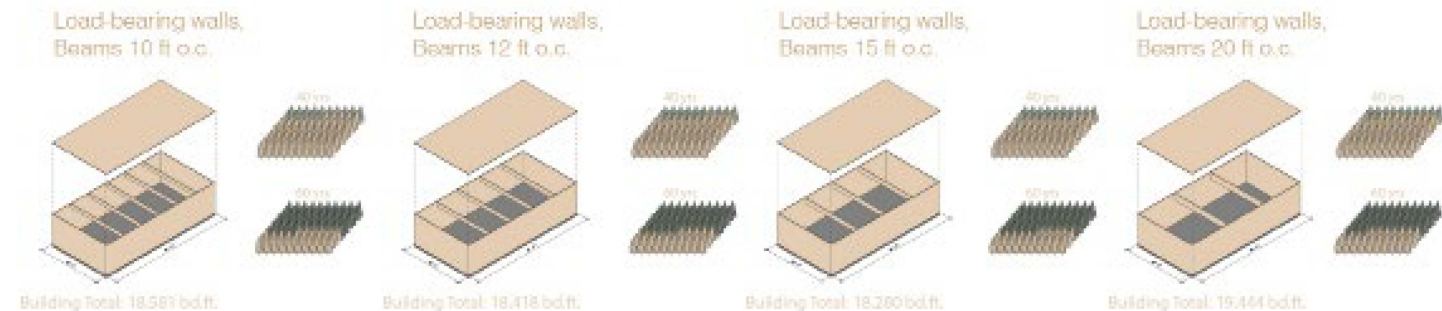
28%
of one acre is
required to construct
building total.



60 yrs: If once acre of Douglas-fir produces approximately: = 72,800 bd.ft.

12%
of one acre is
required to construct
building total.

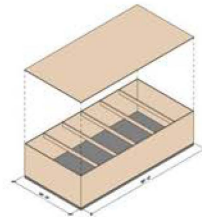




How much less wood?

An average of the wood volume reduction percentages shown on pages (76-77) demonstrate that MPP may generally achieve 19% efficiency in terms of wood volume compared to CLT. This closely resembles Freres Lumber's claim that MPP can use 20% less wood to achieve the same structural efficiency as CLT. This is strictly in terms of wood volume, not log utilization.

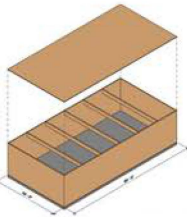
Load-bearing walls,
Beams 10 ft o.c.



Building Total: 18,581 bd.ft.

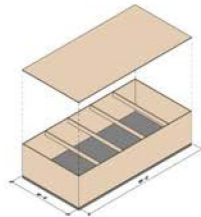
17%
less wood

Load-bearing walls,
Beams 10 ft o.c.



Building Total: 15,391 bd.ft.

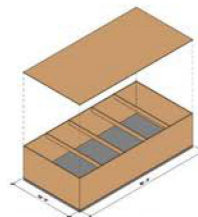
Load-bearing walls,
Beams 12 ft o.c.



Building Total: 18,418 bd.ft.

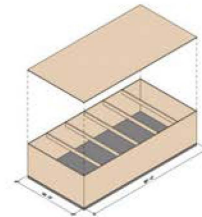
7%
less wood

Load-bearing walls,
Beams 12 ft o.c.



Building Total: 17,130 bd.ft.

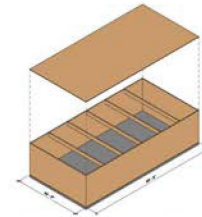
Load-bearing walls,
Beams 10 ft o.c.



Building Total: 18,581 bd.ft.

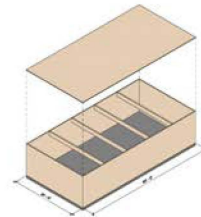
17%
less wood

Load-bearing walls,
Beams 10 ft o.c.



Building Total: 15,391 bd.ft.

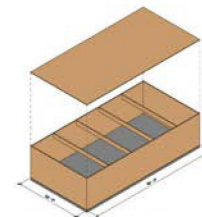
Load-bearing walls,
Beams 12 ft o.c.



Building Total: 18,418 bd.ft.

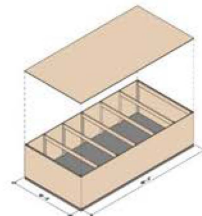
7%
less wood

Load-bearing walls,
Beams 12 ft o.c.



Building Total: 17,130 bd.ft.

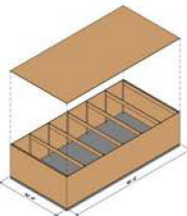
Post and Beam w Shear
Walls, Frames 10ft o.c.



Building Total: 18,304 bd.ft.

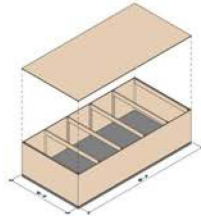
42%
less wood

Post and Beam w Shear
Walls, Frames 10ft o.c.



Building Total: 10,699 bd.ft.

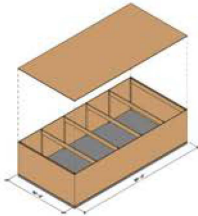
Post and Beam w Shear
Walls, Frames 12ft o.c.



Building Total: 17,974 bd.ft.

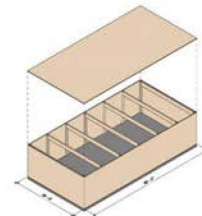
31%
less wood

Post and Beam w Shear
Walls, Frames 12ft o.c.



Building Total: 12,399 bd.ft.

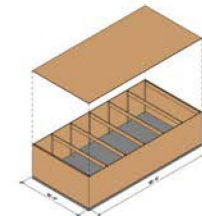
Post and Beam w Shear
Walls, Frames 10ft o.c.



Building Total: 18,304 bd.ft.

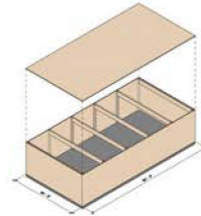
42%
less wood

Post and Beam w Shear
Walls, Frames 10ft o.c.



Building Total: 10,699 bd.ft.

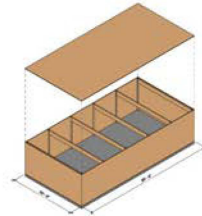
Post and Beam w Shear
Walls, Frames 12ft o.c.



Building Total: 17,974 bd.ft.

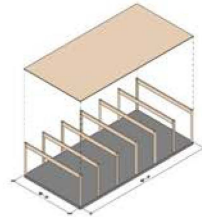
31%
less wood

Post and Beam w Shear
Walls, Frames 12ft o.c.



Building Total: 12,399 bd.ft.

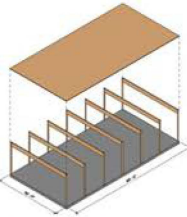
Post and Beam
Frames 10ft o.c.



Building Total: 9,093 bd.ft.

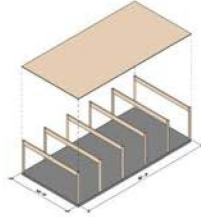
43%
less wood

Post and Beam
Frames 10ft o.c.



Building Total: 5,226 bd.ft.

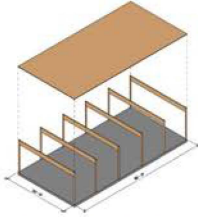
Post and Beam
Frames 12ft o.c.



Building Total: 8,820 bd.ft.

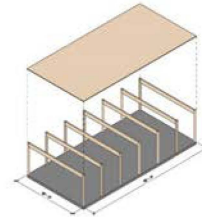
21%
less wood

Post and Beam
Frames 12ft o.c.



Building Total: 6,930 bd.ft.

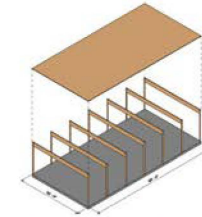
Post and Beam
Frames 10ft o.c.



Building Total: 9,093 bd.ft.

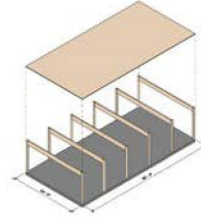
43%
less wood

Post and Beam
Frames 10ft o.c.



Building Total: 5,226 bd.ft.

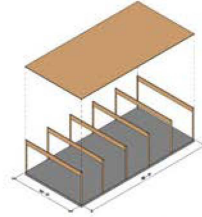
Post and Beam
Frames 12ft o.c.



Building Total: 8,820 bd.ft.

21%
less wood

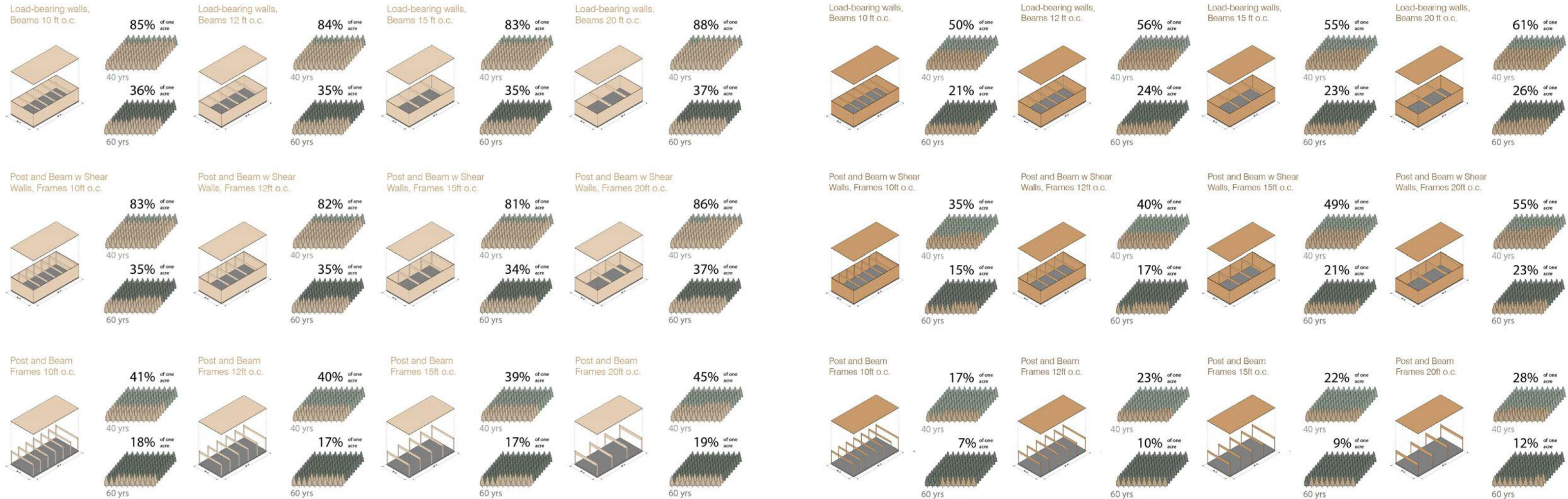
Post and Beam
Frames 12ft o.c.

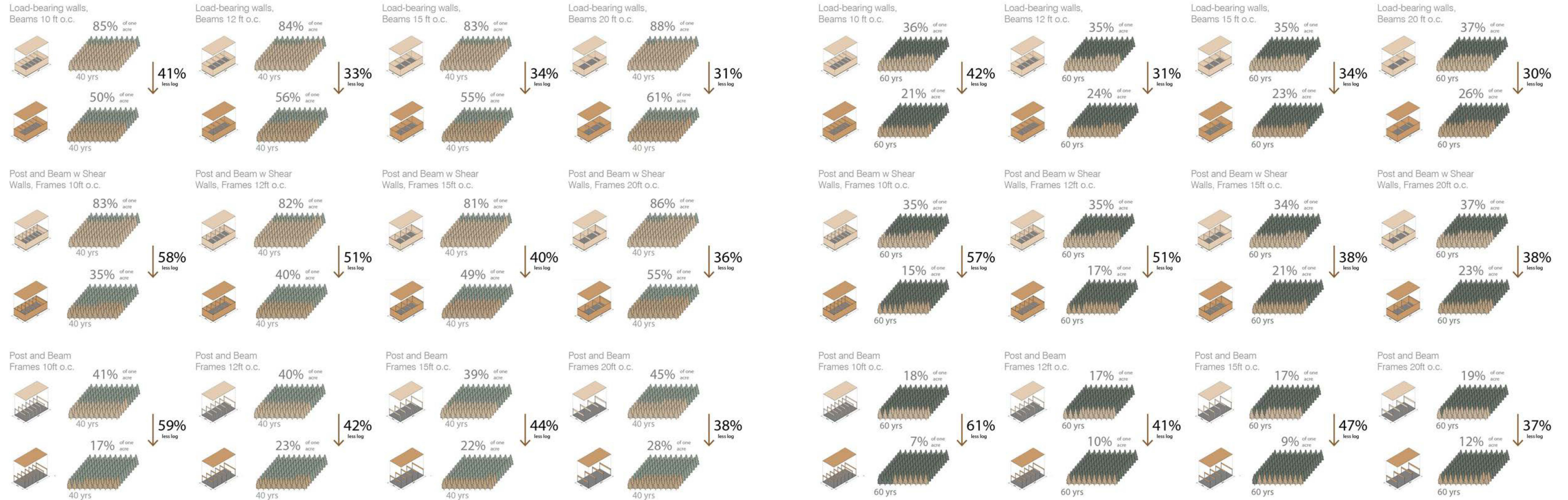


Building Total: 6,930 bd.ft.

How much less logs?

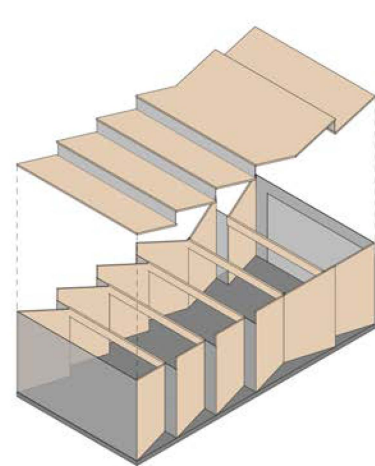
The next four pages compare CLT and MPP in terms log utilization with respect to lumber and veneer required for extraction. This was done for each scenario and for both 40yr stands and 60yr stands. Pages (80-81) highlight the percentage of one acre required for both 40yr and 60yr stands to construct each CLT and MPP building scenario. Pages (82) compare wood consumption per acre between CLT and MPP on a 40yr stand basis, while page (83) does the same on a 60yr stand basis. Both pages then point out the difference in the reduction of tree harvest between the two mass timber products. An average of all percentage differences for both the 40yr and 60yr stand consumption comparisons show that veneer (MPP) extracts 42% less log than does extraction for lumber (CLT). This highlights wood fiber efficiency with respect to how much less log is required for extraction when harvesting trees for veneer and veneer-based products like MPP than harvesting for lumber and lumber-based products like CLT.





Wood Fiber Efficiency of Creative Forms

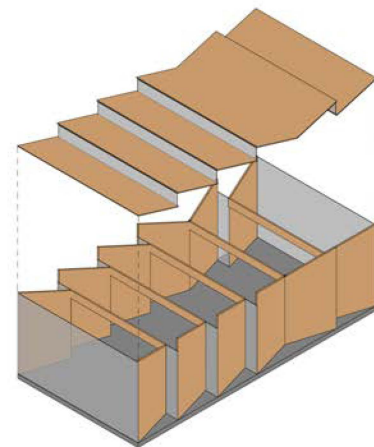
Pages (86-91) continue to explore wood fiber efficiency in terms of volume and log utilization similar to the “box” exercises. However, the following examples look to do so through different approaches to structure.



Roof: 87V 3ply CLT (3.43 in)
 $30' \times 10.5' \times 3.43" = 1,089.45$ (6)
 Total: 6,482.7 bd.ft.

Walls: 105V 3ply CLT (4.14in): load-bearing:
 $15' \times 10.5' + 0.5(10.5')(2.5') = 157.5 \text{ sq ft} + 13.125 \text{ sq ft} = 170.63 \text{ sq ft. (4.14')} = 709.41$
 bd.ft. (12)
 Total: 8,476.92 bd.ft.

Glulam Beams, 10' o.c.:
 $5.12' \times 21' \times 23.83' = 5.12' \times 21' \times 296' = 30,750.72 \text{ cu in.} = 17.8 \text{ cu ft.} = 213.6 \text{ bd.ft. (5)}$
 Total: 1,008 bd.ft.



Roof: 2" MPP
 $30' \times 10.5' \times 2" = 630$ (6)
 Total: 3,780 bd.ft.

Walls: 4" MPP: load-bearing:
 $15' \times 10.5' + 0.5(10.5')(2.5') = 157.5 \text{ sq ft} + 13.125 \text{ sq ft} = 170.63 \text{ sq ft. (4')} = 682.32 \text{ bd.ft. (12)}$
 Total: 8,190.24 bd.ft.

LVL Beams, 10' o.c.:
 $3.5' \times 21' \times 23.83' = 3.5' \times 21' \times 296' = 21,021 \text{ cu in.} = 12.16 \text{ cu ft.} = 145.92 \text{ bd.ft. (5)}$
 Total: 729.6 bd.ft.

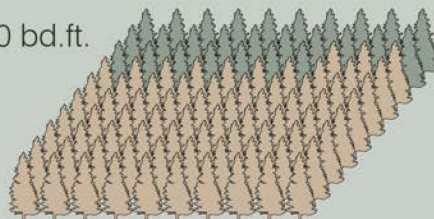
Building Total = 16,028 bd.ft.

Building Total = 12,700 bd.ft.

40 yrs = 22,000 bd.ft.

73%

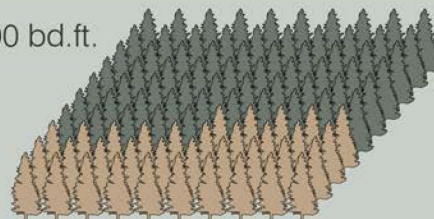
of one acre is required to construct building total.



40 yrs = 30,800 bd.ft.

41%

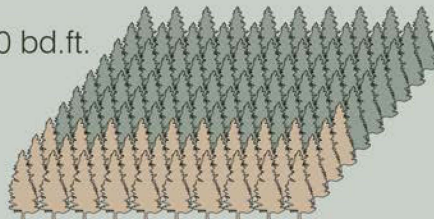
of one acre is required to construct building total.



60 yrs = 52,000 bd.ft.

31%

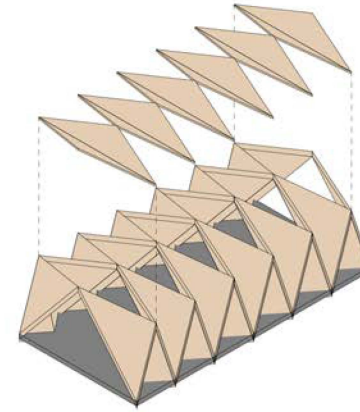
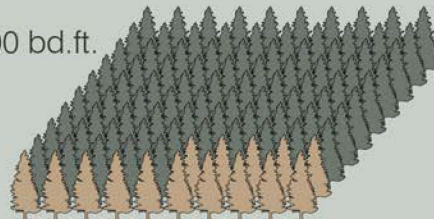
of one acre is required to construct building total.



60 yrs = 72,800 bd.ft.

17%

of one acre is required to construct building total.



Panels: 87V 3-PLY CLT (3.43")

$$A = \sqrt{p(p-a)(p-b)(p-c)}$$

$$p = (a+b+c)/2$$

Panel 1:
 $4'6", 15', 14'6" = 54" \times 180" \times 174"$
 $p = 408.72 = 204$
 $A = \sqrt{p(p-a)(p-b)(p-c)} = \sqrt{204(204-54)(204-180)(204-174)} = \sqrt{204(150)(24)(30)} = 4,693.83 \text{ sq in}$
 $4,693.83 \text{ sq in (3.43 in)} = 16,099.84 \text{ cu in} = 9.32 \text{ cu ft.} = 111.84 \text{ bd.ft. (24)}$
 Total: 2,664.16 bd.ft.

Panel 2:
 $15'9", 14'6", 23'6" = 189", 174", 282"$
 $p = 645.72 = 322.5$
 $A = \sqrt{p(p-a)(p-b)(p-c)} = \sqrt{322.5(322.5-189)(322.5-174)(322.5-282)} = \sqrt{322.5(133.5)(148.5)(40.5)} = 16,091.49 \text{ sq in}$
 $16,091.49 \text{ sq in (3.43 in)} = 55,193.81 \text{ cu in} = 31.94 \text{ cu ft.} = 383.28 \text{ bd.ft. (24)}$
 Total: 9,198.72 bd.ft.

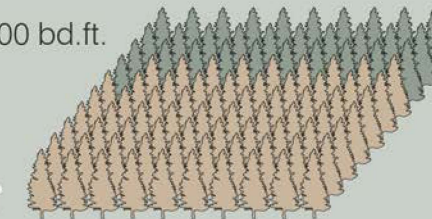
Panel 3:
 $15'9", 15'9", 30' = 189", 189", 360"$
 $p = 738.72 = 369$
 $A = \sqrt{p(p-a)(p-b)(p-c)} = \sqrt{369(369-189)(369-189)(369-360)} = \sqrt{369(180)(180)(9)} = 10,373.06 \text{ sq in}$
 $10,373.06 \text{ sq in (3.43 in)} = 35,579.6 \text{ cu in} = 20.59 \text{ cu ft.} = 247.08 \text{ bd.ft. (12)}$
 Total: 2,904.96 bd.ft.

Building Total = 14,848 bd.ft.

40 yrs = 22,000 bd.ft.

69%

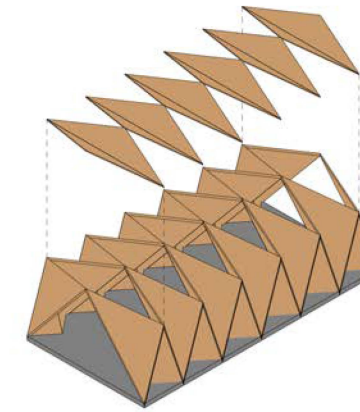
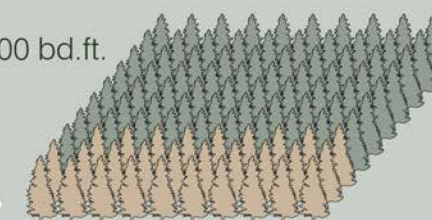
of one acre is required to construct building total.



60 yrs = 52,000 bd.ft.

29%

of one acre is required to construct building total.



Panels: 3" MPP

$$A = \sqrt{p(p-a)(p-b)(p-c)}$$

$$p = (a+b+c)/2$$

Panel 1:
 $4'6", 15', 14'6" = 54" \times 180" \times 174"$
 $p = 408.72 = 204$
 $A = \sqrt{p(p-a)(p-b)(p-c)} = \sqrt{204(204-54)(204-180)(204-174)} = \sqrt{204(150)(24)(30)} = 4,693.83 \text{ sq in}$
 $4,693.83 \text{ sq in (3 in)} = 14,081.49 \text{ cu in} = 8.15 \text{ cu ft.} = 97.8 \text{ bd.ft. (24)}$
 Total: 2,347.2 bd.ft.

Panel 2:
 $15'9", 14'6", 23'6" = 189", 174", 282"$
 $p = 645.72 = 322.5$
 $A = \sqrt{p(p-a)(p-b)(p-c)} = \sqrt{322.5(322.5-189)(322.5-174)(322.5-282)} = \sqrt{322.5(133.5)(148.5)(40.5)} = 16,091.49 \text{ sq in}$
 $16,091.49 \text{ sq in (3 in)} = 48,274.47 \text{ cu in} = 27.94 \text{ cu ft.} = 335.28 \text{ bd.ft. (24)}$
 Total: 8,046.72 bd.ft.

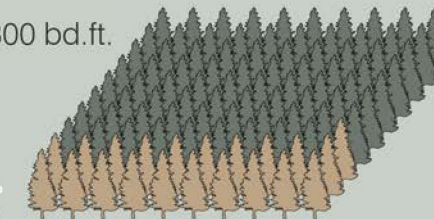
Panel 3:
 $15'9", 15'9", 30' = 189", 189", 360"$
 $p = 738.72 = 369$
 $A = \sqrt{p(p-a)(p-b)(p-c)} = \sqrt{369(369-189)(369-189)(369-360)} = \sqrt{369(180)(180)(9)} = 10,373.06 \text{ sq in}$
 $10,373.06 \text{ sq in (3 in)} = 31,119.18 \text{ cu in} = 18 \text{ cu ft.} = 216 \text{ bd.ft. (12)}$
 Total: 2,592 bd.ft.

Building Total = 12,986 bd.ft.

40 yrs = 30,800 bd.ft.

35%

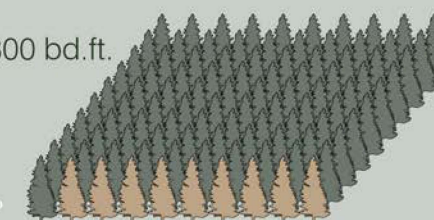
of one acre is required to construct building total.

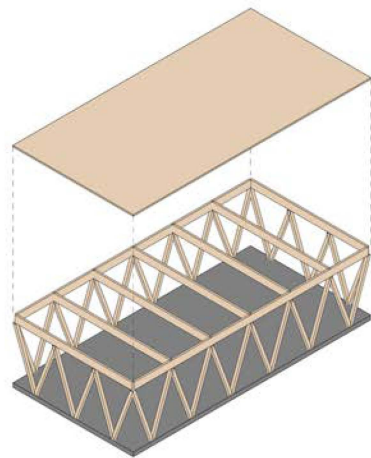


60 yrs = 72,800 bd.ft.

15%

of one acre is required to construct building total.

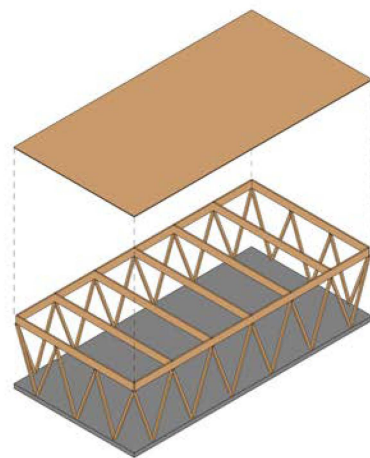




Roof: 87V 3ply CLT (3.43 in)
 $30' \times 60' \times 3.43' =$
 Total: 6,174 bd.ft.

Glulam Beams, 10' o.c.:
 $5.12' \times 21' \times 29.15' = 37,610.5 \text{ cu.in.} = 21.8 \text{ cu.ft.} = 261.6 \text{ bd.ft. (7)} = 1,831.2 \text{ bd.ft.}$
 $5.12' \times 21' \times 60' = 5.12' \times 21' \times 720' = 77,414.4 \text{ cu.in.} = 44.8 \text{ cu.ft.} = 537.6 \text{ bd.ft. (2)}$
 $= 1,015.2 \text{ bd.ft.}$
 Total: 2,906.4 bd.ft.

Columns:
 $8' \times 8' \times 142' = 8' \times 8' \times 170' = 10,880 \text{ cu.in.} = 6.3 \text{ cu.ft.} = 75.6 \text{ bd.ft. (36)}$
 Total: 2,721.6 bd.ft.



Roof: 2" MPP
 $30' \times 61' \times 2' =$
 Total: 3,660 bd.ft.

LVL Beams, 10' o.c.:
 $3.5' \times 21' \times 29.42' = 25,948.44 \text{ cu.in.} = 15.02 \text{ cu.ft.} = 180.24 \text{ bd.ft. (7)} = 1,261.68 \text{ bd.ft.}$
 $3.5' \times 21' \times 60' = 3.5' \times 21' \times 720' = 52,920 \text{ cu.in.} = 30.63 \text{ cu.ft.} = 367.56 \text{ bd.ft. (2)}$
 $= 735.12 \text{ bd.ft.}$
 Total: 1,996.8 bd.ft.

Columns:
 $5.25' \times 5.25' \times 142' = 5.25' \times 5.25' \times 170' = 4,685.63 \text{ cu.in.} = 2.71 \text{ cu.ft.} = 32.52 \text{ bd.ft. (36)}$
 Total: 1,170.72 bd.ft.

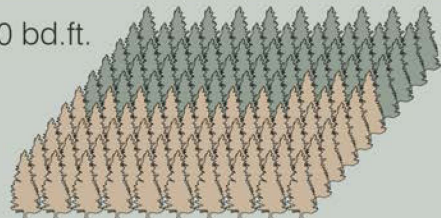
Building Total = 11,802 bd.ft.

Building Total = 6,768 bd.ft.

40 yrs = 22,000 bd.ft.

53%

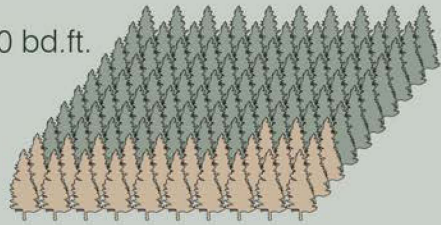
of one acre is required to construct building total.



60 yrs = 52,000 bd.ft.

23%

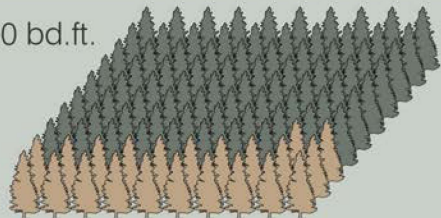
of one acre is required to construct building total.



40 yrs = 30,800 bd.ft.

22%

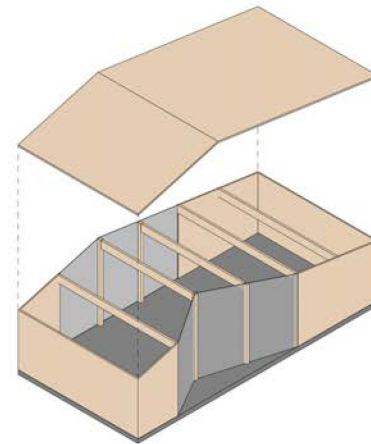
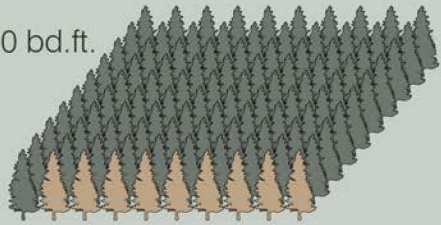
of one acre is required to construct building total.



60 yrs = 72,800 bd.ft.

9%

of one acre is required to construct building total.



Roof: 87V 3ply CLT (3.43 in)
 $30' \times 61' \times 3.43' =$
 Total: 6,507.2 bd.ft.

Walls: 105V 3ply CLT (4.14in); load-bearing:
 $12' \times 29.31' \times 4.14' = 1,456.12 \text{ bd.ft. (2)}$
 $= 2,912.24 \text{ bd.ft.}$
 $12' \times 10' + 0.5(10')(2.83) = 134.15 \text{ sq.in.} \times 4.14' = 555.38 \text{ (2)}$
 $= 1,110.76 \text{ bd.ft.}$
 $12' \times 20' + 0.5(20')(2.83) = 268.3 \text{ sq.in.} \times 4.14' = 1,110.76 \text{ (2)}$
 $= 2,221.52 \text{ bd.ft.}$
 Total: 6,244.52 bd.ft.

Glulam Beams, 10' o.c.:
 $5.12' \times 21' \times 29.31' = 5.12' \times 21' \times 351.72' = 37,816.93 \text{ cu.in.} = 21.88 \text{ cu.ft.} = 262.56 \text{ bd.ft. (3)}$
 $= 231.48 \text{ bd.ft.}$
 $5.12' \times 21' \times 25.83' = 5.12' \times 21' \times 309.96' = 33,326.9 \text{ cu.in.} = 19.29 \text{ cu.ft.}$
 $= 231.48 \text{ bd.ft.}$
 $5.12' \times 21' \times 23' = 5.12' \times 21' \times 276' = 29,675.52 \text{ cu.in.} = 17.17 \text{ cu.ft.}$
 $= 206.04 \text{ bd.ft.}$
 Total: 1,225.2 bd.ft.

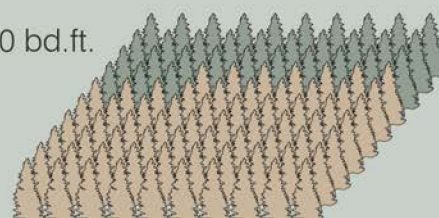
Columns:
 $8' \times 8' \times 172' = 8' \times 8' \times 206' = 13,184 \text{ cu.in.} = 7.63 \text{ cu.ft.} = 91.56 \text{ bd.ft. (2)}$
 $= 183.12 \text{ bd.ft.}$
 $8' \times 8' \times 187' = 8' \times 8' \times 223' = 14,272 \text{ cu.in.} = 8.23 \text{ cu.ft.} = 98.76 \text{ bd.ft. (2)}$
 $= 197.52 \text{ bd.ft.}$
 Total: 380.64 bd.ft.

Building Total = 14,848 bd.ft.

40 yrs = 22,000 bd.ft.

67%

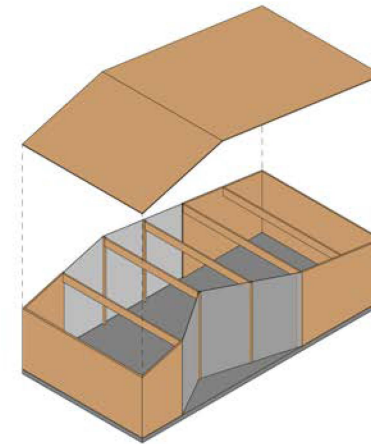
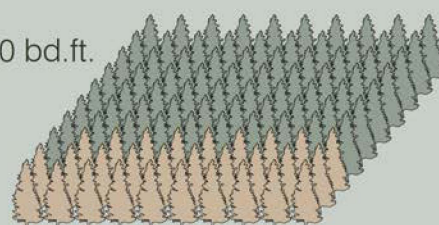
of one acre is required to construct building total.



60 yrs = 52,000 bd.ft.

29%

of one acre is required to construct building total.



Roof: 2" MPP
 $30' \times 61' \times 2' =$
 Total: 3,660 bd.ft.

Walls: 3" and 4" MPP; load-bearing:
 $12' \times 29.33' \times 3' = 1,055.88 \text{ bd.ft. (2)}$
 $= 2,111.76 \text{ bd.ft.}$
 $12' \times 10' + 0.5(10')(2.83) = 134.15 \text{ sq.in.} \times 4' = 536.6 \text{ (2)}$
 $= 1,073.2 \text{ bd.ft.}$
 $12' \times 20' + 0.5(20')(2.83) = 268.3 \text{ sq.in.} \times 4' = 1,073.2 \text{ (2)}$
 $= 2,146.4 \text{ bd.ft.}$
 Total: 5,331.36 bd.ft.

LVL Beams, 10' o.c.:
 $3.5' \times 21' \times 29.31' = 3.5' \times 21' \times 351.72' = 25,851.42 \text{ cu.in.} = 14.96 \text{ cu.ft.} = 179.52 \text{ bd.ft. (3)}$
 $= 328.56 \text{ bd.ft.}$
 $3.5' \times 21' \times 25.83' = 3.5' \times 21' \times 309.96' = 22,782.06 \text{ cu.in.} = 13.18 \text{ cu.ft.}$
 $= 158.56 \text{ bd.ft.}$
 $3.5' \times 21' \times 23' = 3.5' \times 21' \times 276' = 20,286 \text{ cu.in.} = 11.74 \text{ cu.ft.}$
 $= 140.88 \text{ bd.ft.}$
 Total: 828 bd.ft.

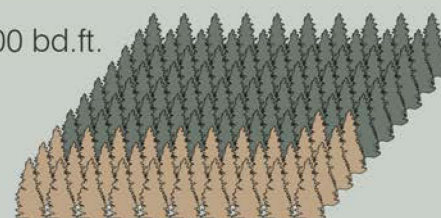
Columns:
 $5.25' \times 5.25' \times 172' = 5.25' \times 5.25' \times 206' = 5,677.88 \text{ cu.in.} = 3.29 \text{ cu.ft.} = 39.48 \text{ bd.ft. (2)}$
 $= 78.96 \text{ bd.ft.}$
 $5.25' \times 5.25' \times 187' = 5.25' \times 5.25' \times 223' = 6,146.44 \text{ cu.in.} = 3.56 \text{ cu.ft.} = 42.72 \text{ bd.ft. (2)}$
 $= 85.44 \text{ bd.ft.}$
 Total: 164.4 bd.ft.

Building Total = 9,984 bd.ft.

40 yrs = 30,800 bd.ft.

32%

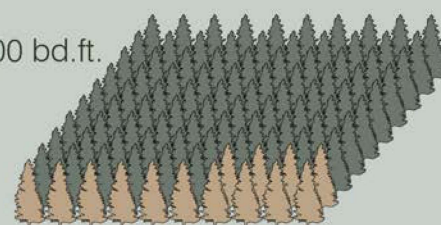
of one acre is required to construct building total.

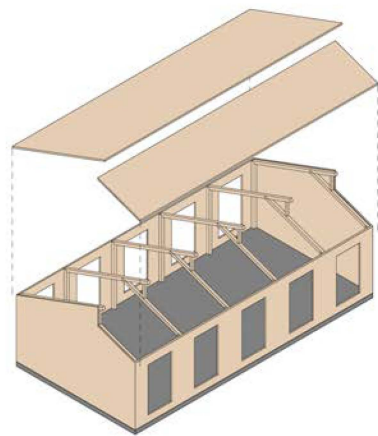


60 yrs = 72,800 bd.ft.

14%

of one acre is required to construct building total.



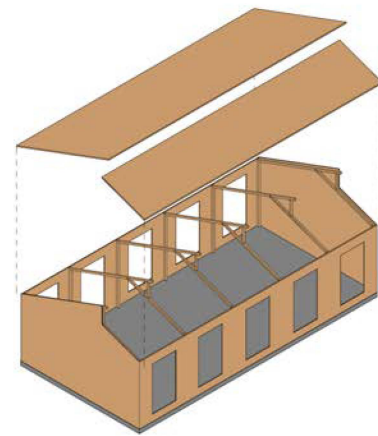


Roof: 87V 3ply CLT (3.43 in)
 $25' \times 60' \times 3.43" = 5,145 \text{ bd.ft.}$
 $11.5' \times 60' \times 3.43" = 2,366.7 \text{ bd.ft.}$
Total: 7,511.7 bd.ft.

Walls: 87V 3ply CLT (3.43in): non-load-bearing:
 $15' \times 29.43' + ((0.5)(20.24')(7.5')) + ((0.5)(9.19')(3.5')) = 441.45 + 75.9 + 16.08 = 533.43 \text{ sq.ft.} \times 3.43" = 1,859.66 \text{ bd.ft.} (2) = 3,699.32 \text{ bd.ft.}$
 $(15' \times 60') - ((66 \text{ sq.ft.} (5)) = 900 \text{ sq.ft.} - 330 \text{ sq.ft.} = 570 \text{ sq.ft.} \times 3.43" = 1,955.1 \text{ bd.ft.} (2) = 3,910.2 \text{ bd.ft.}$
Total: 7,569.52

Trusses, 12' o.c.:
 $8' \times 8' \times 22' = 8' \times 8' \times 264' = 16,896 \text{ cu.in.} = 9.76 \text{ cu.ft.} = 117.36 \text{ bd.ft.}$
 $8' \times 8' \times 14.5' = 8' \times 8' \times 174' = 11,136 \text{ cu.in.} = 6.4 \text{ cu.ft.} = 76.8 \text{ bd.ft.}$
 $8' \times 8' \times 3' = 8' \times 8' \times 36' = 2,304 \text{ cu.in.} = 1.3 \text{ cu.ft.} = 15.6 \text{ bd.ft.}$
Total: 209.76 bd.ft. (6) = 1,258.56 bd.ft.

Columns:
 $8' \times 8' \times 15' = 8' \times 8' \times 180' = 11,520 \text{ cu.in.} = 6.67 \text{ cu.ft.} = 81.04 \text{ bd.ft.} (12) = 980.48 \text{ bd.ft.}$

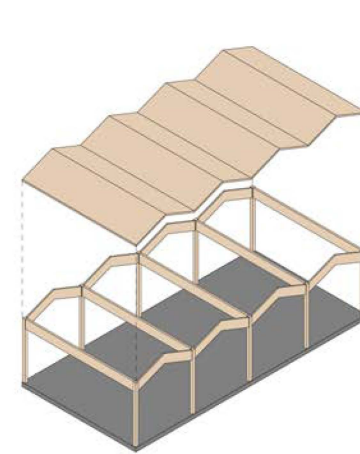


Roof: 2" MPP
 $25' \times 60' \times 2" = 3,000 \text{ bd.ft.}$
 $11.5' \times 60' \times 2" = 1,380 \text{ bd.ft.}$
Total: 4,380 bd.ft.

Walls: 87V 3ply CLT (3.43in): non-load-bearing:
 $15' \times 29.43' + ((0.5)(20.24')(7.5')) + ((0.5)(9.19')(3.5')) = 441.45 + 75.9 + 16.08 = 533.43 \text{ sq.ft.} \times 2" = 1,066.86 \text{ bd.ft.} (2) = 2,133.72 \text{ bd.ft.}$
 $(15' \times 60') - ((66 \text{ sq.ft.} (5)) = 900 \text{ sq.ft.} - 330 \text{ sq.ft.} = 570 \text{ sq.ft.} \times 2" = 1,140 \text{ bd.ft.} (2) = 2,280 \text{ bd.ft.}$
Total: 4,413.72 bd.ft.

Trusses, 12' o.c.:
 $5.25' \times 5.25' \times 22' = 5.25' \times 5.25' \times 264' = 7,276.5 \text{ cu.in.} = 4.21 \text{ cu.ft.} = 50.52 \text{ bd.ft.}$
 $5.25' \times 5.25' \times 14.5' = 5.25' \times 5.25' \times 174' = 4,795.9 \text{ cu.in.} = 2.78 \text{ cu.ft.} = 33.36 \text{ bd.ft.}$
 $5.25' \times 5.25' \times 3' = 5.25' \times 5.25' \times 36' = 992.25 \text{ cu.in.} = 0.57 \text{ cu.ft.} = 6.84 \text{ bd.ft.}$
Total: 90.72 bd.ft. (6) = 544.32 bd.ft.

Columns:
 $5.25' \times 5.25' \times 15' = 5.25' \times 5.25' \times 180' = 4,961.25 \text{ cu.in.} = 2.87 \text{ cu.ft.} = 34.44 \text{ bd.ft.} (12) = 413.28 \text{ bd.ft.}$

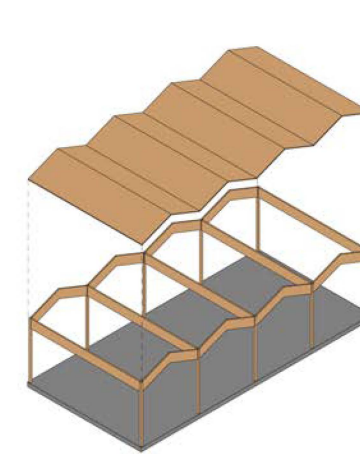


Roof: 87V 3ply CLT (3.43 in)
 1 panel = $8.5' \times 30' \times 3.43" = 874.65 \text{ bd.ft.}$
Total: 6,997.2 bd.ft.

Glulam Beams, 15' o.c.:
 $5.12' \times 27' \times 28.5' = 5.12' \times 27' \times 342' = 47,278.08 \text{ cu.in.} = 27.36 \text{ cu.ft.} = 328.32 \text{ bd.ft.} (5) = 1,641.6 \text{ bd.ft.}$

Angled Beams:
 $5.12' \times 27' \times 7.72' (2) = 5.12' \times 27' \times 154.4' = 25,613.11 \text{ cu.in.} = 14.82 \text{ cu.ft.} = 177.84 \text{ bd.ft.} (8) = 1,422.72 \text{ bd.ft.}$

Columns:
 $8' \times 8' \times 15' = 8' \times 8' \times 180' = 11,520 \text{ cu.in.} = 6.67 \text{ cu.ft.} = 81.04 \text{ bd.ft.} (8) = 648.32 \text{ bd.ft.}$



Roof: 2" MPP
 1 panel = $8.5' \times 30' \times 2" = 510 \text{ bd.ft.}$
Total: 4,080 bd.ft.

LVL Beams, 15' o.c.:
 $3.5' \times 27' \times 28.5' = 3.5' \times 27' \times 342' = 32,319 \text{ cu.in.} = 18.70 \text{ cu.ft.} = 224.4 \text{ bd.ft.}$
Total: 1,120 bd.ft.

Angled LVL Beams:
 $3.5' \times 27' \times 7.72' (2) = 3.5' \times 27' \times 154.4' = 17,508.96 \text{ cu.in.} = 10.13 \text{ cu.ft.} = 121.56 \text{ bd.ft.}$
Total: 972.48 bd.ft.

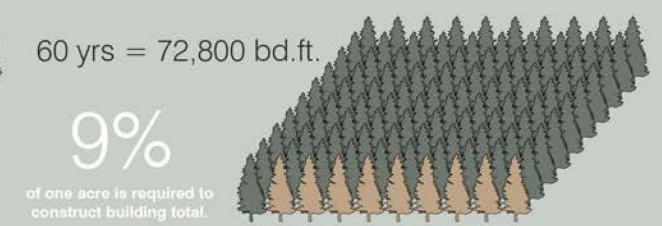
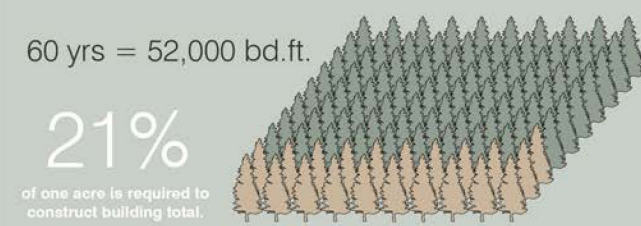
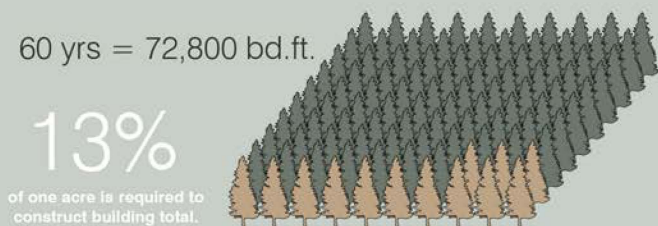
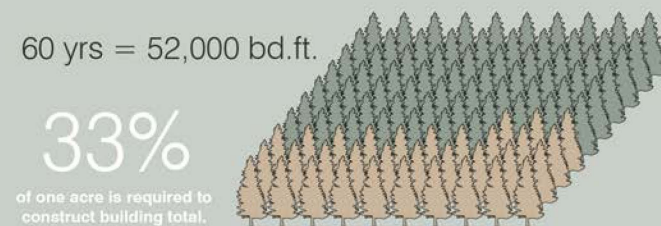
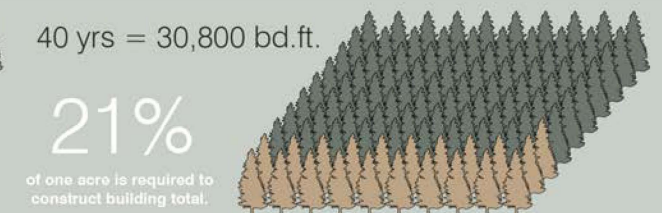
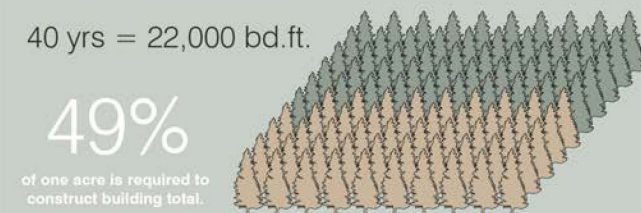
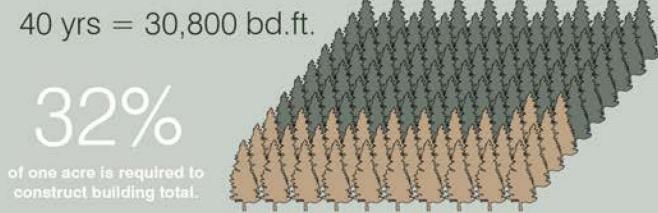
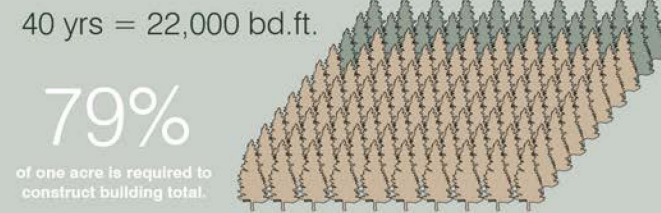
Columns:
 $5.25' \times 5.25' \times 15' = 5.25' \times 5.25' \times 180' = 4,961.25 \text{ cu.in.} = 2.87 \text{ cu.ft.} = 34.44 \text{ bd.ft.}$
Total: 304.4 bd.ft.

Building Total = 17,300 bd.ft.

Building Total = 9,751 bd.ft.

Building Total = 10,862 bd.ft.

Building Total = 6,477 bd.ft.



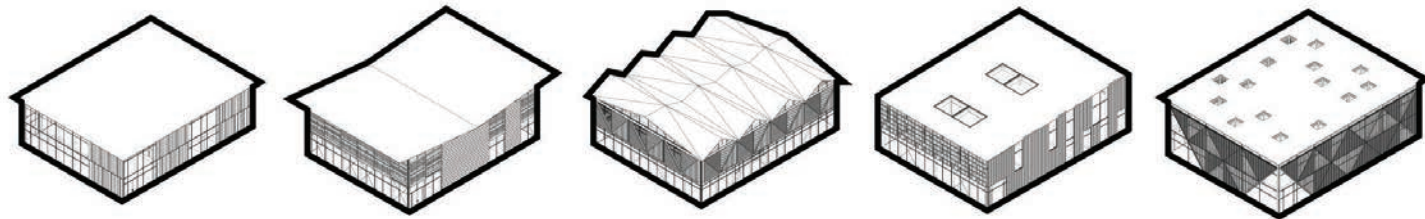
Peavy Forest Education Center

Peavy lodge is in Peavy Arboretum within the McDonald Research Forest at Oregon State University. Situated on 10,000 sq.ft Peavy Lodge is surrounded by various protected tree species. However, the lodge is slated for demolition and replacement. Five redesigns of Peavy Lodge, each accounting for wood fiber usage between CLT and MPP, will emphasize utilization rates of wood fiber between both products. Volumes of wood are then compared to total wood-volume available post-harvest between different stands. Finally, carbon storage for each design is assessed through the woodworks calculator.

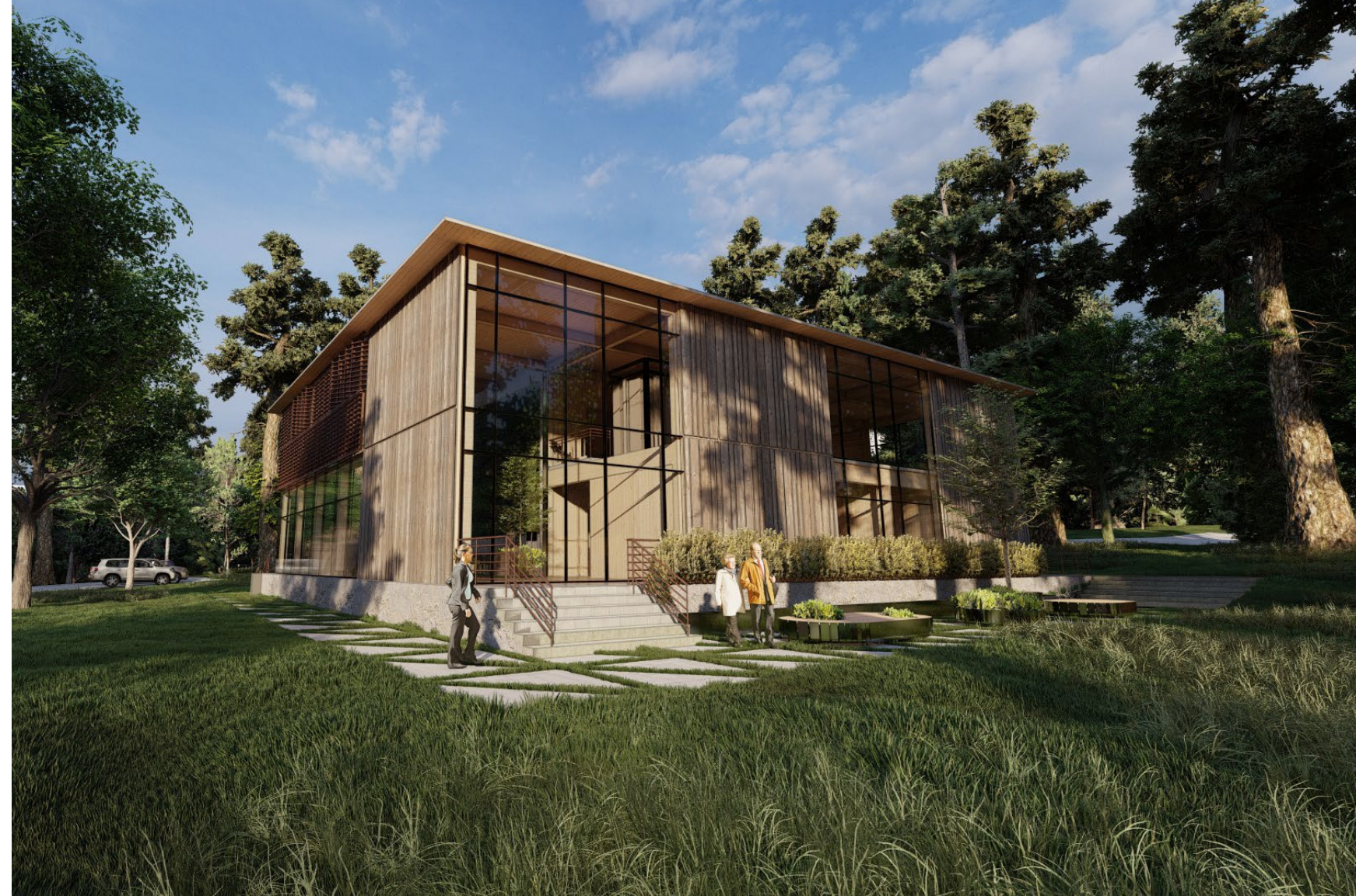
Looking to expand on the work done so far, this final exercise looks to compare MPP and CLT from both forty and sixty year stands as it applies to design, which in this project, is the re-design of the Peavy Lodge into a forest education center. Situated in the Peavy arboretum, protecting its immediate surroundings is of high priority given that trees within the vicinity are part of the arboretum's many tree species. As such, the project area is limited to a 10,000 within the trees. Programmatic elements include classrooms, offices, a cafe and kitchen, as well as an atrium lobby, and exhibition space. Five different conceptual designs, all modeled with the same floor plan and spatial organization, were carried out to visualize how different approaches to design and structure can influence wood usage.

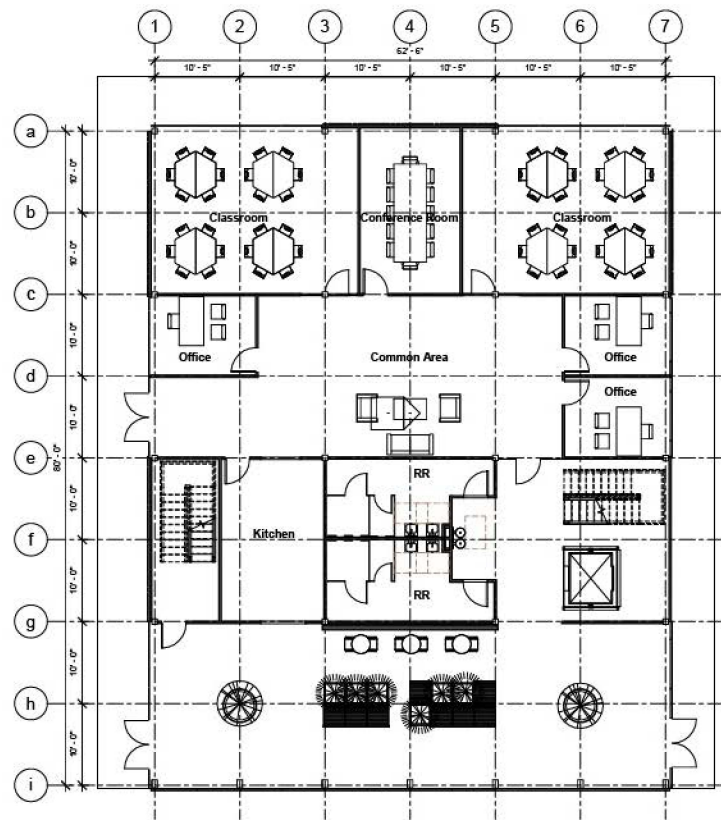
Member sizing was done in accordance to the Fast+Epp calculator as well as from consultation with Mikhail Gershfeld. All building calculations were based off member sizing for CLT and Glulam, with renderings representing CLT and Glulam construction. However, given that MPP can generally achieve a 19% reduction in wood volume, this percent reduction is applied to the total wood volume calculated for each building design.

The order in which all five designs are showcased reflect their wood usage, beginning with least amount of wood volume at the beginning, and progressively using more wood used toward the end. Furthermore, the first design serves as a base case, showcasing simple yet typical construction, while the following designs express other creative approaches to enclose the same volume.

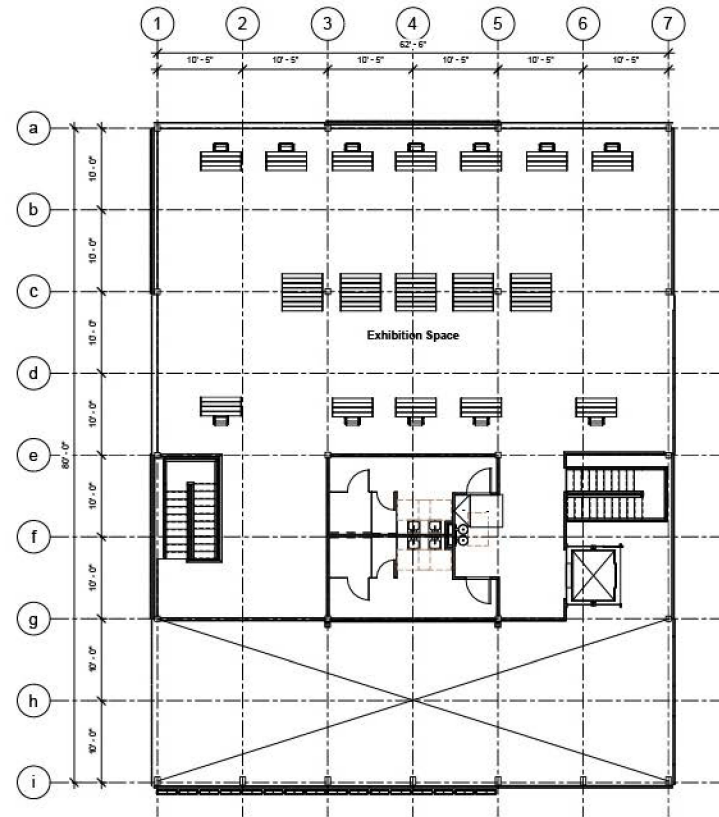


Design 1



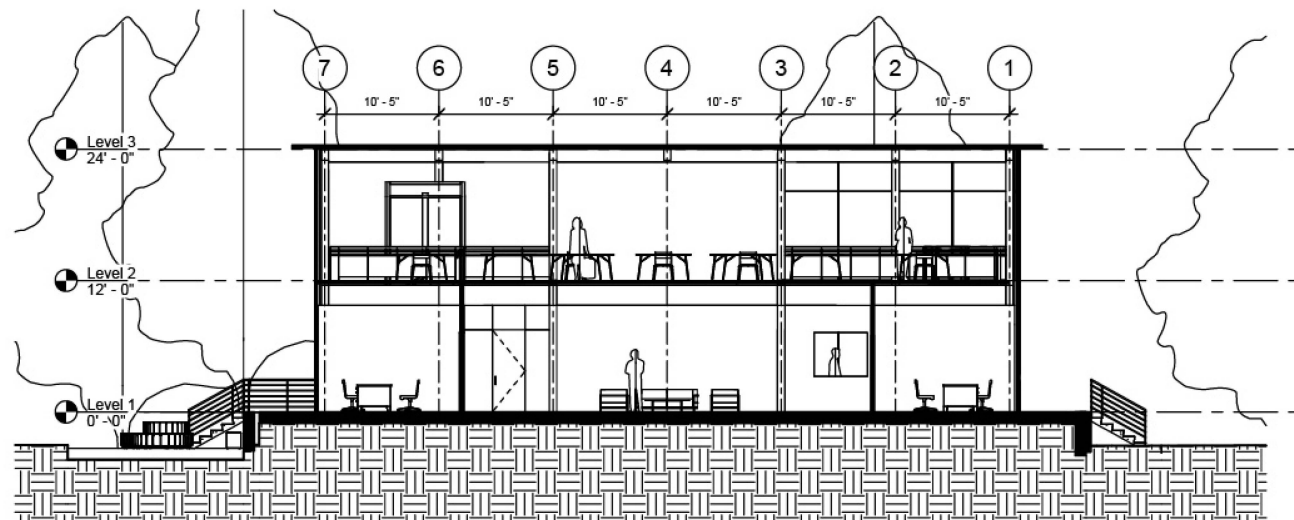


Ground Plan

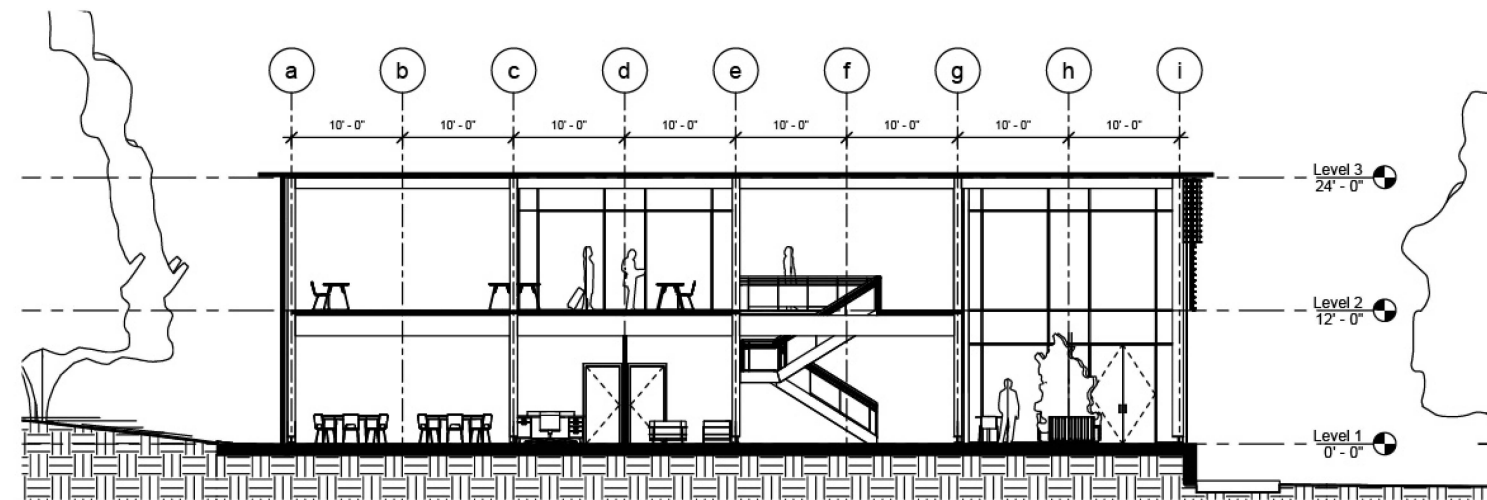


Second Floor Plan





Transverse Section



Longitudinal Section

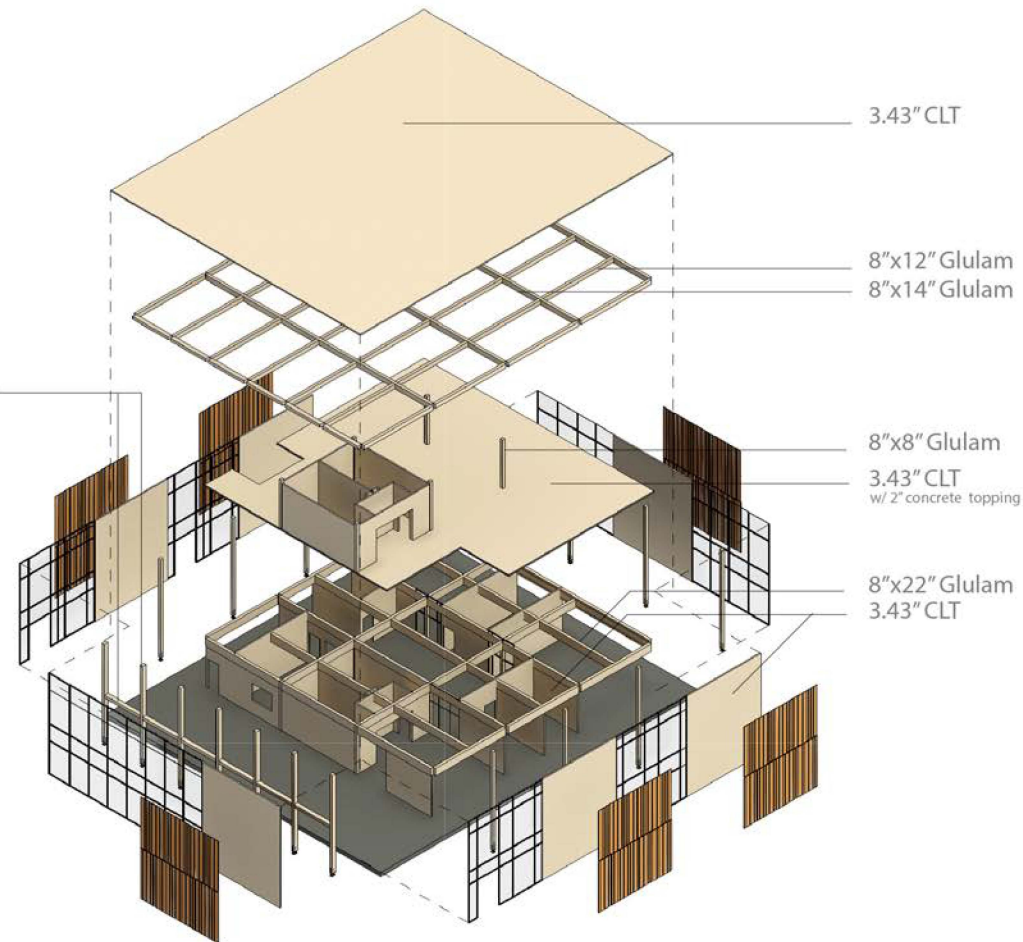
Building Total:
76,397 BF of Lumber

Building Volumes by Element:

Roof: 20,205 BF
Floor: 11,815 BF
Walls: 25,330 BF
Beams: 15,691 BF
Columns: 3,356 BF

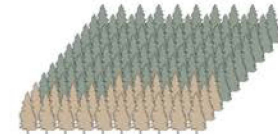
Building Total: -19%
61,882 BF of Veneer

8"x12" Glulam



CLT

19% of 20 acres



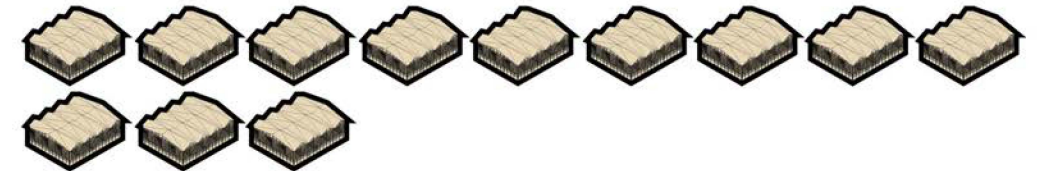
Lumber from 40yr stand
Total Stand Volume: 440,000 BF of Lumber



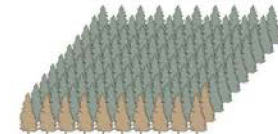
8% of 20 acres



Lumber from 60yr stand
Total Stand Volume: 1,040,000 BF of Lumber



11% of 20 acres

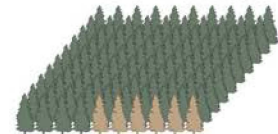


Veneer from 40yr stand
Total Stand Volume: 440,000 BF of Veneer

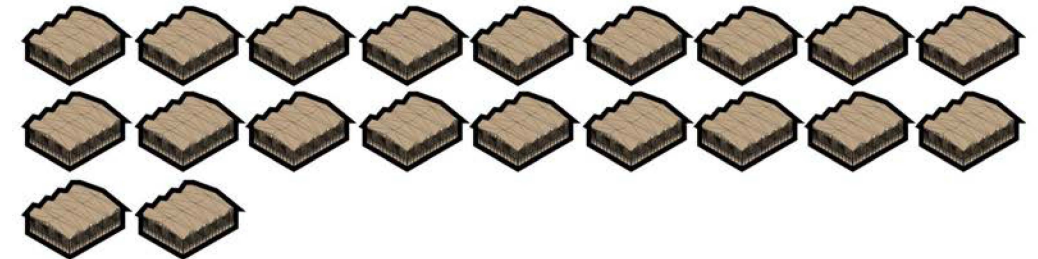


MPP

5% of 20 acres



Veneer from 60yr stand
Total Stand Volume: 1,456,000 BF of Veneer



Design 1



CLT and Glulam Carbon Results

-  Volume of wood products used (m³):
180 m³ (6366 ft³) of lumber and sheathing
-  U.S. and Canadians forests grow this much wood in:
29 seconds
-  Carbon stored in the wood:
162 metric tons of CO₂
-  Avoided greenhouse gas emissions:
63 metric tons of CO₂
-  Total potential carbon benefit:
225 metric tons of CO₂

Equivalent to:

-  **48 cars** off the road for a year
-  Energy to operate **24 homes** for a year

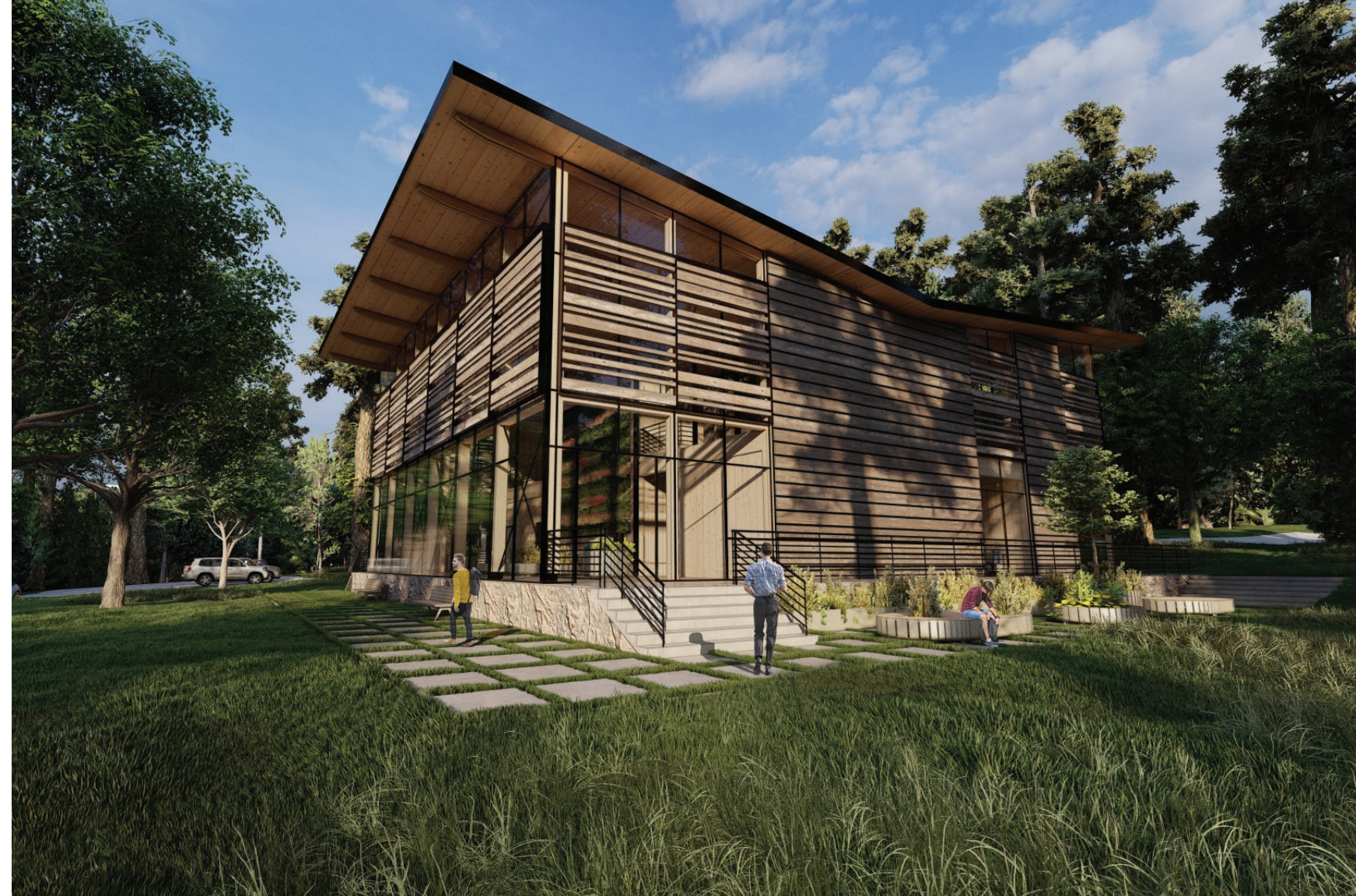
MPP Carbon Results

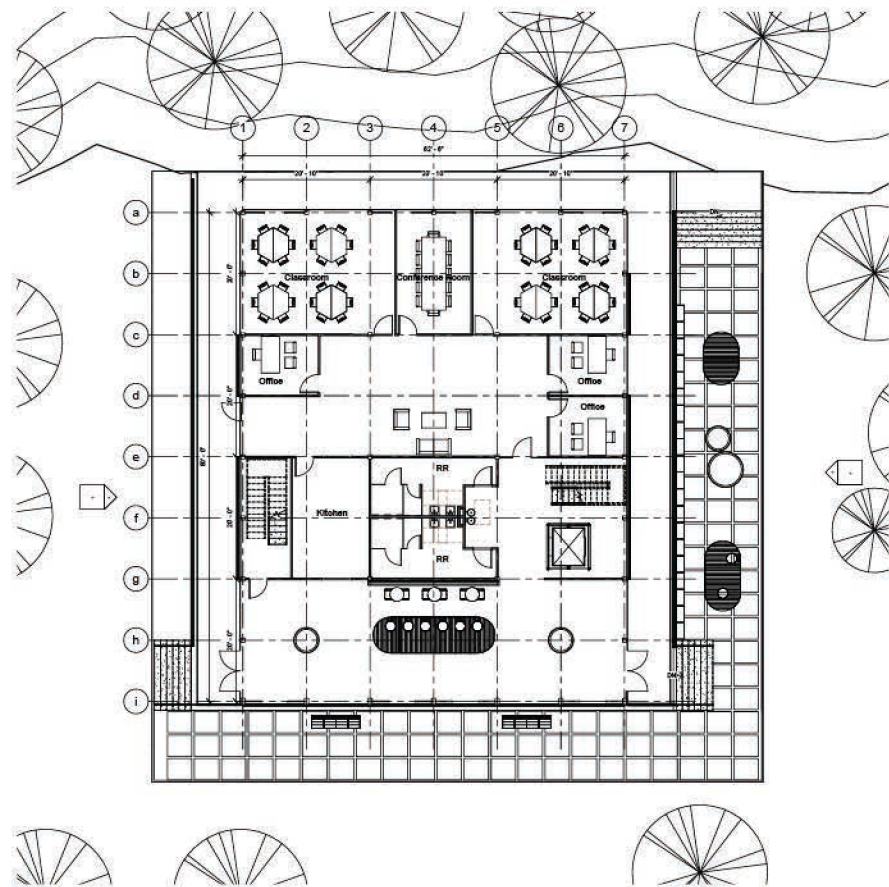
-  Volume of wood products used (m³):
146 m³ (5157 ft³) of lumber and sheathing
-  U.S. and Canadians forests grow this much wood in:
24 seconds
-  Carbon stored in the wood:
127 metric tons of CO₂
-  Avoided greenhouse gas emissions:
49 metric tons of CO₂
-  Total potential carbon benefit:
177 metric tons of CO₂

Equivalent to:

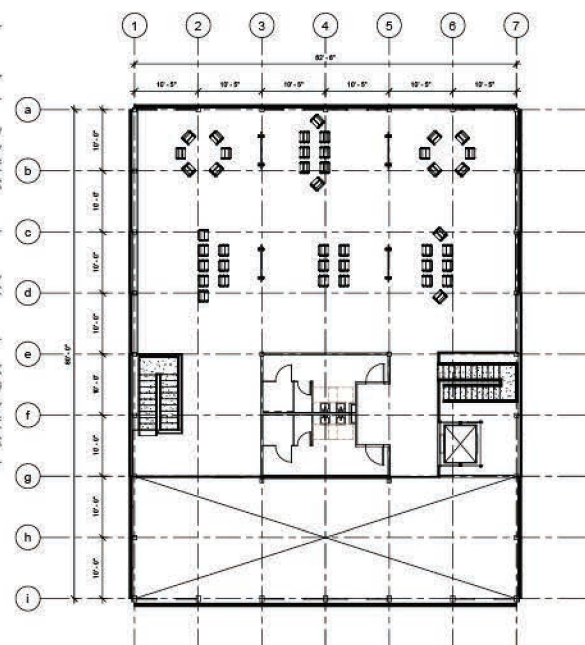
-  **37 cars** off the road for a year
-  Energy to operate **19 homes** for a year

Design 2



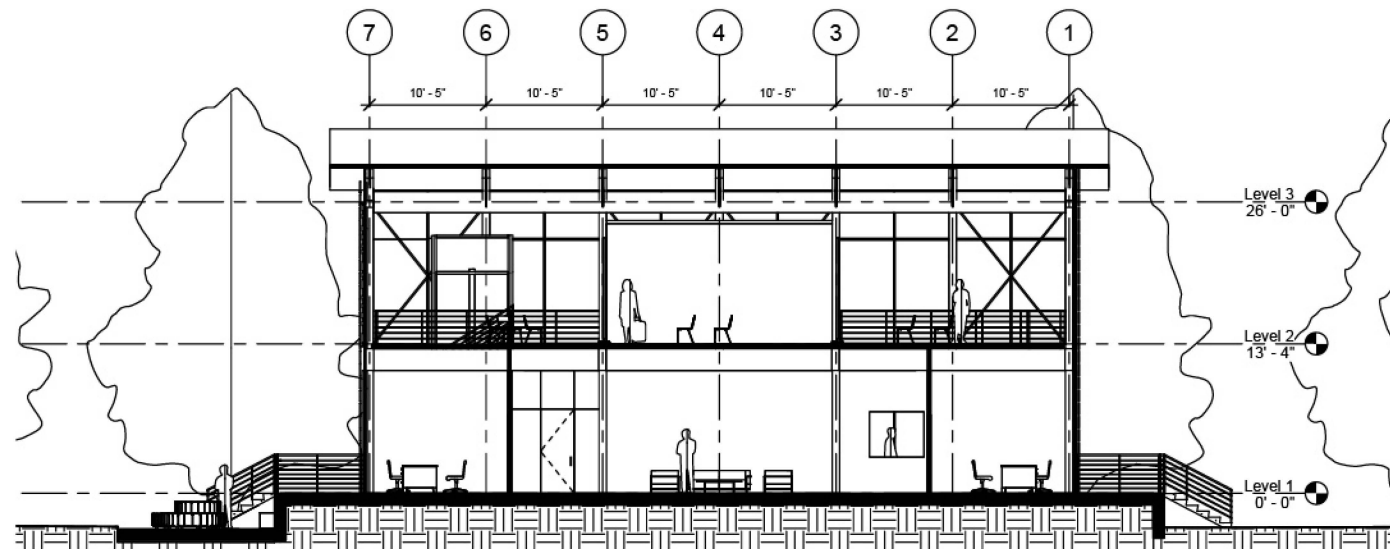


Ground Plan

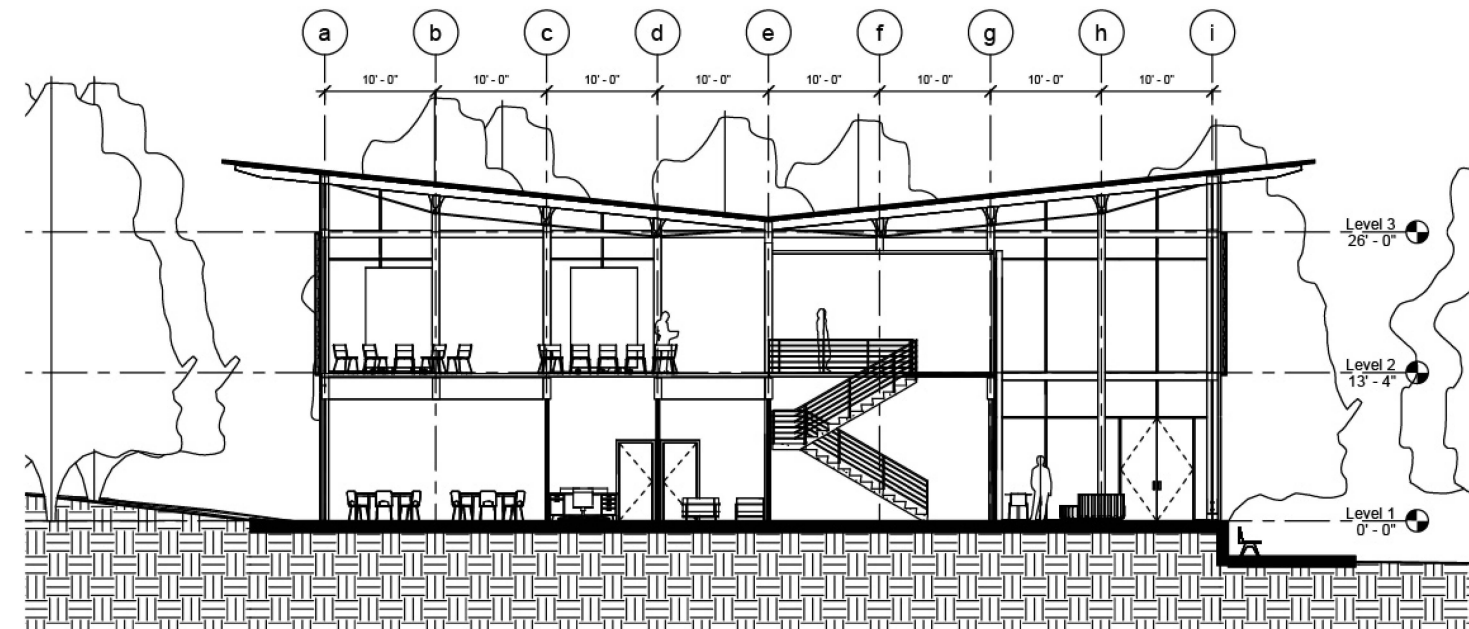


Second Floor Plan





Transverse Section

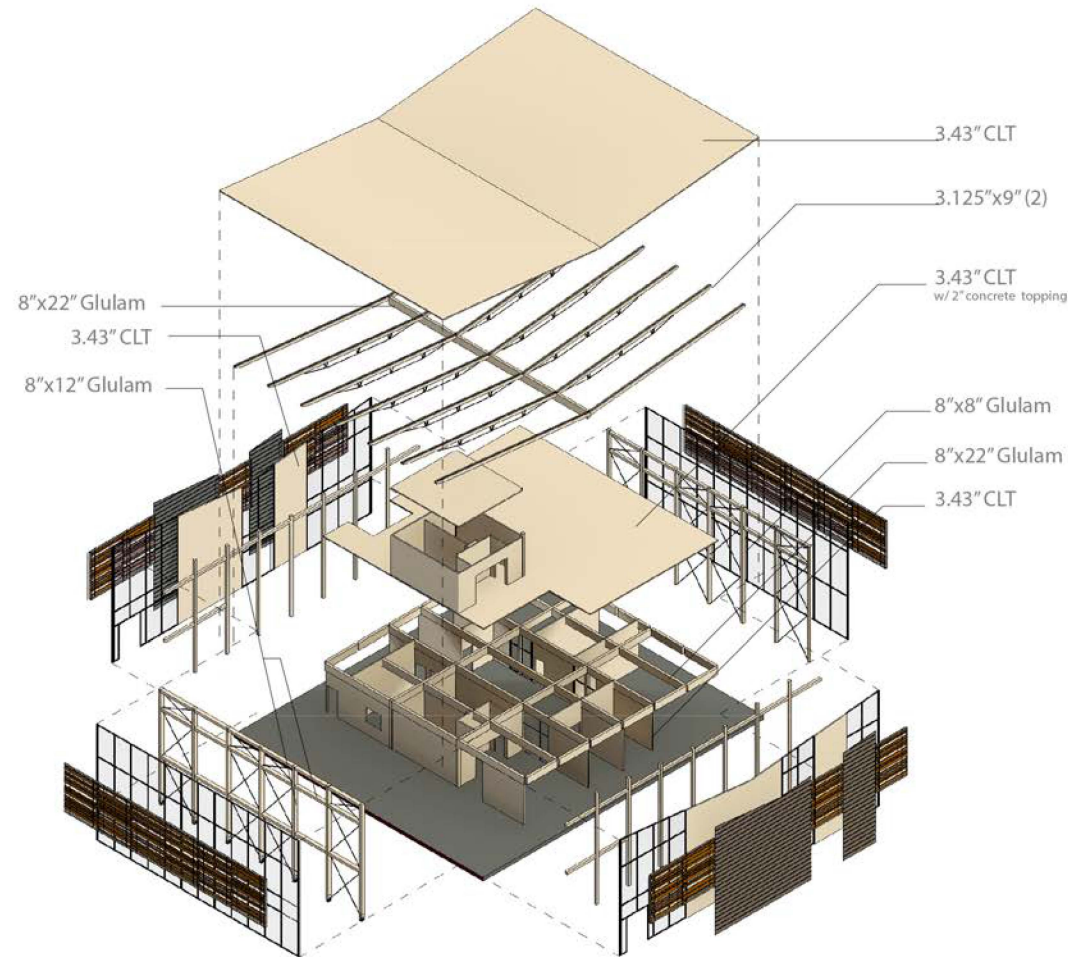


Longitudinal Section

Building Total:
 79,185 BF of Lumber
 Building Volume by Element:

Roof: 13,116 BF
 Floor: 18,435 BF
 Walls: 25,107 BF
 Beams: 16,800 BF
 Columns: 5,727 BF

Building Total: **-19%**
 64,140 BF of Veneer

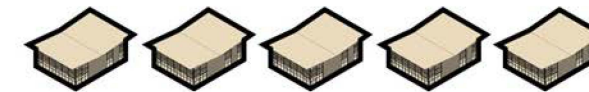


CLT

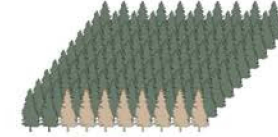
18% of 20 acres



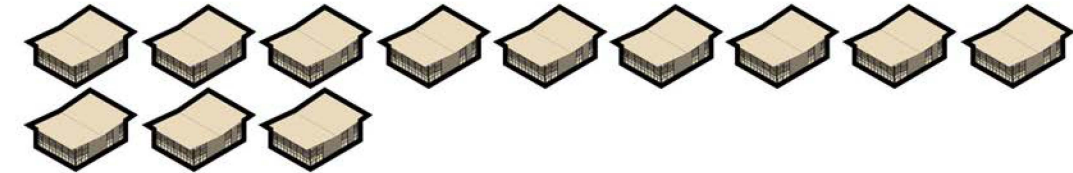
Lumber from 40yr stand
 Total Stand Volume: 440,000 BF of Lumber



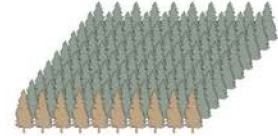
8% of 20 acres



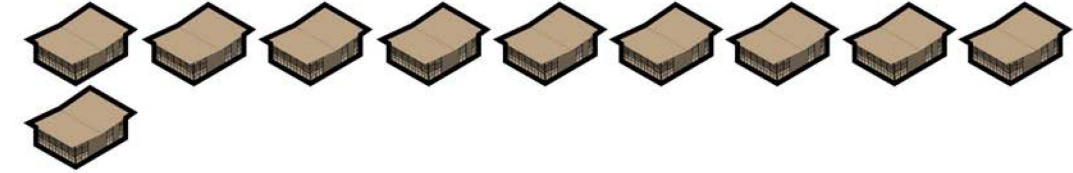
Lumber from 60yr stand
 Total Stand Volume: 1,040,000 BF of Lumber



10% of 20 acres



Veneer from 40yr stand
 Total Stand Volume: 440,000 BF of Veneer

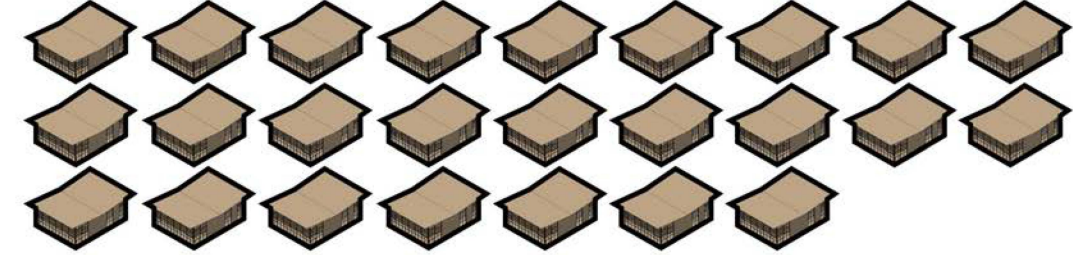


MPP

4% of 20 acres



Veneer from 60yr stand
 Total Stand Volume: 1,456,000 BF of Veneer



Design 2



CLT and Glulam Carbon Results

-  Volume of wood products used (m³):
187 m³ (6598 ft³) of lumber and sheathing
-  U.S. and Canadians forests grow this much wood in:
1 minutes
-  Carbon stored in the wood:
168 metric tons of CO₂
-  Avoided greenhouse gas emissions:
65 metric tons of CO₂
-  Total potential carbon benefit:
233 metric tons of CO₂

Equivalent to:

-  **49 cars** off the road for a year
-  Energy to operate **25 homes** for a year

MPP Carbon Results

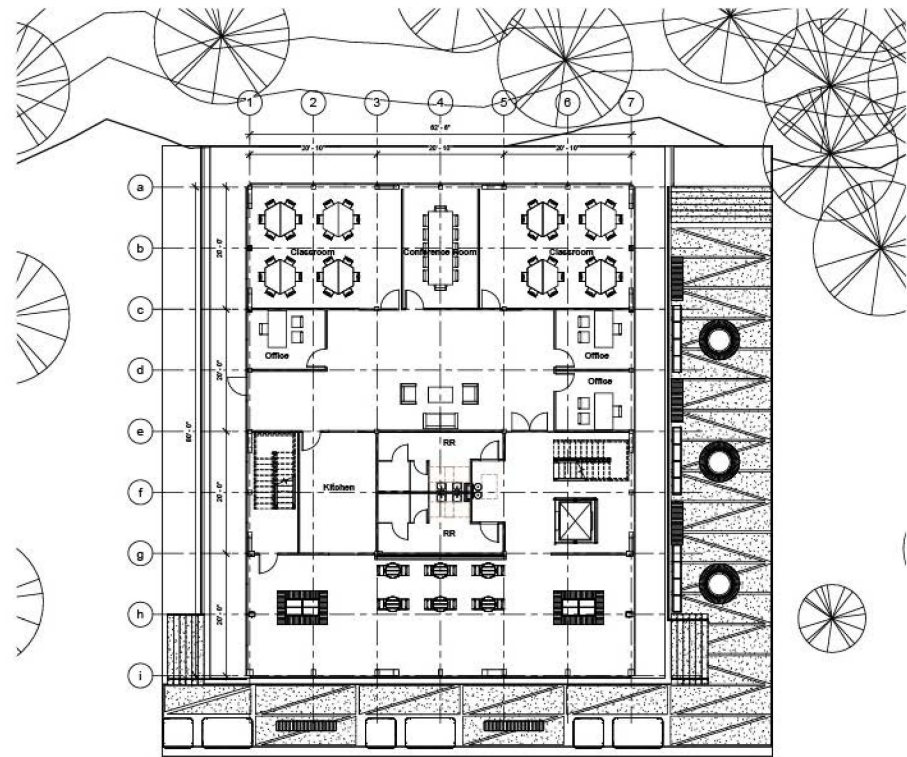
-  Volume of wood products used (m³):
146 m³ (5157 ft³) of lumber and sheathing
-  U.S. and Canadians forests grow this much wood in:
24 seconds
-  Carbon stored in the wood:
127 metric tons of CO₂
-  Avoided greenhouse gas emissions:
49 metric tons of CO₂
-  Total potential carbon benefit:
177 metric tons of CO₂

Equivalent to:

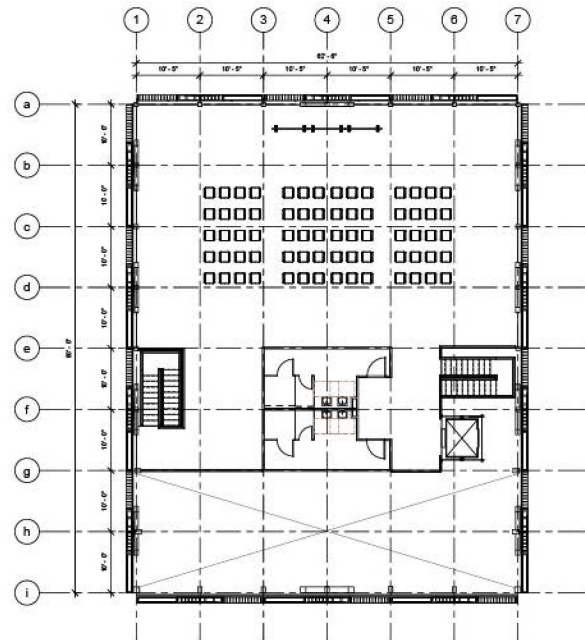
-  **37 cars** off the road for a year
-  Energy to operate **19 homes** for a year

Design 3



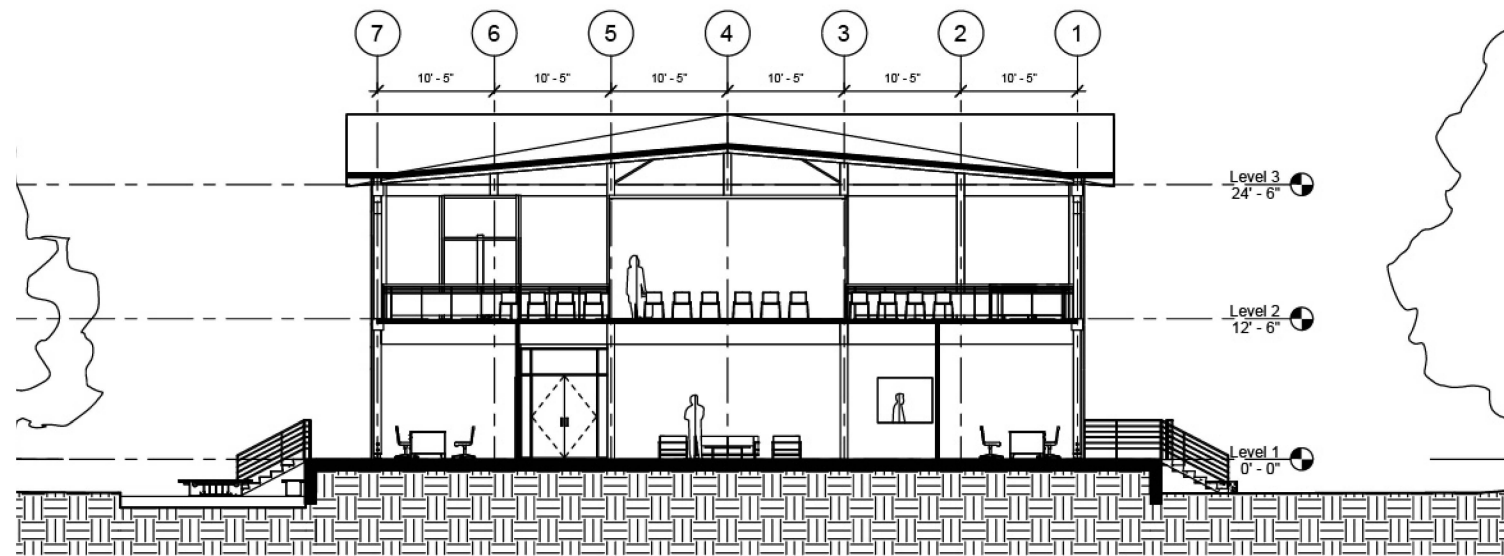


Ground Plan

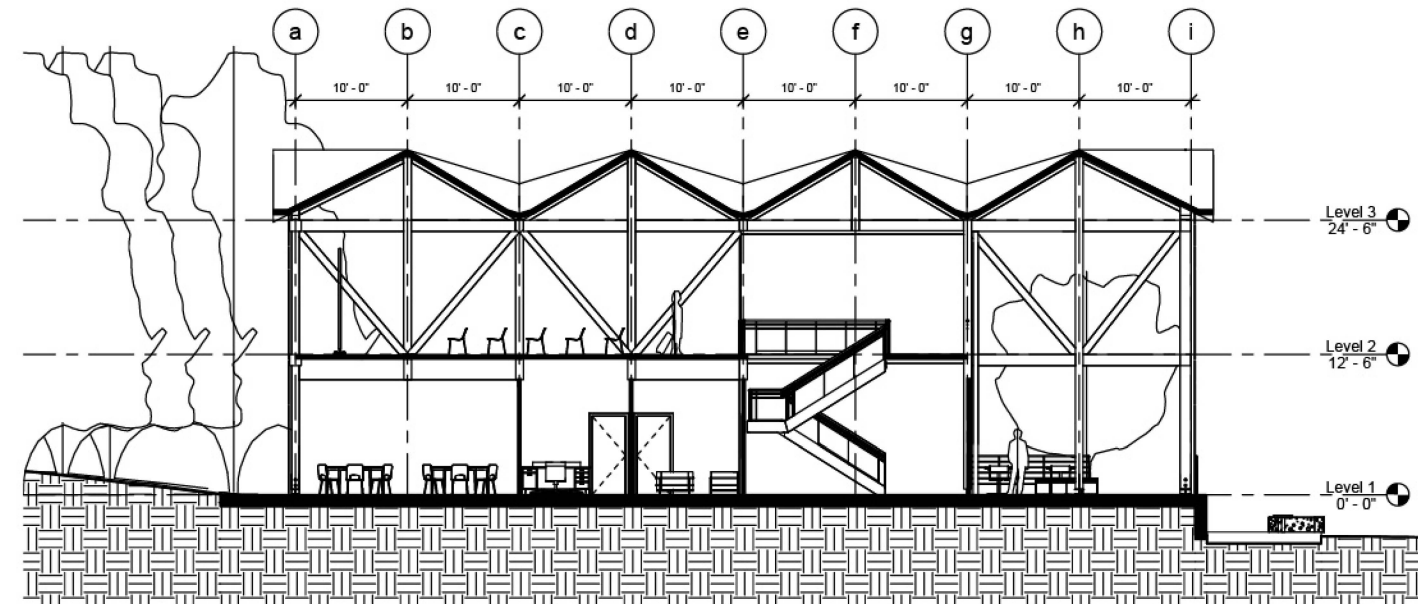


Second Floor Plan





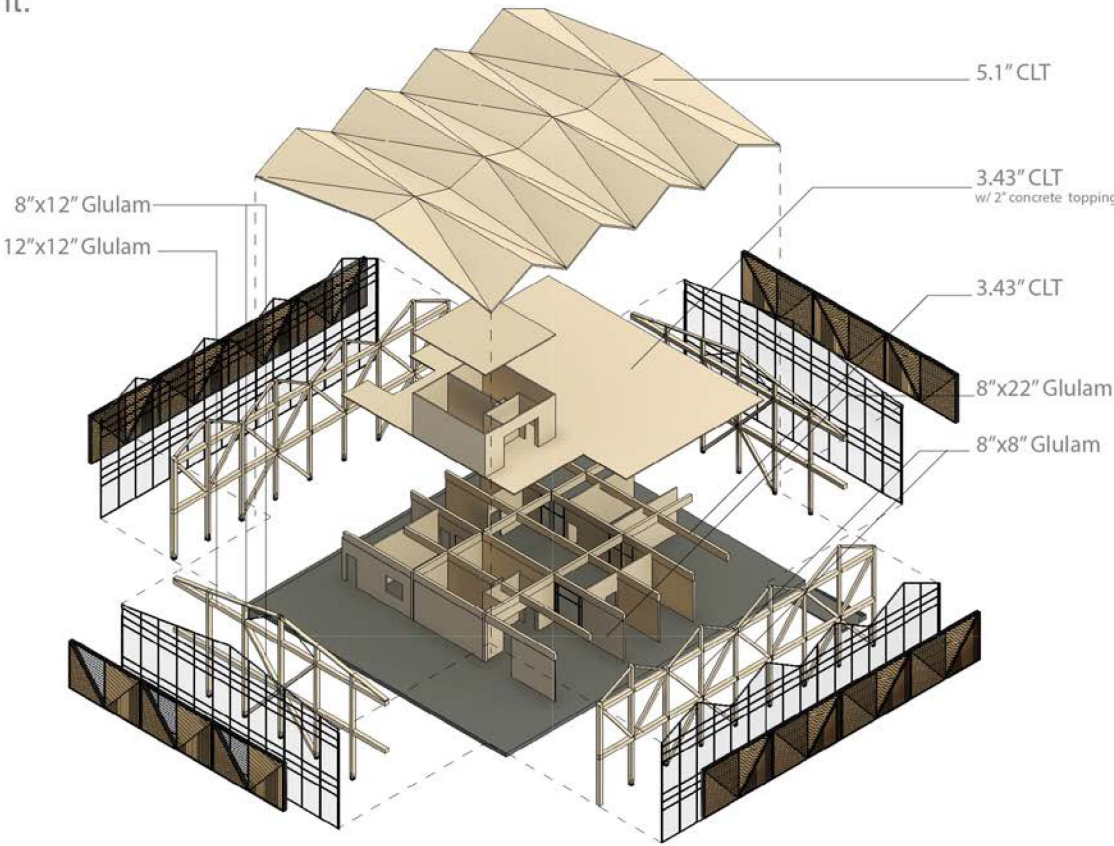
Transverse Section



Longitudinal Section

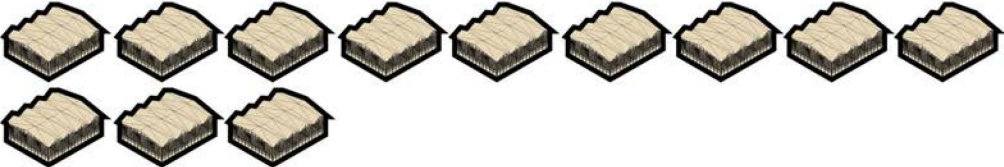
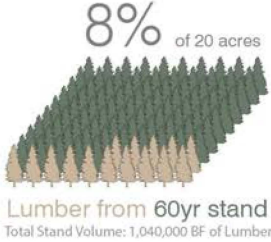
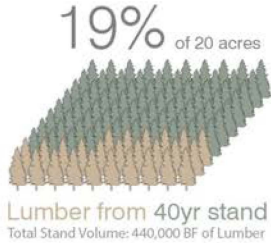
Building Total:
85,098 BF of Lumber
Building Volumes by Element:
Roof: 33,619 BF
Floor: 11,691 BF
Walls: 15,175 BF
Beams: 16,229 BF
Columns: 8,377 BF

Building Total: -19%
68,922 BF of Veneer



Design 3

CLT



MPP





CLT and Glulam Carbon Results

	Volume of wood products used (m ³): 201 m ³ (7090 ft ³) of lumber and sheathing
	U.S. and Canadians forests grow this much wood in: 1 minutes
	Carbon stored in the wood: 181 metric tons of CO ₂
	Avoided greenhouse gas emissions: 70 metric tons of CO ₂
	Total potential carbon benefit: 250 metric tons of CO ₂

Equivalent to:

	53 cars off the road for a year
	Energy to operate 26 homes for a year

MPP Carbon Results

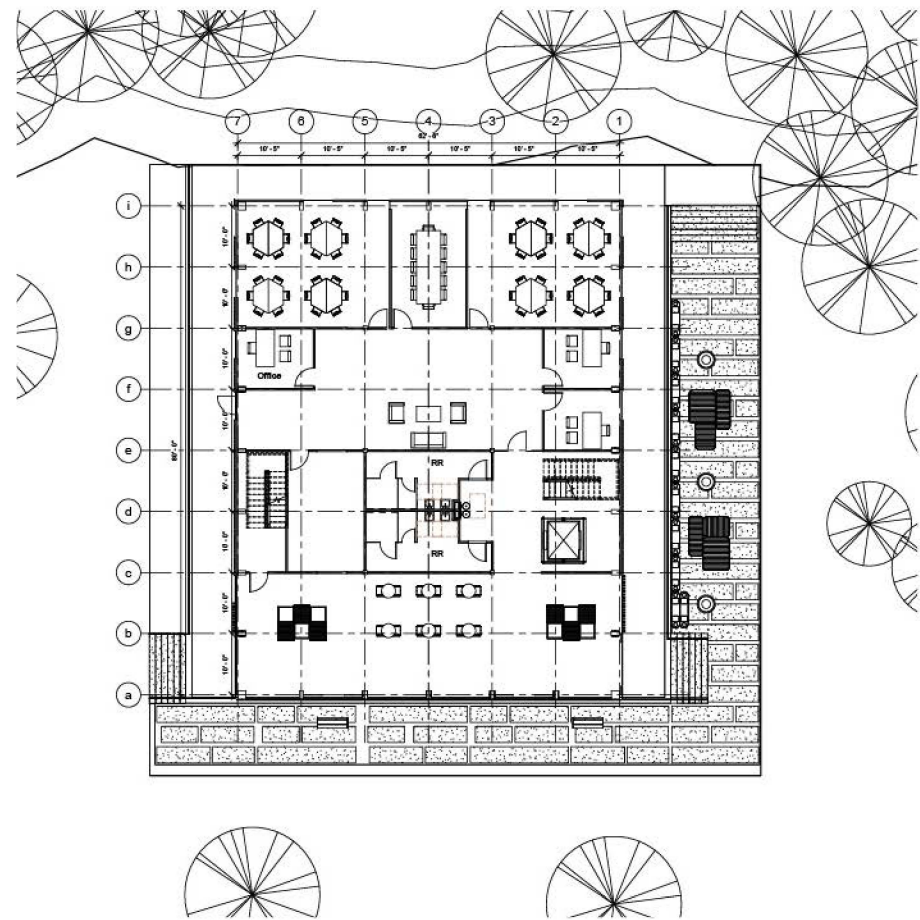
	Volume of wood products used (m ³): 163 m ³ (5743 ft ³) of lumber and sheathing
	U.S. and Canadians forests grow this much wood in: 27 seconds
	Carbon stored in the wood: 142 metric tons of CO ₂
	Avoided greenhouse gas emissions: 55 metric tons of CO ₂
	Total potential carbon benefit: 197 metric tons of CO ₂

Equivalent to:

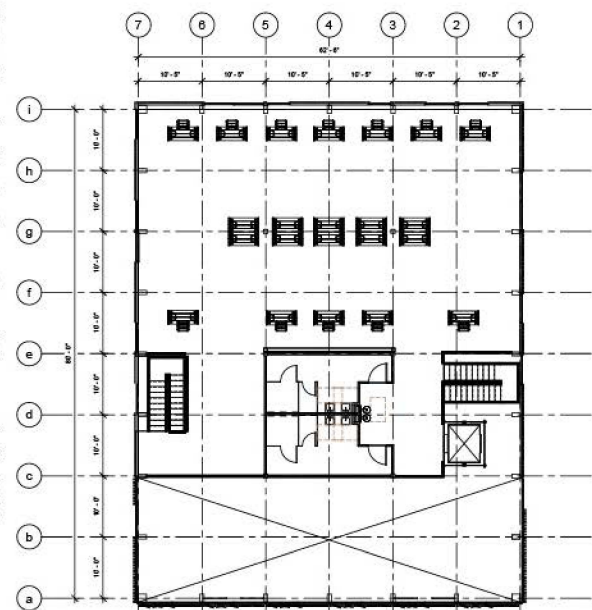
	42 cars off the road for a year
	Energy to operate 21 homes for a year

Design 4



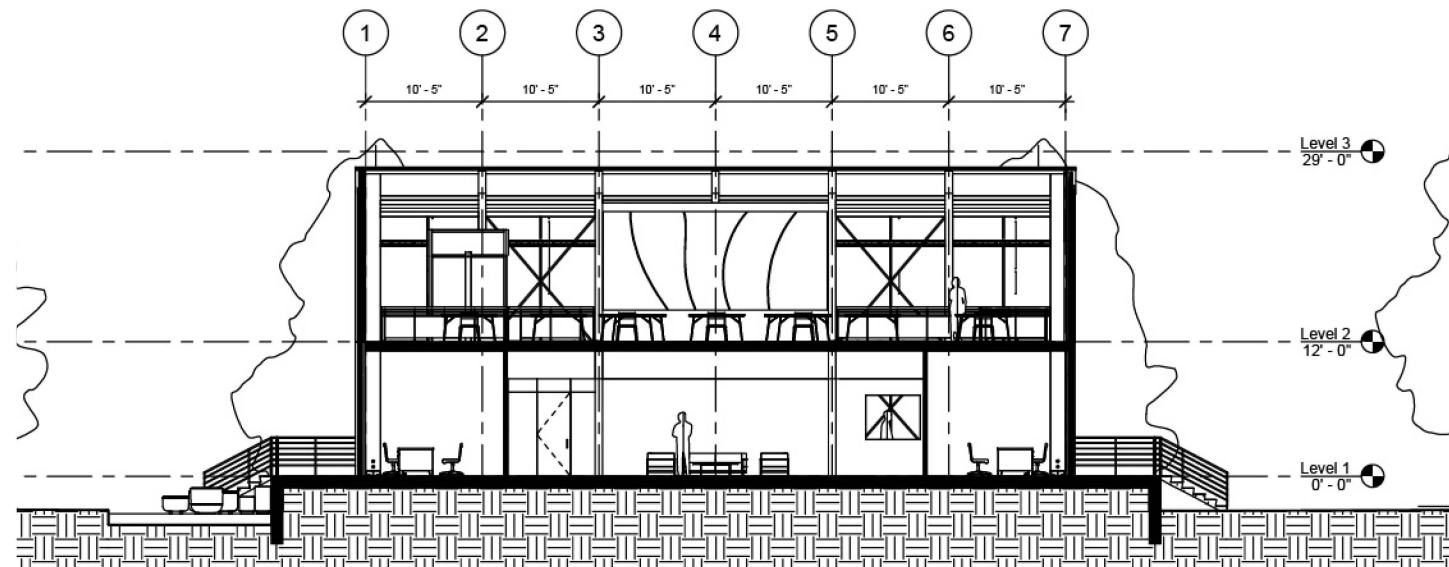


Ground Plan

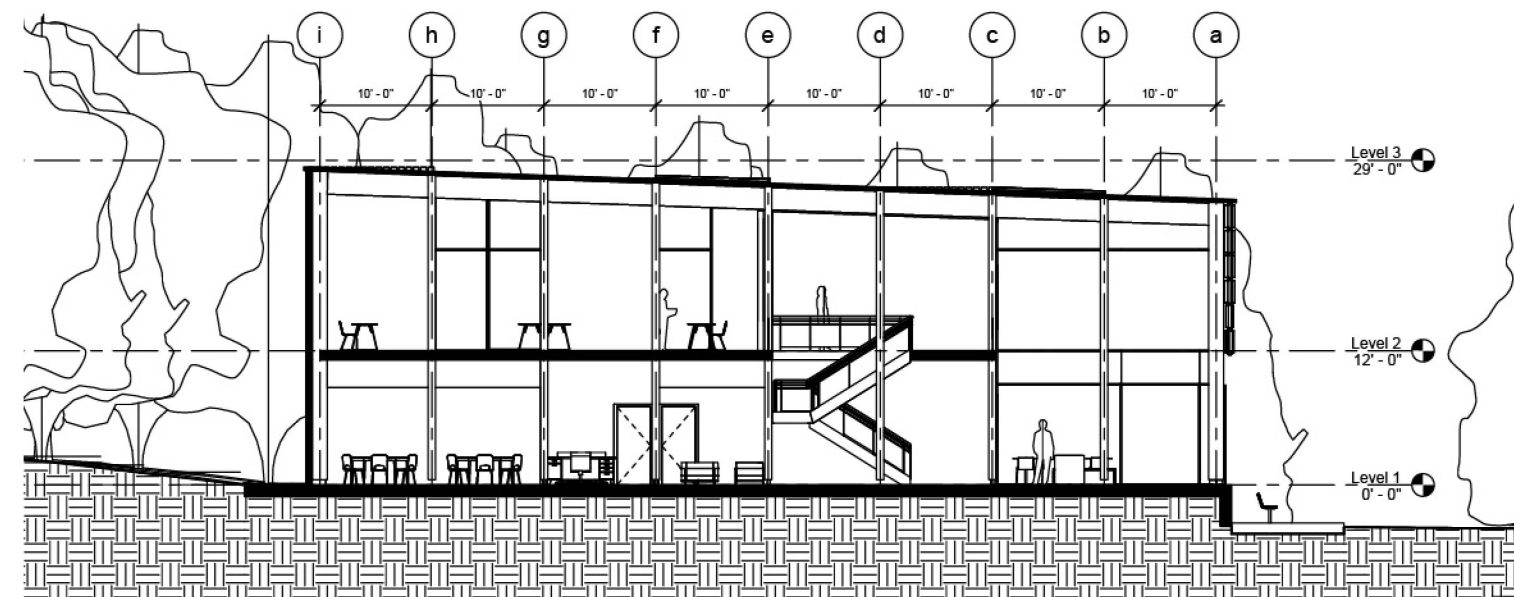


Second Floor Plan





Transverse Section



Longitudinal Section

Building Total:

108,500 BF of Lumber

Building Volumes by Element;

Roof: 17,054 BF

Floor: 33,177 BF

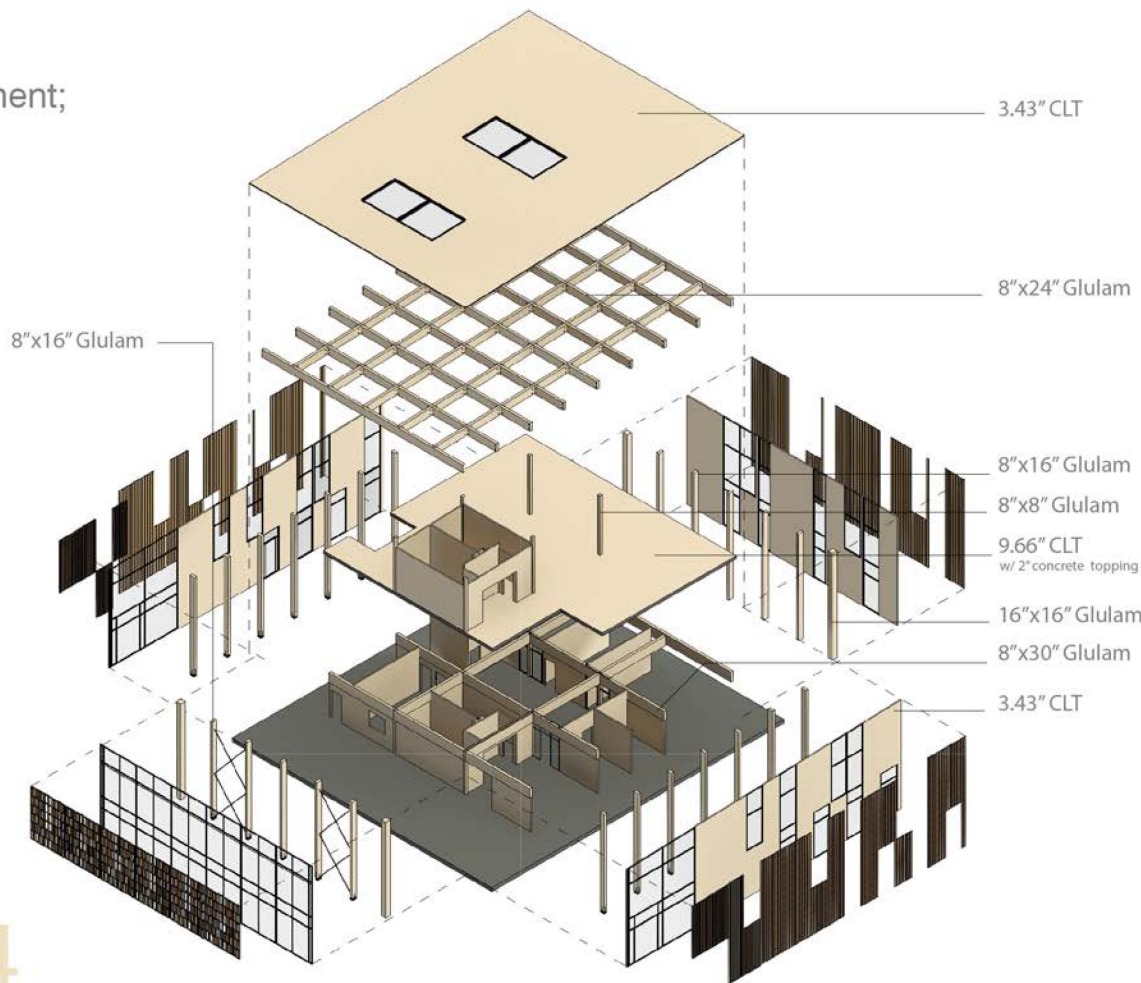
Walls: 26,530 BF

Beams: 22,110 BF

Columns: 9,630 BF

Building Total: **-19%**

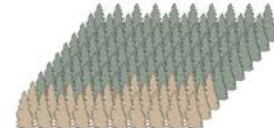
87,885 BF of Veneer



Design 4

CLT

25% of 20 acres

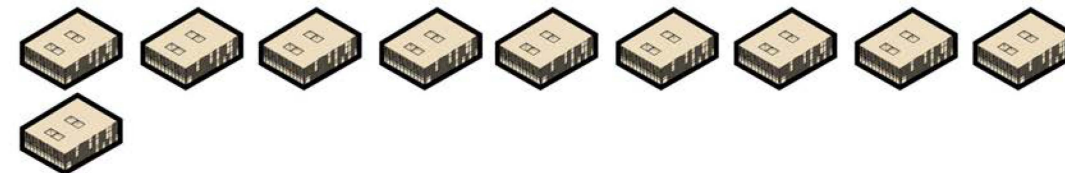
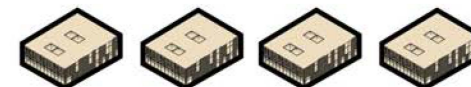


Lumber from 40yr stand
Total Stand Volume: 440,000 BF of Lumber

10% of 20 acres



Lumber from 60yr stand
Total Stand Volume: 1,040,000 BF of Lumber



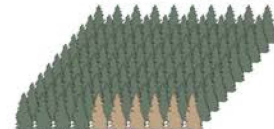
MPP

14% of 20 acres

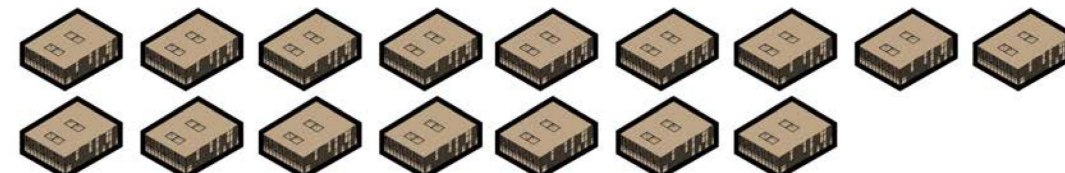


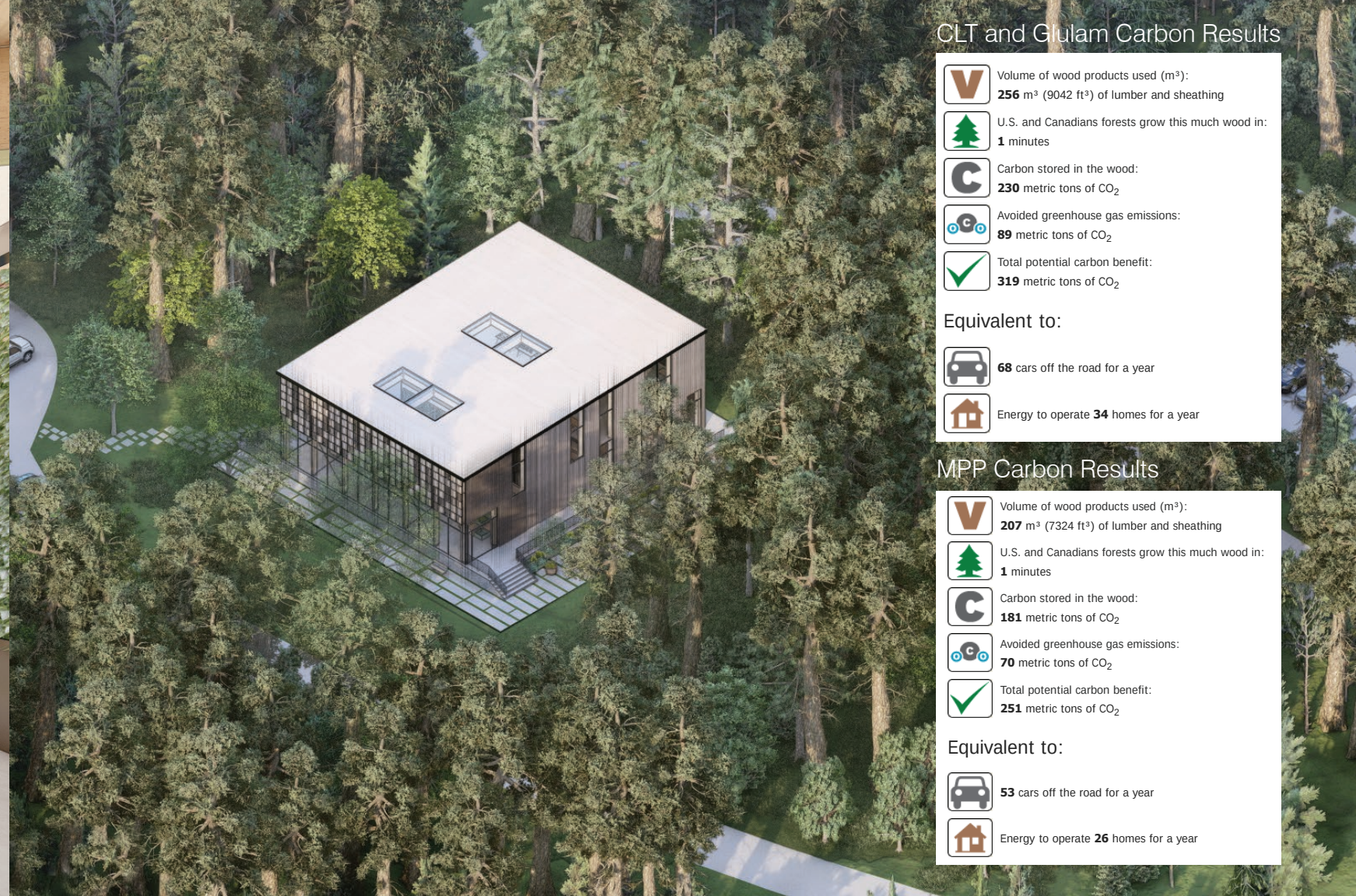
Veneer from 40yr stand
Total Stand Volume: 440,000 BF of Veneer

6% of 20 acres



Veneer from 60yr stand
Total Stand Volume: 1,456,000 BF of Veneer





CLT and Glulam Carbon Results

-  Volume of wood products used (m³):
256 m³ (9042 ft³) of lumber and sheathing
-  U.S. and Canadians forests grow this much wood in:
1 minutes
-  Carbon stored in the wood:
230 metric tons of CO₂
-  Avoided greenhouse gas emissions:
89 metric tons of CO₂
-  Total potential carbon benefit:
319 metric tons of CO₂

Equivalent to:

-  **68 cars** off the road for a year
-  Energy to operate **34 homes** for a year

MPP Carbon Results

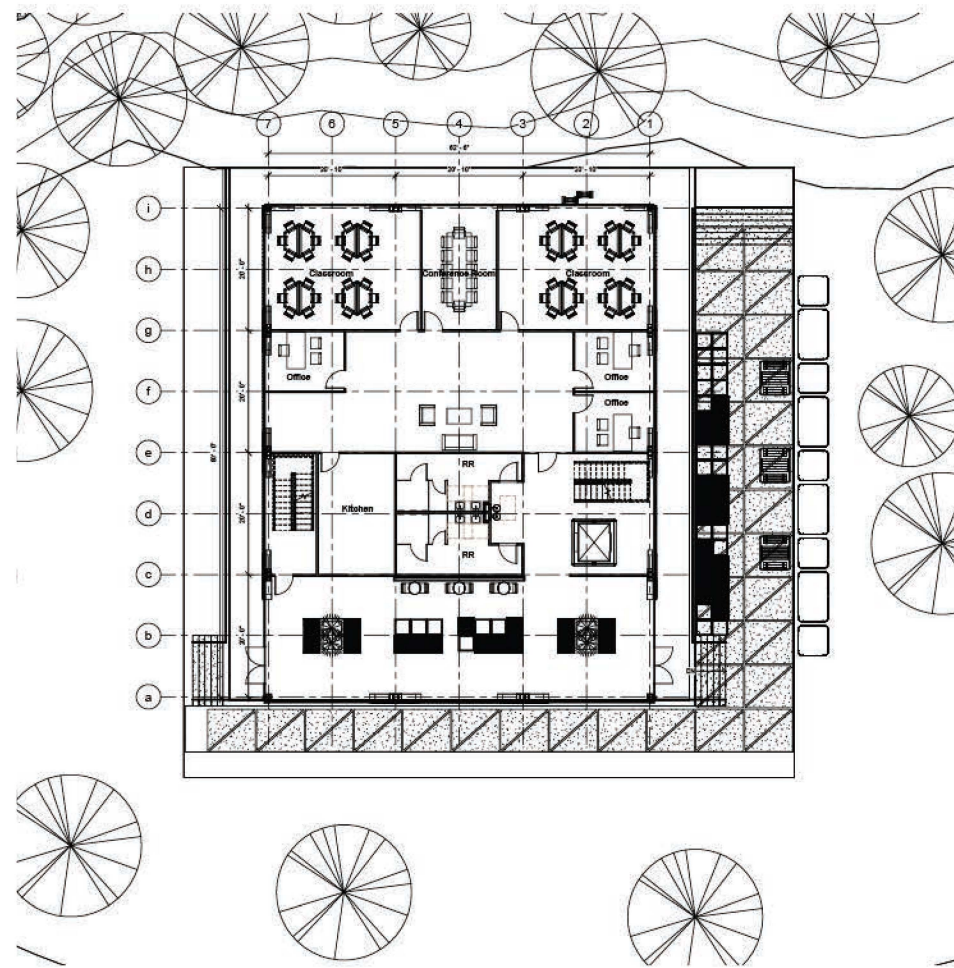
-  Volume of wood products used (m³):
207 m³ (7324 ft³) of lumber and sheathing
-  U.S. and Canadians forests grow this much wood in:
1 minutes
-  Carbon stored in the wood:
181 metric tons of CO₂
-  Avoided greenhouse gas emissions:
70 metric tons of CO₂
-  Total potential carbon benefit:
251 metric tons of CO₂

Equivalent to:

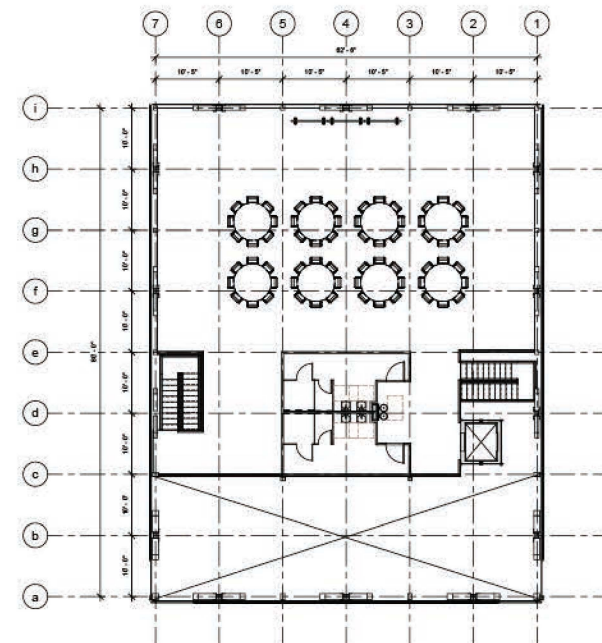
-  **53 cars** off the road for a year
-  Energy to operate **26 homes** for a year

Design 5



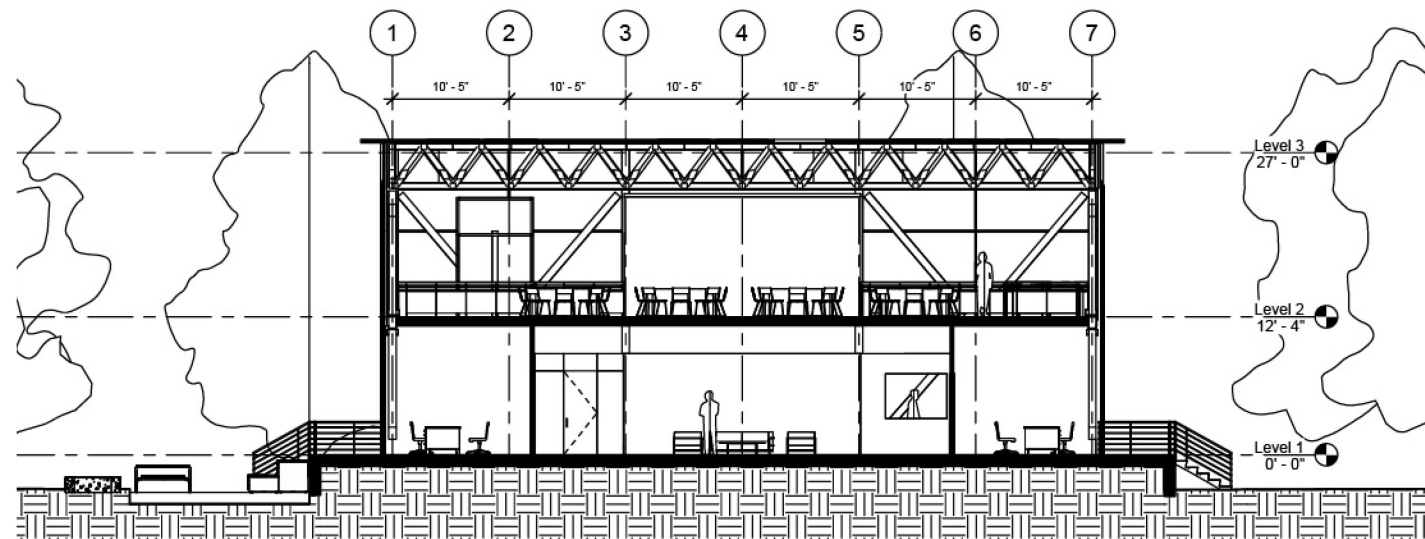


Ground Plan

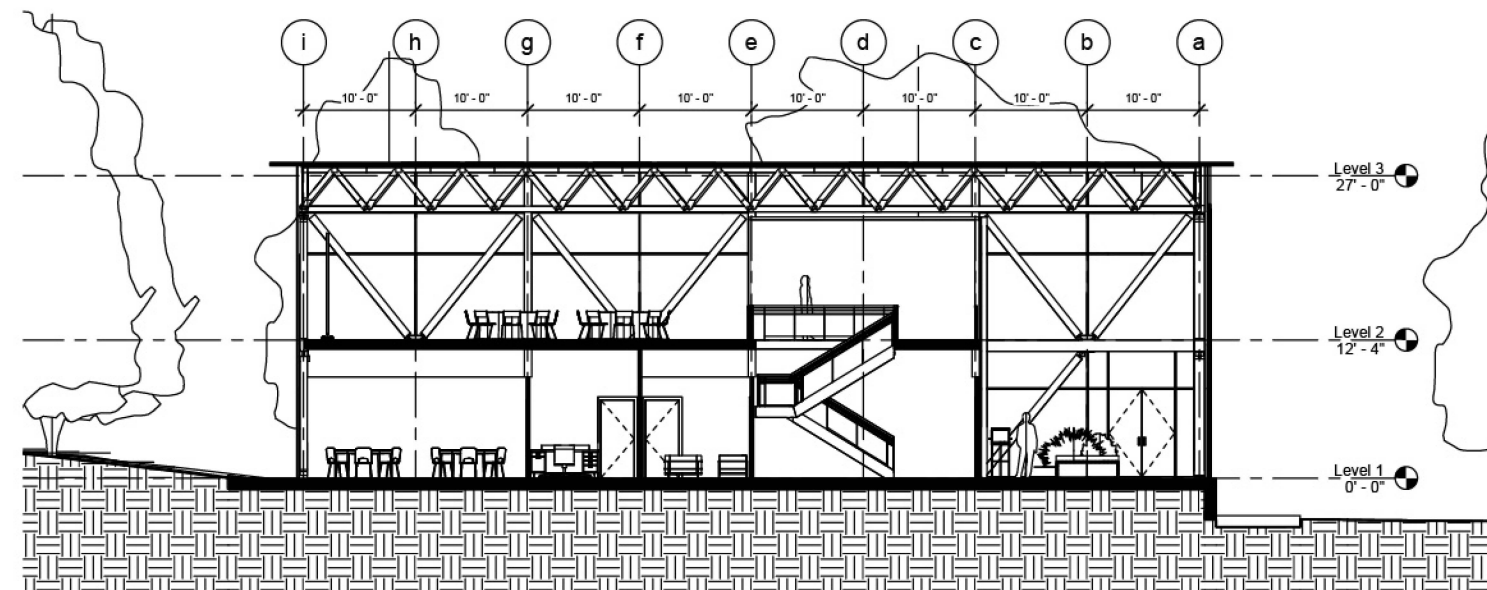


Second Floor Plan





Transverse Section



Longitudinal Section

Building Total:

113,175 BF of Lumber

Building Volumes by Element:

Roof: 20,351 BF

Space Truss: 29,244 BF

Floor: 32,553 BF

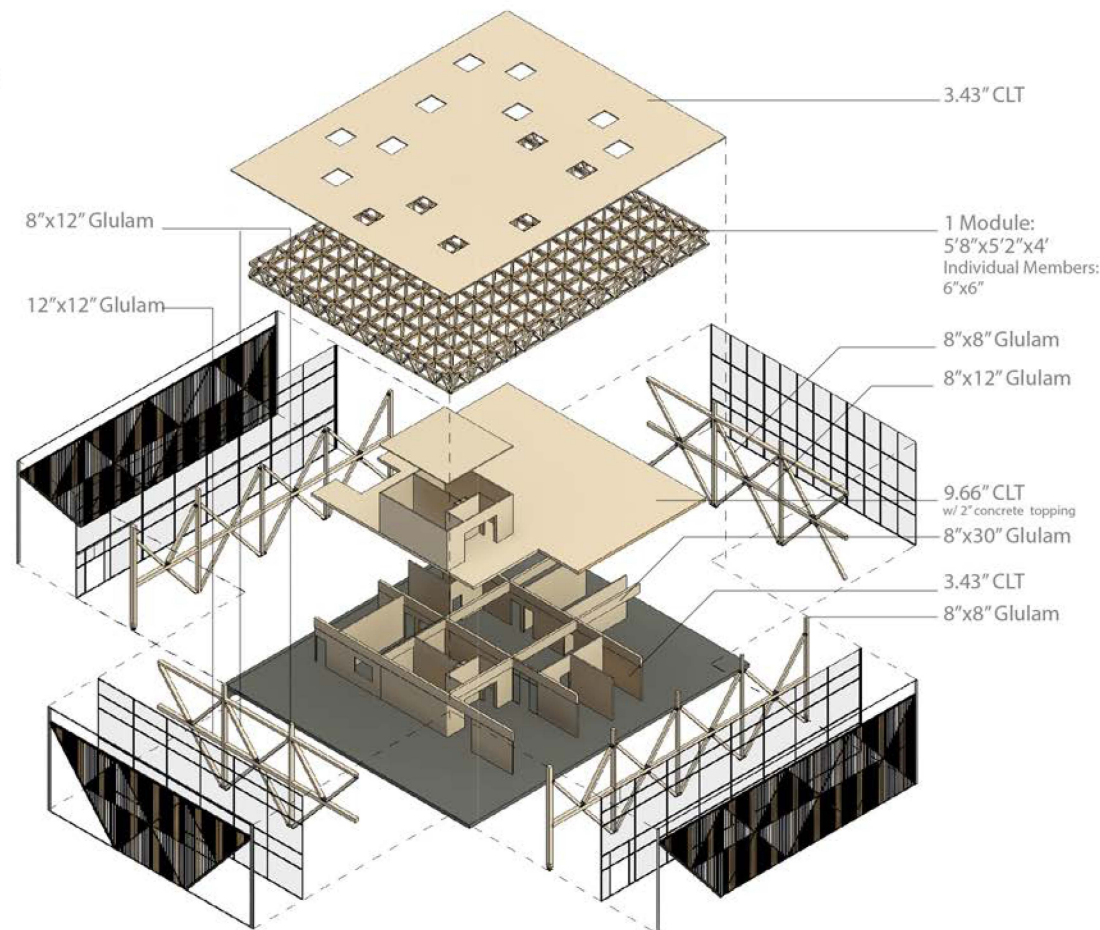
Walls: 14,456 BF

Beams: 9,342 BF

Columns: 7,221 BF

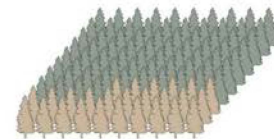
Building Total: -19%

91,672 BF of Veneer



CLT

26% of 20 acres



Lumber from 40yr stand
Total Stand Volume: 440,000 BF of Lumber



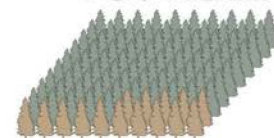
11% of 20 acres



Lumber from 60yr stand
Total Stand Volume: 1,040,000 BF of Lumber



15% of 20 acres



Veneer from 40yr stand
Total Stand Volume: 440,000 BF of Veneer

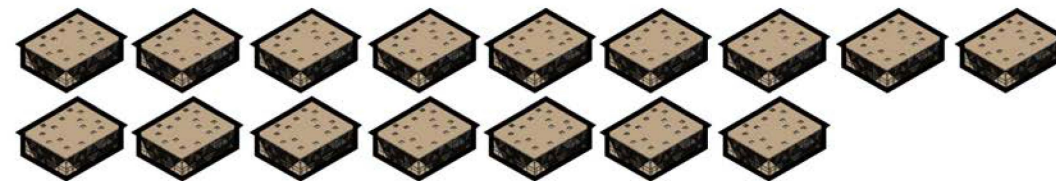


MPP

6% of 20 acres



Veneer from 60yr stand
Total Stand Volume: 1,456,000 BF of Veneer



Design 5



CLT and Glulam Carbon Results



Volume of wood products used (m³):
267 m³ (9431 ft³) of lumber and sheathing



U.S. and Canadians forests grow this much wood in:
1 minutes



Carbon stored in the wood:
240 metric tons of CO₂



Avoided greenhouse gas emissions:
93 metric tons of CO₂



Total potential carbon benefit:
333 metric tons of CO₂

Equivalent to:



70 cars off the road for a year



Energy to operate **35** homes for a year

MPP Carbon Results



Volume of wood products used (m³):
216 m³ (7639 ft³) of lumber and sheathing



U.S. and Canadians forests grow this much wood in:
1 minutes



Carbon stored in the wood:
189 metric tons of CO₂



Avoided greenhouse gas emissions:
73 metric tons of CO₂



Total potential carbon benefit:
261 metric tons of CO₂

Equivalent to:

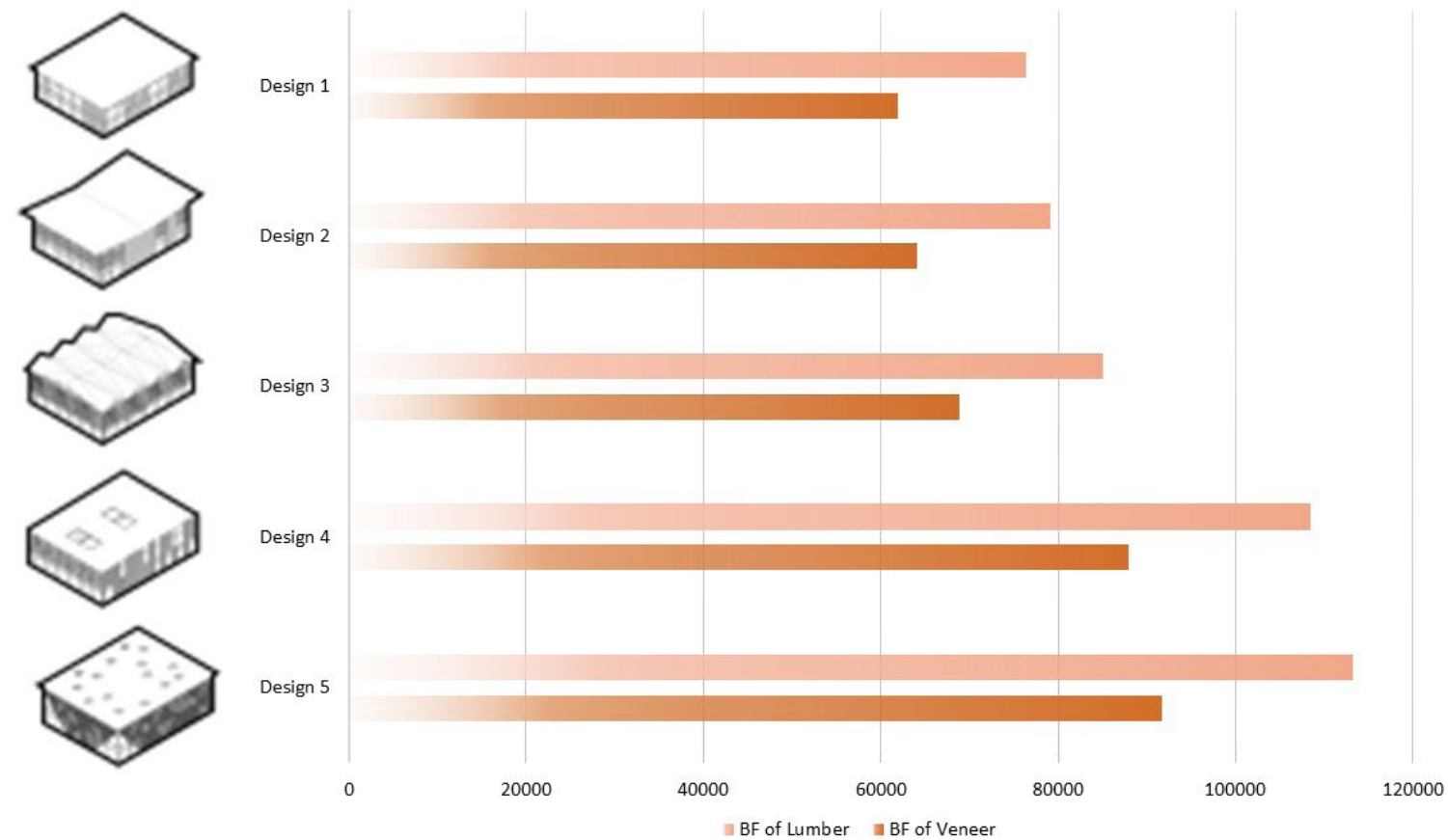


55 cars off the road for a year



Energy to operate **28** homes for a year

Building Total Summary of 5 Conceptual Designs



Conclusions and Future Research



Conclusions

This work exhibited a number of visual demonstrations of the impacts of AEC decisions on wood volume and its efficient utilization. From the results presented, conclusions can be drawn.

1. The longer trees grow, the more carbon is sequestered and accumulated as woody biomass.

As expected, stands that incorporate longer rotations will yield greater wood volume and therefore carbon storage. What was most surprising, however, is the vast difference in wood volume available post-harvest over a twenty-year period. A stand of Douglas-fir harvested at 60 years produces more than twice as much wood (136%) than a stand harvested at 40 years. This finding highlights that longer rotations achieve wood demand with greater yield over a smaller land-based area. An approach that maximizes wood yield over a smaller area lends to less extensive harvest operations which benefits efficient wood production under conditions of climate change. Aside from carbon and timber supply, longer rotations may also benefit several other ecosystem services.

2. Veneer-based products like MPP utilize wood more efficiently than lumber-based products like CLT.

This conclusion was also to be expected as the peeling process in veneer production more effectively utilizes roundwood than does optimizing rectangular shapes out of a circular cross-section apparent to lumber production. Furthermore, the density of structurally bonded veneer achieves higher densities compared to that of lumber, allowing for even less wood fiber to achieve the same structural performance goals (on average by as much as 19%). Beyond maximizing wood yield at the forest level, efficient utilization of available wood post-harvest at the product manufacture level can further take advantage of wood fiber. Results show that innovation in different EWPs can help to reduce wood fiber consumption and increase its efficiency utilization.

3. Although there are many different ways to approach design for timber structural systems, this study looked to demonstrate how design can influence wood volume usage. Making thoughtful design choices can lead to efficient use of wood.

Future Research Questions

1. Incentives to extend rotation periods? Carbon credits, compensation easements, etc...
2. The impact of thinning operations on total outcome of merchantable wood volume? Different stand rotation lengths?
3. Wood yield and carbon over time? Three rotations of 40 years vs two rotations at 60 yrs?
4. Carbon implications of greater resin usage in veneer products vs lumber products?

Annotated Bibliography

1. Architecture 2030

2. Brecka, Aaron F. J., Yan Boulanger, Eric B. Searle, Anthony R. Taylor, David T. Price, Yingying Zhu, Chander Shahi, and Han Y. H. Chen. 2020. “Sustainability of Canada’s Forestry Sector May Be Compromised by Impending Climate Change.” *Forest Ecology and Management* 474 (October): 118352. <https://doi.org/10.1016/j.foreco.2020.118352>.

Summary

Climate change is projected to directly affect timber supply through significant changes in forest dynamics (i.e. regeneration, growth and succession). Reduced moisture availability will be one of the greatest consequences of climate change as large swaths of boreal forest will be exposed to increased risk of drought or wildfire. Dry regions are likely to become much drier, which in turn reduces available harvestable biomass. Because conifer tree biomass will be most affected, one direct outcome is an overall decrease in harvestable stands. Declines in harvestable biomass can have serious economic implications as conifers are preferred by industry. Decreasing annual harvest volumes might help to maintain a smaller but more stable wood supply as current harvesting rates in a changing climate might overwhelm forests to provide a sustainable wood volume.

3. Case, Michael J., Brittany G. Johnson, Kristina J. Bartowitz, and Tara W. Hudiburg. 2021. “Forests of the Future: Climate Change Impacts and Implications for Carbon Storage in the Pacific Northwest, USA.” *Forest Ecology and Management* 482 (February): 118886. <https://doi.org/10.1016/j.foreco.2020.118886>.

Summary

This paper discusses current understanding of climate change impacts on the productivity of different forest types in the PNW as well as addresses current knowledge gaps. Direct impacts of climate change on PNW forests to store carbon include increased drought, consequent tree mortality, changing tree growth rates, altered productivity, changes in tree composition and reduced soil moisture. Indirect impacts on forests such as natural and human disturbances may further reduce forest carbon storage.

4. CORRIM. 2020. “Forest Sustainability in the Pacific Northwest: Key Metrics.”

Summary

This report provides key metrics of PNW Douglas-fir forests. PNW forests produce 34% of US lumber and veneer from only 6.7% of US timberland. As of 2020, current SFM practices have allowed PNW forests to support as much wood and therefore carbon storage as they did nearly 70 years ago. The greatest threat to PNW forests is not timber harvest but land-use change. HWP and replanting post-harvest serves as a viable climate change mitigation strategy.

5. Hudiburg, Tara, Beverly Law, David P. Turner, John Campbell, Dan Donato, and Maureen Duane. 2009. “Carbon Dynamics of Oregon and Northern California Forests and Potential Land-Based Carbon Storage.” *Ecological Applications: A Publication of the Ecological Society of America* 19 (1): 163–80. <https://esajournals.onlinelibrary.wiley.com/doi/abs/10.1890/07-2006.1>.

Summary

This study argues that forests in Oregon and Northern California have the potential to significantly increase their carbon stocks. Study results indicate that these forests are at 54% of their theoretical maximum for carbon sequestration assuming the absence of significant disturbance. It is acknowledged that leaving stands unmanaged for centuries to reach these high levels of carbon sequestration may be unreasonable given current high-frequency fires. It is therefore suggested that carbon sequestration increase by extending stand rotations by 30-50 years and by reducing harvest acreage in areas with the highest carbon storing potential.

6. Hudiburg, Tara W., Beverly E. Law, William R. Moomaw, Mark E. Harmon, and Jeffrey E. Stenzel. 2019. “Meeting GHG Reduction Targets Requires Accounting for All Forest Sector Emissions.” <https://doi.org/10.1088/1748-9326/ab28bb>.

Summary

Western U.S. forests are a net sink of carbon because they sequester more carbon than is emitted. However, it is suggested that these forests can be more productive in sequestering carbon as over a hundred years of wood harvest in these forests has reduced the potential annual sink by an average of 21%. Authors allude to longer rotations, reduced harvest, and wise use of HWP. Accurate forest-related emissions reporting of state CO2 budgets are also strongly encouraged to meet GHG reduction targets.

7. Johnstone, Jill F., Craig D. Allen, Jerry F. Franklin, Lee E. Frelich, Brian J. Harvey, Philip E. Higuera, Michelle C. Mack, et al. 2016. “Changing Disturbance Regimes, Ecological Memory, and Forest Resilience.” *Frontiers in Ecology and the Environment* 14 (7): 369–78. <https://doi.org/10.1002/fee.1311>.

Summary

Forest resilience is shaped by patterns of past disturbances. Under climate change, disruption of these patterns with respect to frequency, scale and intensity can lessen ecosystem resilience to disturbance regimes that forests were well adapted to. This effect may only be noticeable after the disturbances have occurred.

8. Law, Beverly E., Tara W. Hudiburg, Logan T. Berner, Jeffrey J. Kent, Polly C. Buotte, and Mark E. Harmon. 2018. “Land Use Strategies to Mitigate Climate Change in Carbon Dense Temperate Forests.” *Proceedings of the National Academy of Sciences of the United States of America* 115 (14): 3663–68. <https://doi.org/10.1073/pnas.1720064115>.

Summary

Benefits provided by afforestation, reforestation, changes in forest management, and bioenergy from PNW forests are examined. It is argued that forests remain a more credible land sink for carbon storage than HWP since forests can store carbon for centuries rather than decades typical of wood product lifespans. While substitution benefits from HWP may reduce overall forest sector related emissions, it is argued that substitution benefits are generally overstated and cannot offset losses induced by frequent harvest cycles, supply chain emissions, and decay. Collection of harvest residues for bioenergy are also claimed to be overstated and that it is unlikely to decrease forest sector emissions. Authors therefore encourage increasing carbon storage in high-biomass forests by extending harvest rotations, afforestation, and reforestation.

9. Lippke, Bruce, Elaine Oneil, Rob Harrison, Kenneth Skog, Leif Gustavsson, and Roger Sathre. 2011. “Life Cycle Impacts of Forest Management and Wood Utilization on Carbon Mitigation: Knowns and Unknowns.” *Carbon Management* 2 (3): 303–33. <https://doi.org/10.4155/cmt.11.24>.

Summary

This research review examines the complexities inherent to life cycle carbon emissions accounting. Attention is given to areas with robust findings as well as to areas of uncertainty that may impact key assumptions of carbon in forests and in products. As a result, many opportunities for reducing carbon emissions are identified, along with knowledge gaps, and proposed policies.

10. Littell, Jeremy S., David L. Peterson, and Michael Tjoelker. 2008. “Douglas-Fir Growth in Mountain Ecosystems: Water Limits Tree Growth from Stand to Region.” *Ecological Monographs* 78 (3): 349–68. <https://doi.org/10.1890/07-0712.1>.

Summary

Douglas-fir from U.S. northwest mountain ecosystems were sampled to understand their climate-growth relationship. Sensitivity to summer water balance indicated that reduced rainfall and soil moisture during warmer summer months are likely to decrease Douglas-fir growth. At higher elevations, Douglas-fir might see increased growth given potentially longer growing seasons.

10. Mc ARDLE, Richard E. 1949. “The Yield of Douglas Fir in the Pacific Northwest.”

11. Mildrexler, David J., Logan T. Berner, Beverly E. Law, Richard A. Birdsey, and William R. Moomaw. 2020. “Large Trees Dominate Carbon Storage in Forests East of the Cascade Crest in the United States Pacific Northwest.” *Frontiers in Forests and Global Change* 3. <https://doi.org/10.3389/ffgc.2020.594274>.

Summary

Large diameter trees (DBH of 21 inches or greater) store disproportionate amounts of carbon, with each additional increment of DBH growth accumulating a sharp increase in carbon stored. The proportion of large diameter trees and the respective amount of carbon stored were studied among five dominant tree species in Oregon and Washington State forests east of the Cascades Mountains. Large diameter trees represented 3% of the 636,520 trees surveyed on forest inventory plots but stored 42% of the total above ground carbon. Over concern that harvesting large trees will release significant amounts of biogenic carbon, authors advocate the protection of large trees not only for their significant carbon storage but also for other ecosystem co-benefits that they provide.

12. Oswalt, Sonja N., W. Brad Smith, Patrick D. Miles, and Scott A. Pugh. 2019. “Forest Resources of the United States, 2017: A Technical Document Supporting the Forest Service 2020 RPA Assessment.” *Gen. Tech. Rep. WO-97*. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 97. <https://doi.org/10.2737/WO-GTR-97>.

Summary

Forests and woodlands cover one third of U.S. land. Annually, harvesting occurs on less than 2% of forested land while 3% of which is affected by natural disturbances. Natural disturbances including wildfire, insects and disease are the biggest threat to the nation's forests. Low harvesting rates, aging forests, mortality from insect and disease, and extreme weather events have combined to facilitate conditions for wildfire. Heavy mortality rates are witnessed in softwood volumes in the West.

13. Peterson, David W., Becky K. Kerns, and Erich K. Dodson. 2014. “Climate Change Effects on Vegetation in the Pacific Northwest: A Review and Synthesis of the Scientific Literature and Simulation Model Projections.” <https://www.researchgate.net/publication/269036898>.

Summary

This study reviewed scientific literature and model projections of vegetation vulnerability to climate change and disturbances across five different PNW biomes. Climate change is expected to alter vegetation physiological processes, ecosystem processes, and eco-

land managers can best mitigate these risks. A “toolbox approach” is therefore suggested which promotes resistance, resilience and facilitating response to change.

14. Ramage, Michael H., Henry Burridge, Marta Busse-Wicher, George Fereday, Thomas Reynolds, Darshil U. Shah, Guanglu Wu, et al. 2017. “The Wood from the Trees: The Use of Timber in Construction.” Renewable and Sustainable Energy Reviews 68 (February): 333–59. <https://doi.org/10.1016/j.rser.2016.09.107>.

Summary

This overview investigates timber at both the micro and macro scale. Beginning at the individual wood cell, the authors work their way up to review of mass timber products in general, and eventually to discussion of global forestry trends and policies.

15. Restaino, Christina M., David L. Peterson, and Jeremy Littell. 2016. “Increased Water Deficit Decreases Douglas Fir Growth throughout Western US Forests.” Proceedings of the National Academy of Sciences of the United States of America 113 (34): 9557–62. <https://doi.org/10.1073/pnas.1602384113>.

Summary

With warming temperatures and consequent drought, changing tree growth rates can affect tree mortality and feedbacks to the carbon cycle. Networks of Douglas-fir across the western US were evaluated and results showed that projected increasing temperatures are expected to reduce the growth of Douglas-fir. This study provides evidence of the negative impact of water stress on forests ecosystems, including conditions that alter the ability of forests to sequester carbon, maintain biodiversity, and remain resilient to disturbances.

16. Smithwick, Erica A. H., Mark E. Harmon, Suzanne M. Remillard, Steven A. Acker, and Jerry F. Franklin. 2002. “Potential Upper Bounds of Carbon Stores in Forests of the Pacific Northwest.” Ecological Applications: A Publication of the Ecological Society of America 12 (5): 1303–17. [https://doi.org/10.1890/1051-0761\(2002\)012\[1303:pubocs\]2.0.co;2](https://doi.org/10.1890/1051-0761(2002)012[1303:pubocs]2.0.co;2).

Summary

17. Simmons, Eric A., Kate C. Marcille, Gary J. Lettman, Todd A. Morgan, Dorian C. Smith, Luke A. Rymniak, and Glenn A. Christensen. n.d. “Oregon’s Forest Products Industry and Timber Harvest 2017 With Trends Through 2018.”

18. Williams, Neil G., and Matthew D. Powers. 2019. “Carbon Storage Implications of Active Management in Mature Pseudotsuga Menziesii Forests of Western Oregon.” Forest Ecology and Management 432 (January): 761–75. <https://doi.org/10.1016/j.foreco.2018.10.002>.

Summary

The impact of active management on carbon storage in Douglas-fir stands across Western Oregon was assessed. Results conclude that high intensity active management will lead to a substantial reduction in carbon storage in contrast to passive and light-touch management. Furthermore, it was found that 20-50 years after thinning, carbon storage in mature stands managed over extended rotations may be comparable to that in unmanaged stands. Ultimately, mature Douglas-fir forests of the PNW not only dominate a sizeable portion of forested land, but also function as major carbon stores even when centuries short of old-growth conditions.

Image Sources

Cover - Photo by shayd johnson on Unsplash

Pg.5 - Photo by Jason Leem on Unsplash

Pg.9 - Photo by Matthew Henry on Unsplash

Pg.11 - <https://www.andersen-const.com/portfolio/project/oregon-state-university-forest-science-complex>

Pg.13 - Photo by Anton Dios on Adobe Stock, Photo by Hoda Bogdan on Adobe Stock, Photo by Francisco Fernandes on Unsplash

Pg. 17 - Photo by David Barker on Unsplash

Pg. 19 - Photo by Jamie Morris on Unsplash

Pg. 21 - Photo by Matt Palmer on Unsplash

Pg. 23 - Photo by Ross Stone on Unsplash

Pg. 25 – Photo by Ryan Ancill on Unsplash

Pg. 29 – Photo by Olena Sergienko on Unsplash

Pg. 31 – Photo by Zuzana Kacerova on Unsplash

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