

HUGO

Designing with Mass Timber

COMPARATIVE ANALYSIS OF MASS TIMBER
AND CONCRETE PROTOTYPES



CORGAN 

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This project was done in partnership with:



VARI
IRVING, TEXAS
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Background

In 2023, Corgan's Office practice along with Hugo, the firm's research and innovation team, conducted a design sprint to explore the drivers of mass timber's growing popularity and understand the implications of using mass timber. This sprint included a literature review to identify the state of the industry including the current market and manufacturing, benefits to users and clients, and drivers for continued growth. Additionally, the team examined the differences between concrete and mass timber construction through a prototypical six-story office building design in Dallas, Texas. This comparative study aimed to understand the financial, experiential, and sustainable benefits of mass timber versus concrete construction.

The design and evaluation of these prototypes were done in partnership with Swinerton, a national construction company, Texas Air Systems, and Timberlab, a research subsidiary of Swinerton, who has paved the way for innovation in mass timber building delivery over the past five years.

MASS TIMBER PROTOTYPE STUDY
CORGAN



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Mass Timber Overview

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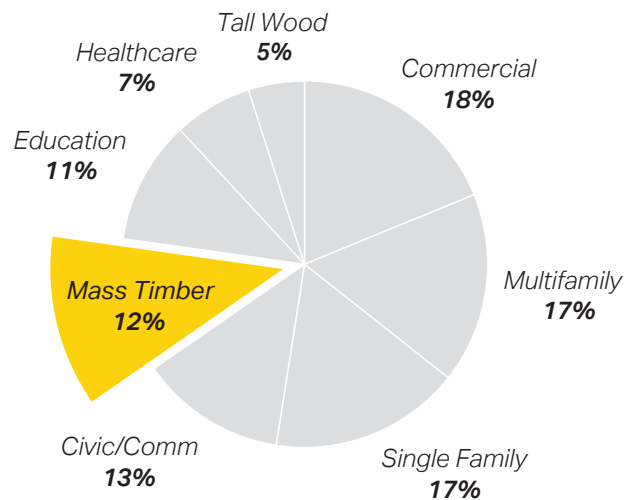
State of the Industry

Mass Timber Market

As interest in mass timber is increasing across the southeastern United States, and recent code changes enable its integration into a variety of building types, developers are looking to add mass timber construction to their more sustainable portfolios.

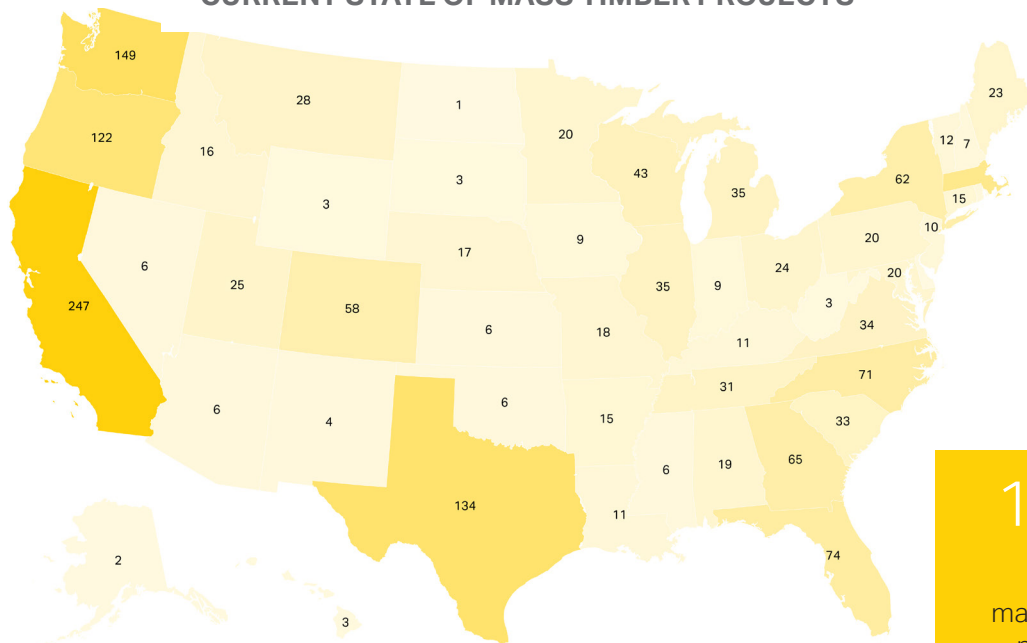
Compared to typical concrete construction, mass timber introduces a variety of benefits to the built environment, including a low carbon footprint, a range of structural capabilities, positive user impact, and cost advantages. When considering construction technique and materiality, it is important to understand the financial, experiential, functional, and sustainable benefits of engineered wood construction, to inform better decision-making by designers, developers, and across the design process.

Anticipated Projects by Market Sector



Adapted from Timber Trends 2022 report from Think Wood®

CURRENT STATE OF MASS TIMBER PROJECTS

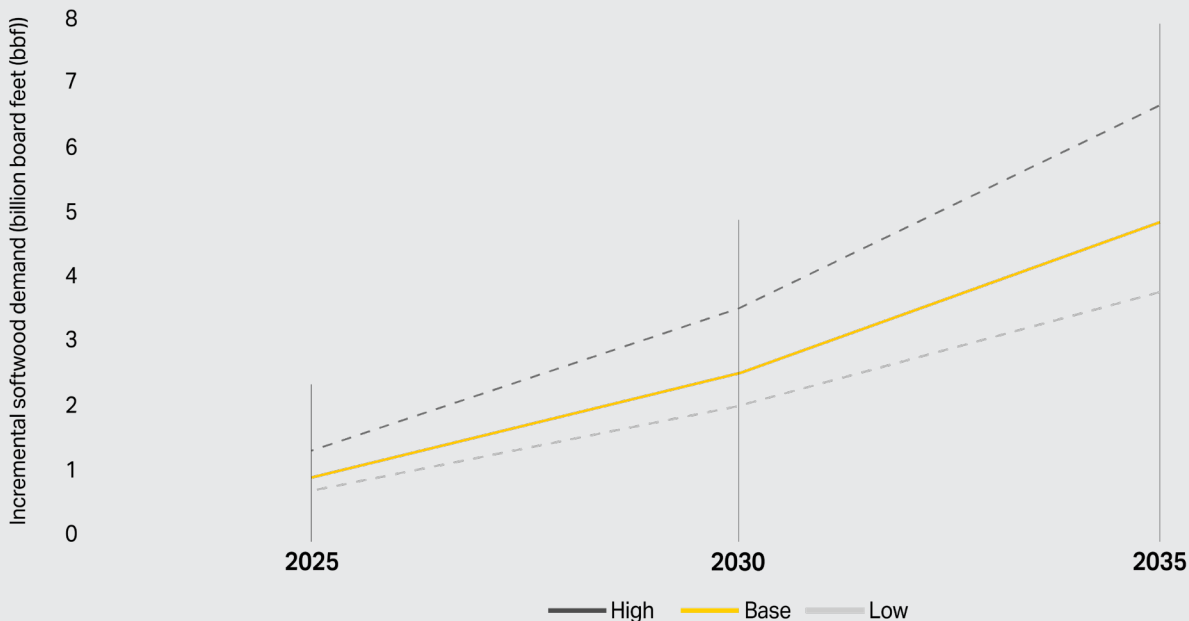


1,622
active mass timber projects in the U.S.¹

Adapted from Woodworks Innovation Network - Dec 2022¹

Mass Timber Outlook

US Incremental Lumber Demand



Adapted from: SLB Mass Timber Demand Outlook²

The Woodworks Innovation Network, a resource publicly provided by Woodworks, inventories many mass timber projects, and categorizes each for case study analysis. In the U.S., a total number of 1,622 mass timber projects are either completed/in construction (767 projects) or in design (910 projects) as of December 2022.¹ The Woodworks Innovation Network tool highlights the density and phasing development of many projects.

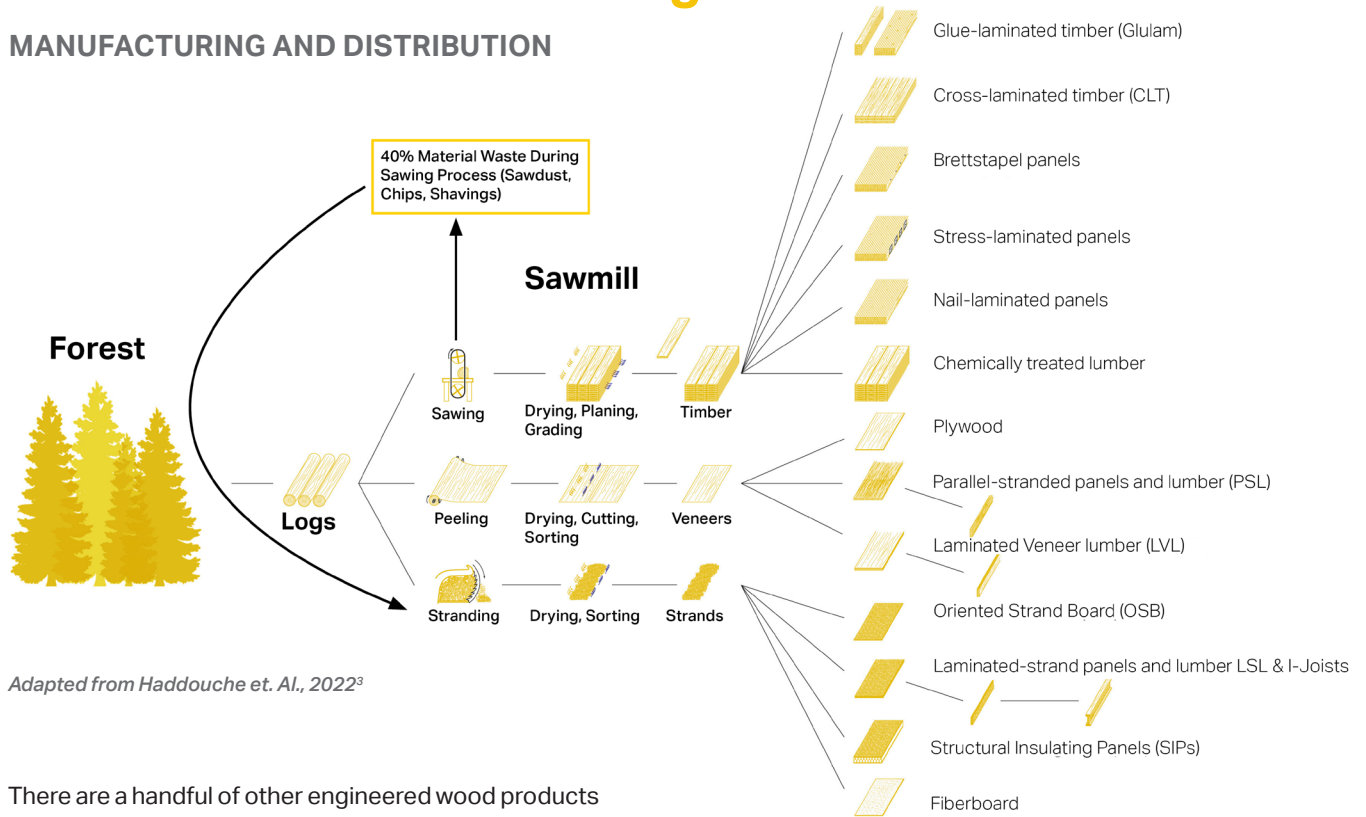
As mass timber is increasingly being used in projects across the United States, more manufacturers are joining the market to meet demand for the use of engineered wood as a sustainable building product. As shown in the graph above, there is a predicted increase in the demand of incremental lumber in the U.S. over the next decade, requiring an increase in production as well.

Commonly seen framing systems in the world of mass timber use the following components: post and beam; floor and wall panel systems; and hybrid systems (wood and steel or concrete). These are combined in various configurations to create what we see today in mass timber case studies.

The mass timber product market is saturated with glue-laminated timber (Glulam) and cross-laminated timber (CLT) engineered wood products. In addition to those, timber can be combined with concrete and steel construction to form hybrid structural systems. Other forms of engineered wood are dowel laminated timber (DLT) and nail laminated timber (NLT). There are several specialty products like mass-ply laminated panels or specialty length glue-laminated beams and panels, but most manufacturers in the U.S. produce glulam and CLT columns, beams, and panels.

Products + Manufacturing

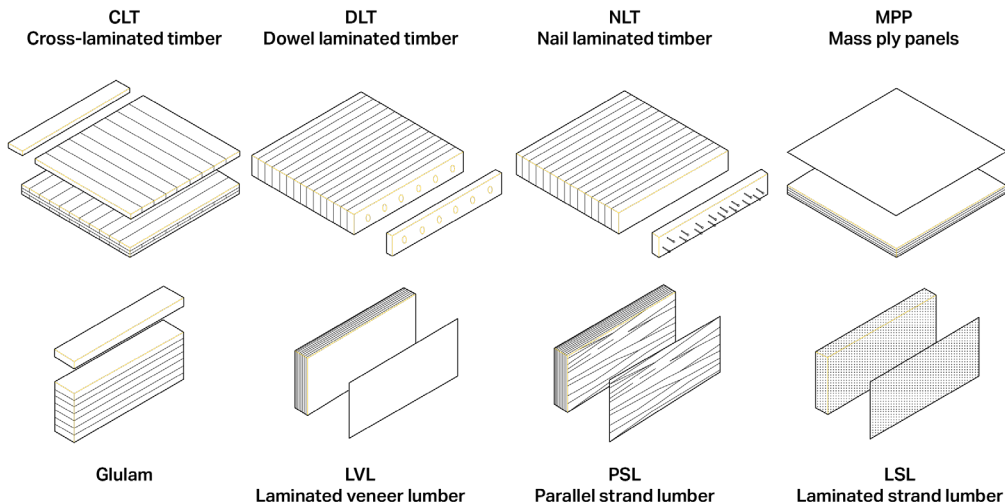
MANUFACTURING AND DISTRIBUTION



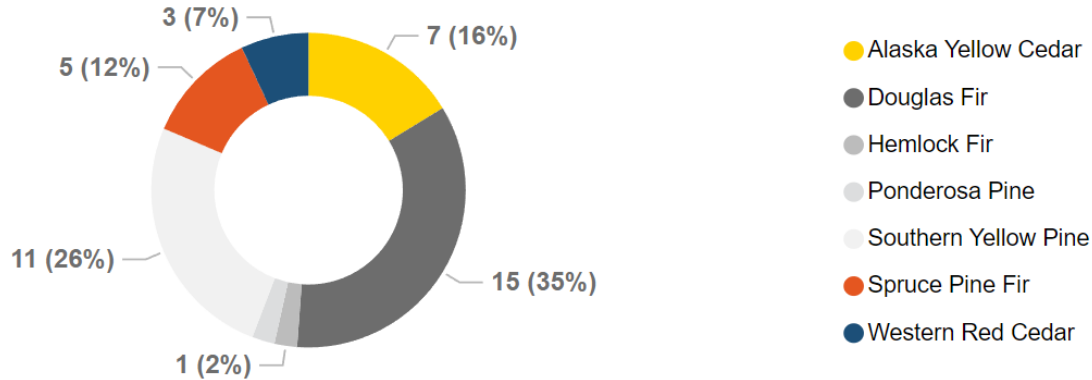
Adapted from Haddouche et. Al., 2022³

There are a handful of other engineered wood products to choose from for large format beams, columns, and structural panels. Some examples are Structural Composite Lumber (SCL) which is a category that encompasses several methods of wood composition like laminated veneer lumber (LVL), parallel strand lumber (PSL), laminated strand lumber (LSL), and oriented strand lumber (OSL). The benefits of this type of engineered wood include using scrap/waste wood material from general timber milling and combining this

otherwise waste material with adhesives to create durable and robust members called "billets." SCL works by orienting the grain, veneers, or flakes in the same direction, which is in turn stronger than typical lumber. The product is sewn into typical sizes and is virtually free from warping and splitting.



MASS TIMBER SPECIES BY SUPPLIER



As a part of our study, we analyzed characteristics of 23 United States mass timber manufacturers; product offerings, distance from the site, species, inventory, and geographic location. Of the 23 glulam suppliers in the United States, 35% (8) of them supply CLT products.⁴ Additionally, the largest portion of the mass timber industry is the Douglas Fir Species from the Pacific Northwest, with 15 suppliers (35%), and second to that is the Southern Yellow Pine Species in the Southeastern US, with 11 suppliers (26% of industry).⁴

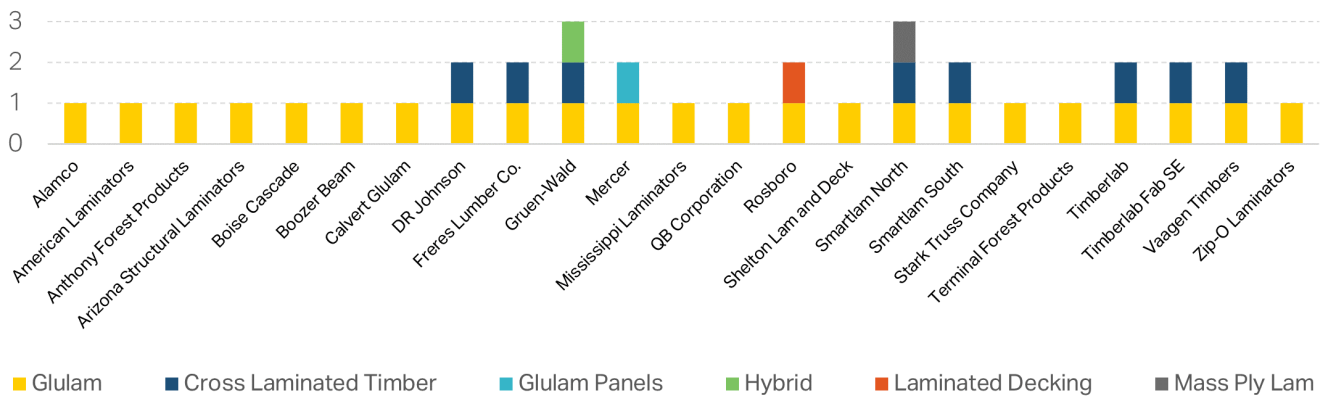
23

Glulam suppliers
in the U.S.⁴

8

CLT suppliers in
the U.S.⁴

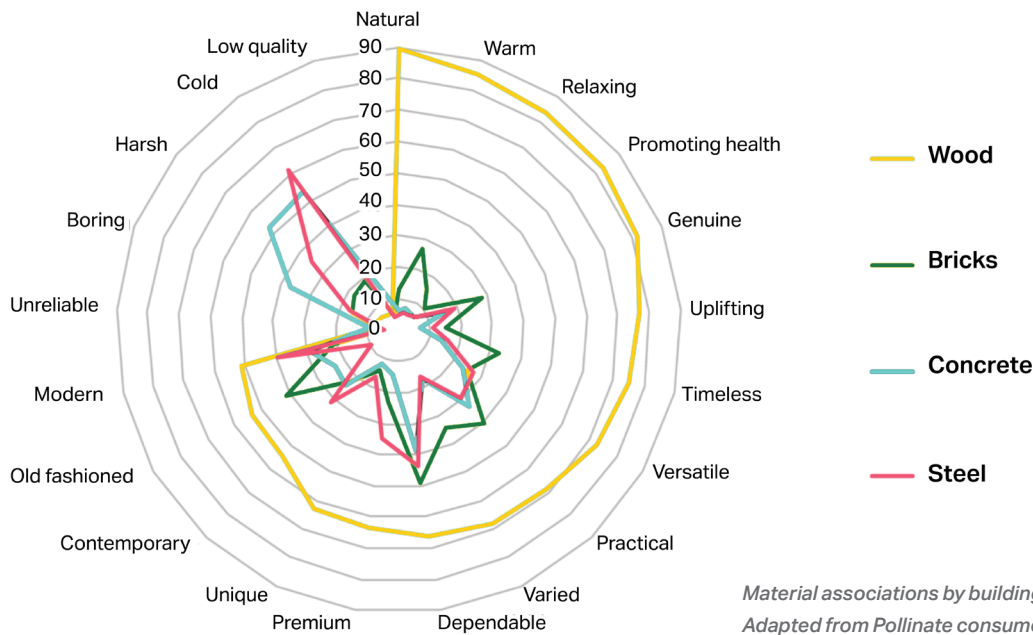
PRODUCT BY SUPPLIER



Benefits for Users

Studies show that the use of wood in interior design has a positive effect on user wellbeing.^{5,6,7} The intrinsic relationship between wood and biophilic design creates an opportunity to bring warmth, connection to natural elements, and relaxation to users nearby. This has been analyzed through several different senses, such as the visual, the haptic, and the olfactory.

Wellbeing



In a study conducted by Pollinate, a market research company, surveying 1,000 indoor office workers in Australia, workers associate wood with higher levels of wellbeing (+13%), prompting lower absenteeism, higher levels of concentration, and improved mood and daily productivity (+8%). This led to increased worker satisfaction levels, benefiting both the user and the employer. Biophilic design in the workplace has been reported as increasing productivity by up to 15%, while improving staff retention rates and overall user favorability.⁶

The use of wood as a design material has been reported to lower blood pressure and heart rate in users, increase

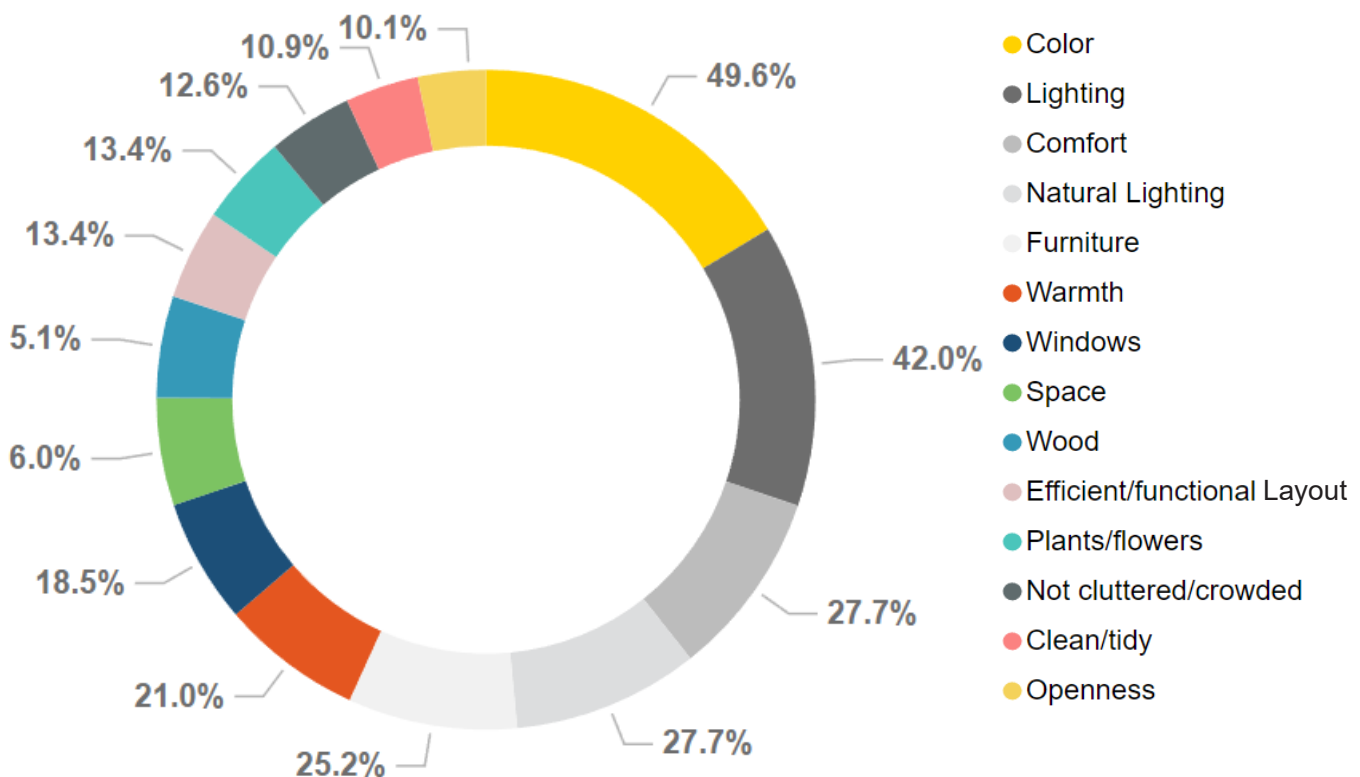
activation of the parasympathetic nervous system (calmness), and create a sense of invitation.⁶ The amount of wood in an occupiable space is also relevant to user wellbeing; rooms with 45% of surfaces comprised of wood have been shown to boost comfort levels and lower blood pressure, even by respondents who claimed that they disliked the wood.⁷ In another study, researchers found that immersion of users in mass timber spaces could be comparable to the practice of Japanese forest bathing, Shinrin-yoku, which has been found to elevate immune function and lower stress and adrenaline using aromatherapy.²

According to the *Make it Wood—Wellness Wood Report*⁵

Impact on wellbeing based on typology:

- **Office Design:** Productivity can be increased by 8% and rates of wellbeing increased by 13%.
- **Education Spaces:** Increased rates of learning, improved test results, concentration levels and attendance, reduced impacts of ADHD.
- **Healthcare Spaces:** Post-operative time to recovery reduced by 8.5%, reduced need for pain medication by 22%.
- **Retail:** The presence of vegetation & landscaping has been found to increase average rental rates on retail spaces with tenants indicating they were willing to pay 8-12% more for goods and services.
- **Homes:** 7-8% less crime attributed to areas with access to nature and can command an increase of 4-5% in property price.

CHARACTERISTICS AFFECTING FAVORABILITY OF OFFICE USERS



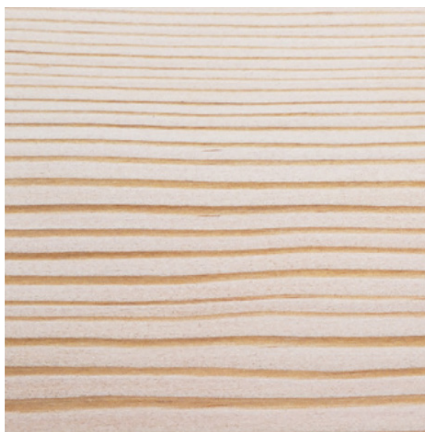
Adapted from *The Psychological Effects of Wood Products*⁶

Aesthetics + Sensory Affordances

Using wood in haptic user experience elements, such as door handles, elevator fit outs, and furniture, has been shown to create calming and favorable reactions.⁶ Scientifically, this may be caused by the lower thermal conductivity of wood as a material, compared to steel or concrete, which makes the temperature of the wood closer to the temperature of the surrounding space.⁶ Research shows that respondents connect with wood mostly through its distinctions, such as contrast, color, knots, and texture.⁷ This is especially noted in wood that has a natural finish, as opposed to deep staining.⁷ Due to its aesthetic value over concrete and steel, wood structures can increase property value, especially in exposed applications. Research has shown that yellow tones increase the sense of warmth within user experience and increase favorability.



COLOR

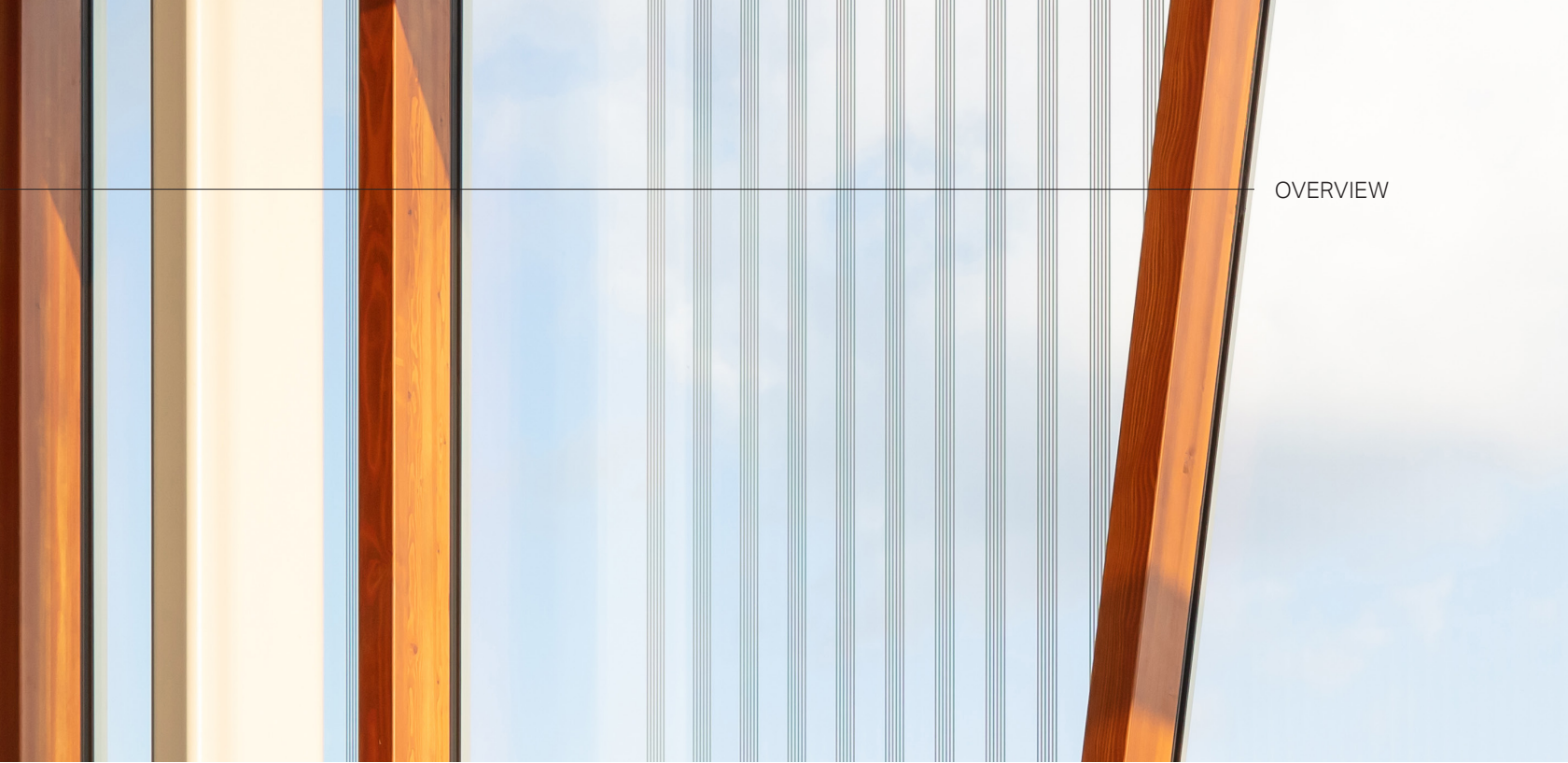



GRAIN ORIENTATION



CONTOURS

Adapted from The Nature of Wood by Terrapin⁷



Wood Type				
	Douglas Fir-Larch	Hemlock Fir	Spruce-Pine Fir	Southern Yellow Pine
Species	Douglas Fir and Western Larch	Western Larch, California Red Fir, Grand Fir, Noble Fir, Pacific Silver Fir, and White Fir	White Spruce, Engelmann Spruce, Red Spruce, Black Spruce, Jack Pine, Lodge-pole Pine, Balsam Fir, and Alpine Fir	Longleaf, Loblolly Pine, Shortleaf Pine, and Slash Pine
Color	Reddish-brown to yellow	Yellow-brown to white	White to pale yellow	Pale yellow to golden
Other Characteristics	<ul style="list-style-type: none"> • High degree of hardness • High resistance to decay 	<ul style="list-style-type: none"> • Takes paint well • Holds nails well • Excellent gluing characteristics 	<ul style="list-style-type: none"> • Takes paint well • Holds nails well • Excellent gluing characteristics 	<ul style="list-style-type: none"> • Superior load-bearing capacity • Holds fasteners well • High degree of hardness

Appearance standards for both CLT and glulam have been established to control the number of knots, voids, and grain/coloration in the wood. Structural classifications are less stringent on the aesthetic qualities of the surface of the wood/lamination; however, architectural and premium applications need to meet the ANSI/APA PRG 320 Standard

for Performance-Rated Cross-Laminated Timber (IBC 2303.1.4).⁹ Section 7.3 of PRG 320 states, "CLT panel appearance shall be as agreed to between the buyer and the seller."⁹ Above is a diagram of various common species used in engineered wood products. The physical and structural characteristics vary slightly among each.

Benefits for Clients

Using engineered wood products throughout interior spaces can be an opportunity for building owners to leverage natural materials and experience higher user satisfaction and other wellness benefits.

In buildings where the structure is either concrete or steel, the interior spaces are often clad with gypsum board, dropped ceilings, or soffits to hide the spray-applied fire-resistive coatings.



In a fire resistance test of a 5-ply cross-laminated timber (CLT) panel wall, the panel was exposed to temperatures exceeding 1,800 Fahrenheit and lasted 3 hours and 6 minutes, which exceeds the two-hour rating that building codes require.¹⁰ During fires, exposed mass timber chars on the exterior, forming a layer of insulation that protects the internal mass of wood from fire. Additionally, when the code requires gypsum wall board coverage of the wood structure, mass timber can achieve near damage-free performance during a contents-fire burnout event.¹¹

Cost savings can also be realized from adjustments to building height when using mass timber construction. In a typical concrete or steel structure commercial office design, lay-in ceilings are used to hide mechanical equipment - such as air distribution, lighting, fire suppression systems, and data cables - within a plenum, in addition to providing visual cover to structure with non-finish-grade fireproofing. Adding the depth of concrete framing to the depth required for an above ceiling plenum will typically set the floor-to-floor height. With mass timber, the structural system itself has a desirable aesthetic. Raised flooring systems are typically utilized for mass timber construction which thereby diminishes the need for larger above ceiling plenum space. This offers the opportunity to reduce the overall floor-to-floor height and provide valuable savings on envelope costs.

Our research found a

13%

decrease in building height
when using UFAD and CLT
exposed ceilings

Our comparison of the two construction techniques found a 13% decrease in overall building height with the same number of floors, and same floor-to-ceiling height ratio in mass timber construction as compared to concrete construction.

Funding Opportunities

\$32M

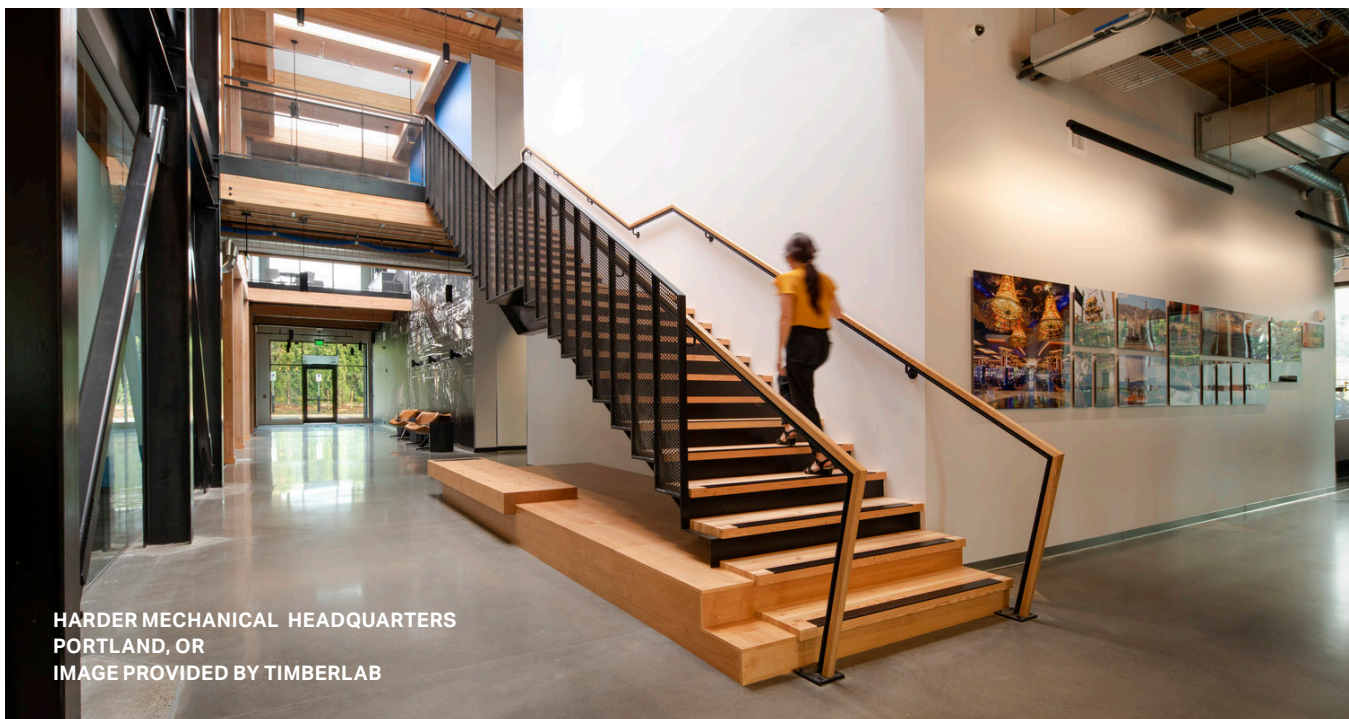
Wood Innovations Grant
funding from U.S. Government
(2022)¹²

\$12M

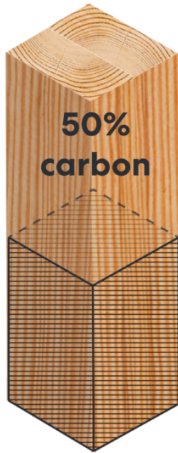
Bipartisan Infrastructure Law,
expanding the use of wood
products (2021)¹³

The U.S. government has issued grants and funding for standardized testing and implementation of mass timber in all sectors of construction. In 2022, it was announced that more than \$32 million in funding aimed to support research into wood innovations and community wood grants would be provided to increase the use of mass timber in the construction industry, and promote sustainable practices at

the national level.¹² Bolstered by \$12 million from the 2021 Bipartisan Infrastructure Law, these grants aim to expand the use of wood products, strengthen emerging wood markets, and support active management to improve forest health and resilience, especially considering the ongoing multi-state wildfire crisis.¹³



HARDER MECHANICAL HEADQUARTERS
PORTLAND, OR
IMAGE PROVIDED BY TIMBERLAB



Life Cycle Analysis

It is widely accepted that on average, mass timber holds 50% carbon content by weight.¹⁴ This means that trees absorb carbon dioxide in their growth process, so 50% of their mass is CO₂. This value varies from species to species but is a generally accepted value for the analysis of carbon sequestration.

See Study Limitations on page 51 for information on current carbon calculation practices.

SPECIES	DENSITY OF WOOD AT 15% MC (LB/FT ³)	DRY DENSITY OF WOOD (LB/FT ³)	ESTIMATED CARBON STORED (LB/FT ³)	ESTIMATED CO ₂ EQUIVALENT (LB/FT ³)
DOUGLAS FIR-LARCH	34.5	30	15	55
HEM-FIR	30.7	26.7	13.3	48.9
SPRUCE PINE FIR	27.8	24.2	12.1	44.3
SOUTHERN YELLOW PINE	36.3	31.6	15.8	57.9

Adapted from Lamlo et. Al., 2003¹⁴

The amount of carbon stored in the wood varies across the densities of the numerous wood species. For example, Southern Pine is the densest of the four species, and therefore stores the highest amount of carbon, as seen in the table above.

The various life cycle assessment phases for a building are categorized across production and construction stages for more accurate analysis of energy usage and emissions. However, the life cycle of mass timber construction exists beyond the building, from the regeneration of trees to the disposal or recycling of wood materials.

PRODUCTION STAGE
(Mandatory)

A1	A2	A3
Extraction and upstream production	Transport to factory	Manufacturing

CONSTRUCTION STAGE

A4	A5
Transport to site	Installation

PRODUCTION STAGE: MODULES A1 – A3
A1 starts with raw material extraction or harvest; A2 is the transportation of those raw materials to the factory or mill; and A3 is manufacturing of the product itself. Together, these modules are often referred to as "cradle-to-gate," or the carbon impact of a product from the moment it's extracted or produced to the moment it is available for purchase.

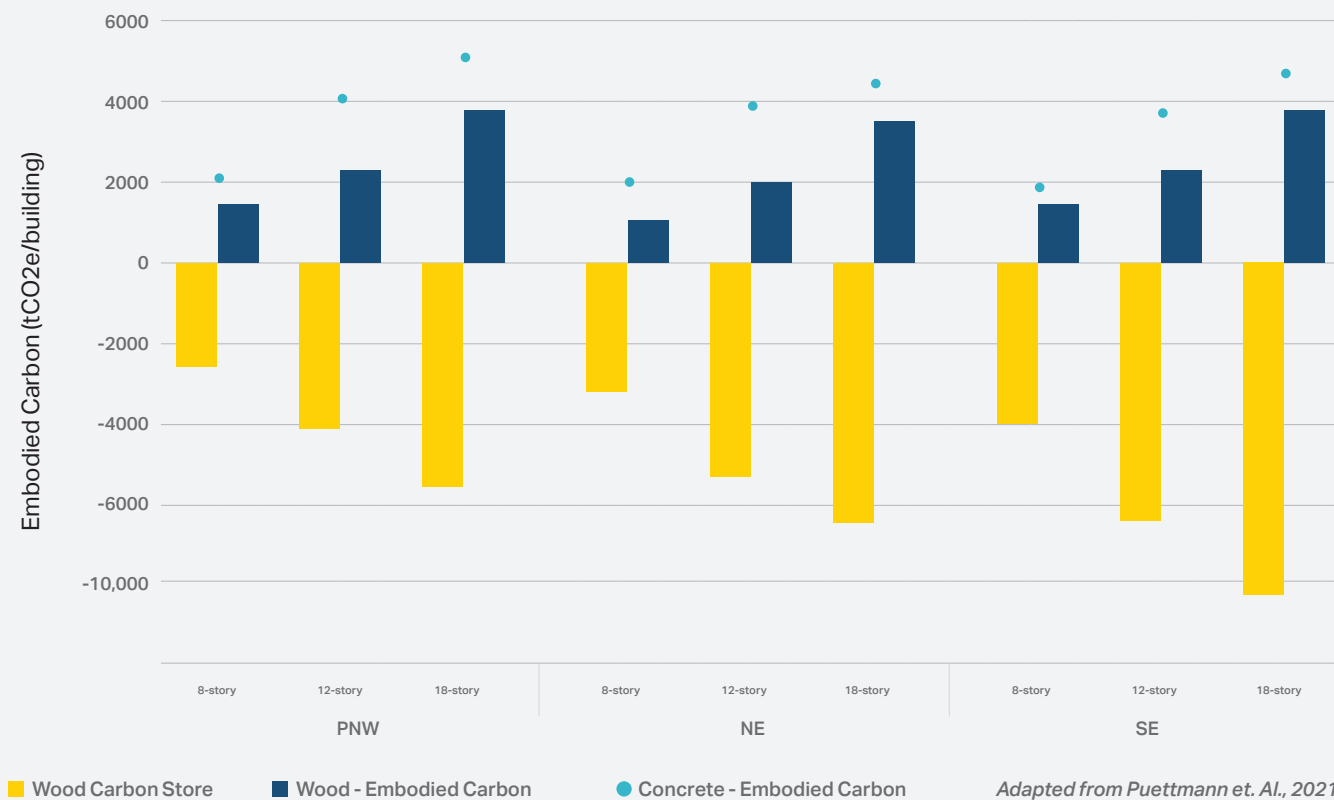
CONSTRUCTION STAGE: MODULES A4 AND A5
A4 is transportation of the product to the construction site; A5 is installation and/or the construction process.

Adapted from Woodworks - Intro to Whole Building Life Cycle Assessment¹⁵

The Global Warming Potential (GWP) of concrete and steel has been shown to be much higher than mass timber due to their manufacturing and sourcing processes.^{16,17} Exposed concrete surfaces absorb CO₂ throughout the course of their life cycle, allowing the building to absorb 10% of cement and concrete production emissions over time.¹⁸

10%
of production carbon absorbed back into exposed concrete surface over time¹⁸

CARBON ACCOUNTING IN BUILDINGS



In a case study comparing 3 types of mass timber buildings (from different regions in the US) with concrete versions of the same size, the concrete schemes' embodied carbon levels were approximately double the wood schemes' embodied carbon levels. The carbon store in the wood negated the embodied carbon by 50%, due to the wood absorbing half of its mass as carbon.²⁰ The highest amount of carbon sequestration was in the Southeastern U.S. due to the use of Southern Yellow Pine. The global warming potential of concrete varies based on the aggregate type in the mixture.

Both generic and recycled aggregate have similar GWP levels per ton, between 3 and 7 kgCO₂e/ton.³ This is equivalent to .075 to .175 kgCO₂/ft³.¹⁹

Similarly, in a study that compared the embodied carbon potential of mass timber and steel buildings, (in 5- and 12-story schemes) the results show that the steel scheme had ~25% more carbon emissions in the 5-story scheme and 30% more emissions in the 12-story scheme.²⁰

Putting Mass Timber in Context

A holistic understanding of mass timber includes code considerations from the IBC 2021.²¹ This helps to inform several design decisions, such as number of floors, maximum allowable building height and assembly occupancy, fire ratings, and the ability to expose mass timber structural elements.

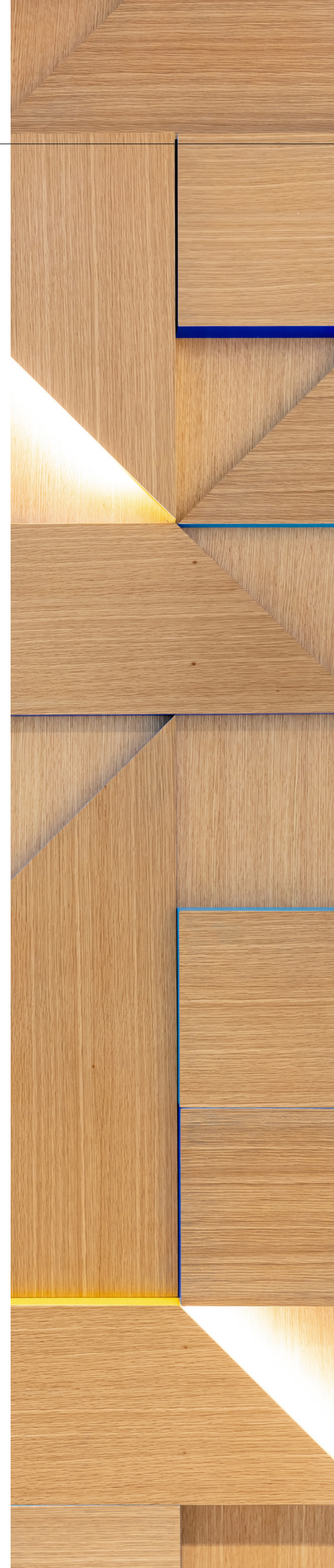
Code

Mass timber falls under heavy timber construction materials, and it is applicable in both Type A and Type B construction. For the purposes of our design investigation, Type III and Type IV construction and fire rating types were selected. The two specific construction types that we explored for our prototype comparison study were the Type III-A and the Type IV-HT. The main difference between these is the fire rating for interior walls and concealed spaces. Additionally, steel connections must be concealed for fire protection purposes.

Type IV-HT (Heavy Timber) construction is a type of construction in which the exterior walls are assembled of noncombustible materials and the interior building elements are assembled of solid wood, laminated heavy timber, or structural composite lumber (SCL), without concealed spaces. A benefit of using Type IV-HT is that it does not require protective finishes on the timber structure.²¹

	TYPE III-A	TYPE IV-HT
MAX ALLOWABLE HEIGHT	85 ft	85 ft
ASSEMBLY OCCUPANCY	Up to Level 4	Up to Level 4
BUSINESS OCCUPANCY	6 stories	6 stories
FIRE RATING	1 hour	HT (Prescriptive sizes)
CONCEALED PLACES	Allowed	Allowed

Adapted from: Timberlab²²



REQUIRED FIRE-RESISTANCE RATINGS BY CONSTRUCTION TYPE (IBC TABLE 601)

BUILDING ELEMENT	I-A	I-B	IV-I	IV-B	IV-C	IV-HT
Primary Structural frame	3*	2*	3	2	2	HT
Ext. Bearing Walls	3*	2*	3	2	2	2
Int. Bearing Walls	3*	2*	3	2	2	1/HT
Floor Construction	2	2*	2	2	2	HT
Roof Construction	1 ½*	1*	1 ½	1	1	HT

Source: *Tall Wood Buildings in the IBC: Up to 18 Stories of Mass Timber, Woodworks*¹¹ *These values can be reduced based on certain conditions in IBC 403.2.1, which do not apply to Type IV buildings.

REQUIRED NONCOMBUSTIBLE PROTECTION ON MASS TIMBER ELEMENTS BY CONSTRUCTION TYPE

	IV-A	IV-B	IV-C	IV-HT
TIMBER EXPOSURE ALLOWANCES	No exposed timber permitted	Ceilings and integral beams up to an area equaling 20% of fire area or dwelling unit area	Full interior timber exposure permitted*	Full interior timber exposure permitted*
		Or alls and integral columns up to an area equaling 40% of fire area or dwelling unit area		
		Or combination of each, with the sum of ratios (actual exposed divided by allowable exposed) not to exceed 1.0		
INTERIOR SURFACE OF BUILDING ELEMENTS	Always required. 2/3 of FRR, 80 minutes minimum	Required with exceptions. 2/3 of FRR, 80 minutes minimum	Not required*	Not required*
EXTERIOR SIDE OF EXTERIOR WALLS	40 minutes	40 minutes	40 minutes	15/32" FRT sheathing or 1/2" gypsum board or noncombustible material
TOP FLOOR (ABOVE MASS TIMBER)	1" minimum	1" minimum	Not required*	Not required*
SHAFTS	2/3 of FRR, 80 minutes minimum, inside and outside	2/3 of FRR, 80 minutes minimum, inside and outside	40 minutes minimum, inside and outside	Not required*

Source: *Mass Timber Design Manual, Woodworks, 2022*²³

*Not required by construction type. Other code requirements may apply.
5/8" Type x gypsum - 40 minutes

Sourcing and Embodied Carbon

FORESTRY

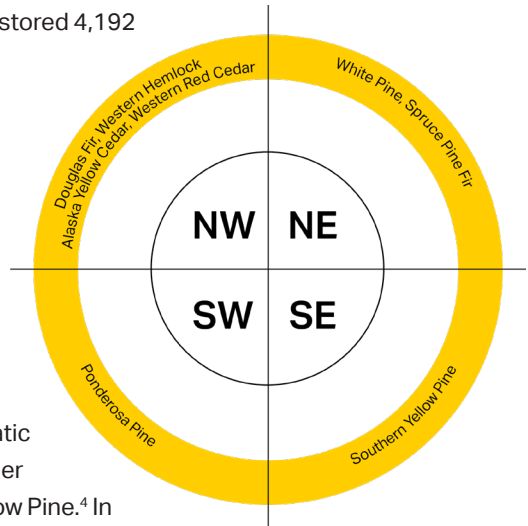
Woodworks calculated it would take 46 minutes for the Oregon timberlands to regrow the wood used in the First Tech Federal Credit Union project. This structure also stored 4,192 metric tons of carbon in its mass.

46 min

for Oregon timberlands to regrow the project's wood²⁴

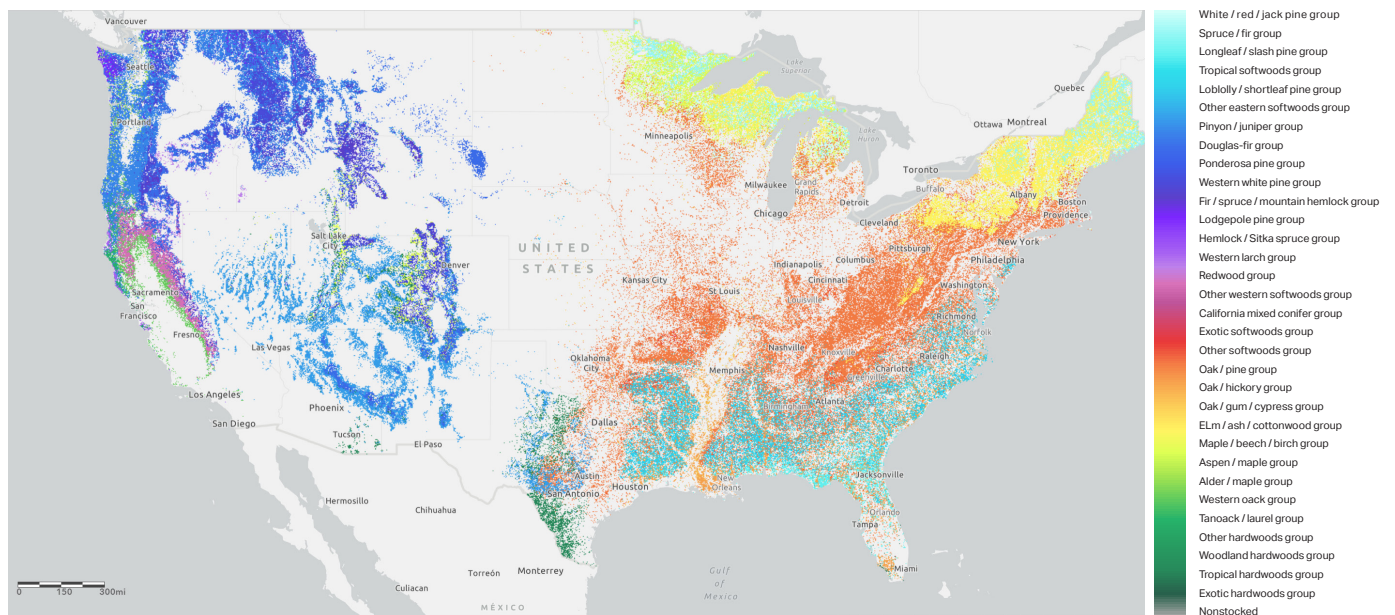
4,192

metric tons of carbon stored in the mass timber structure²⁴

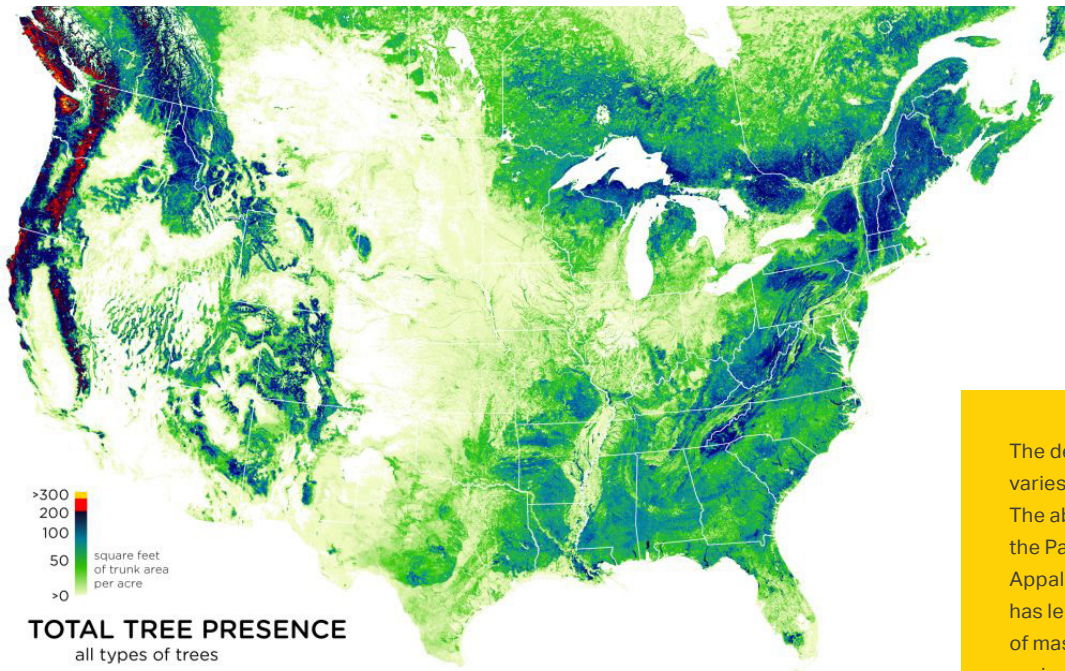


Tree abundance and species prevalence varies due to geographic and climatic differences. In the Northeast, the most common species used for mass timber are Spruce Pine Fir and White Pine, while in the Southeast, it is Southern Yellow Pine.⁴ In the Pacific Northwest they have several, namely Douglas Fir and Western Hemlock.⁴ In the Southwest, there is lower manufacturing and use of mass timber. However, projects there have been built with wood from different regions; the closest species being Ponderosa Pine.⁴

TIMBER SUPPLY: U.S. FOREST GROUP TYPES

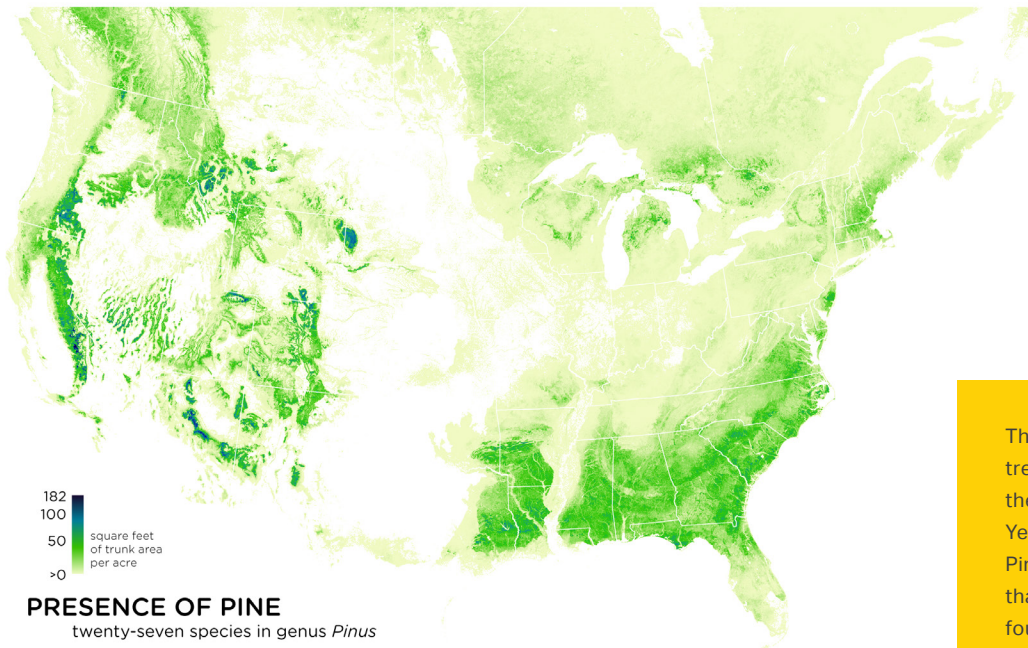


Source: ESRI ArcGIS – Forest Type Groups of the Continental US – USDA²⁶



The density of tree species varies across the nation. The abundance of trees in the Pacific Northwest and Appalachian Mountain region has led to stronger production of mass timber in those regions, and higher utilization of it in architectural design.

Source: Bill Rankin, Radical Cartography²⁷



The most common type of tree used for mass timber in the Southeast is Southern Yellow Pine. Southern Yellow Pine (SYP) is a species group that is made up of primarily four trees: loblolly pine, longleaf pine, shortleaf pine, and slash pine.

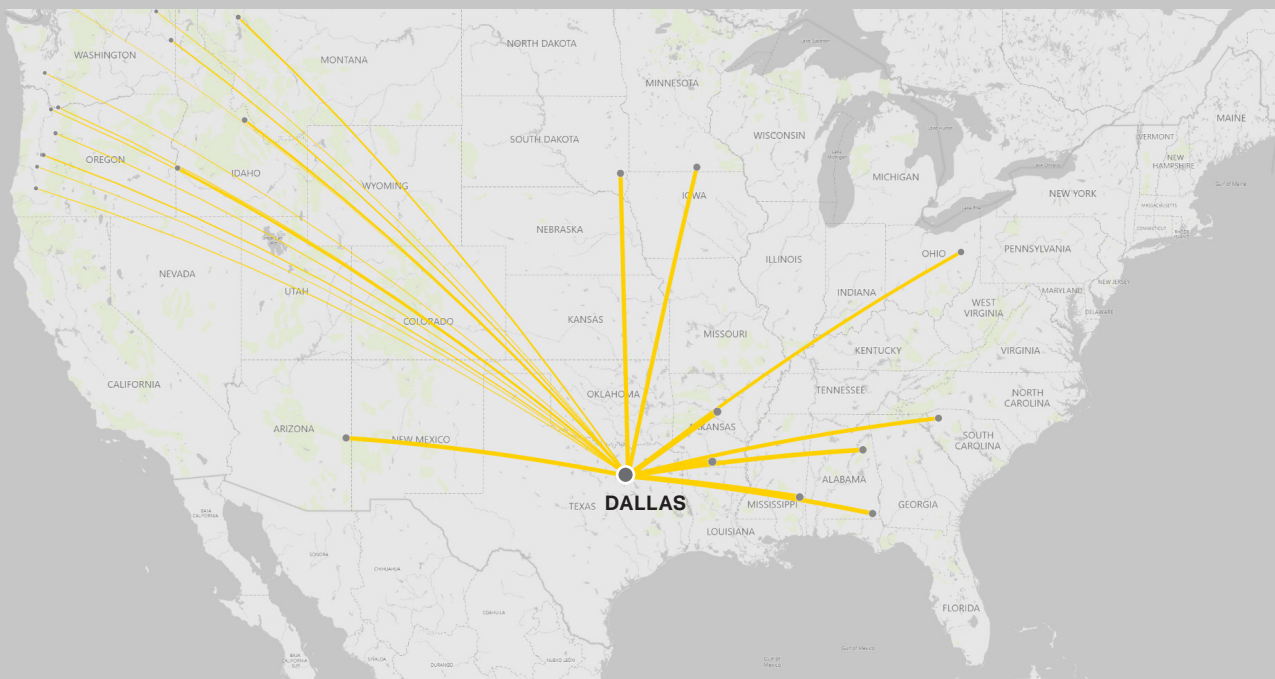
Source: Bill Rankin, Radical Cartography²⁷

MANUFACTURING AND SUPPLY

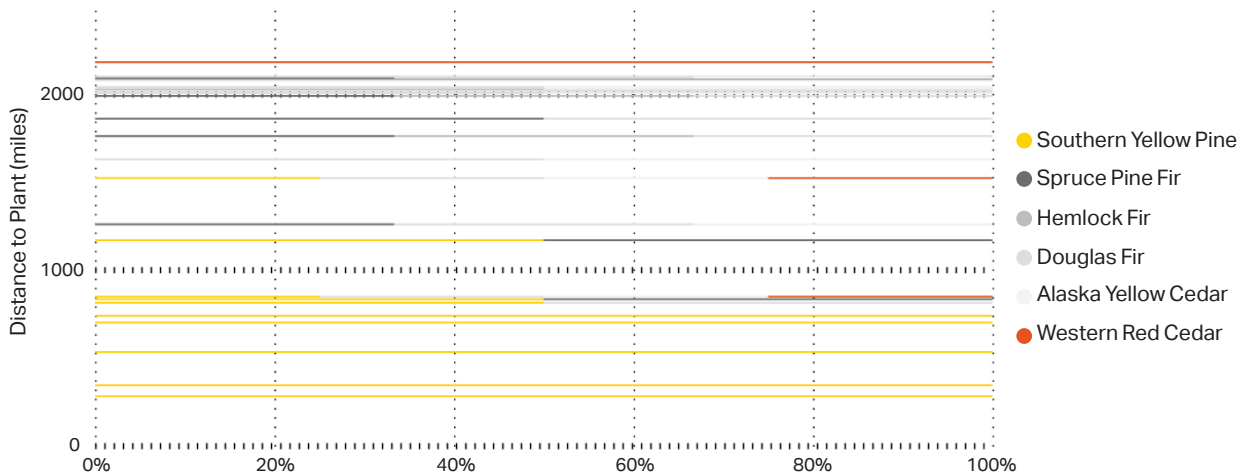
According to the Engineered Wood Association (APA), 36% of mass timber product manufacturers are located within 1,000 miles of the site in Dallas, Texas, where we have chosen to conduct our prototype investigations - with the nearest being only 280 miles away in El Dorado, Arkansas, and the furthest being 737 miles away in Dothan, Alabama.

The rest of the manufacturers are considered part of the Northern or Pacific Northwest markets. The main species in the southern manufacturing plants is Southern Yellow Pine, while other regions produce Spruce Pine Fir, Douglas Fir Larch, and Hemlock Fir.⁴

US Mass Timber Suppliers in Relation to Dallas, Texas



Distance by Species to Dallas, Texas



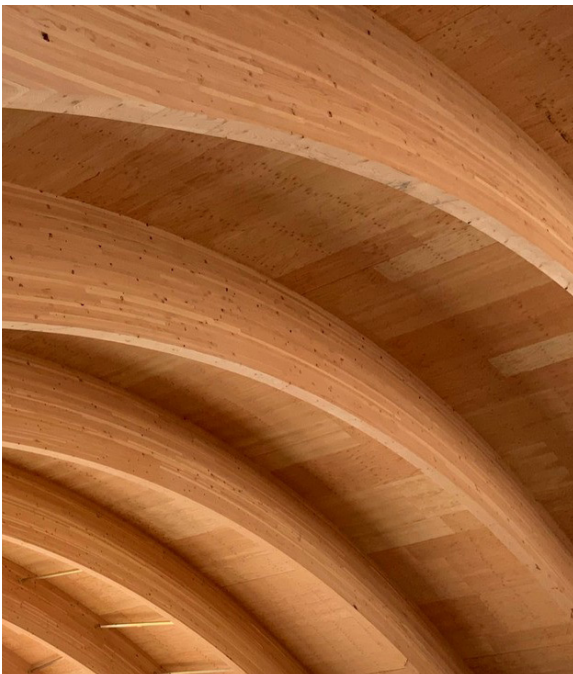
LABOR AND CONSTRUCTION

Labor sourcing is one of the biggest challenges within mass timber construction since it is a young industry and skilled laborers are sparse, residing mostly in the PNW region. Erica Spiritos, Vice President and Director of Preconstruction at Timberlab, mentions that for projects in central and southeastern U.S., the labor strategy involves relocating a system superintendent, foreman, and even a 4-6-person crew, from the West coast to oversee construction. According to her, there are two teams involved in the

process — the prefabrication kit of parts team, and the on-site assembly and construction team. A virtual coordination process occurs in all disciplines, to an accuracy of 1/16 of an inch, creating higher speeds of production and assembly, and increased accuracy on site. All trades are coordinated in the manufacturing process. This allows for up to a 25% increase in construction speed for the project.¹⁰

25% increase

in construction speed of mass timber compared to concrete¹⁰



Conclusion

This research showed several trends in the mass timber industry and construction typology, as well as several forecasts for what could be achieved by designing with mass timber as opposed to concrete. Mass timber structure can expect to be 1/5th the weight of concrete structure of the same size, while having the capability of sequestering 50% of its mass in carbon. Mass timber buildings typically show an increased speed of construction by 15-25%^{10,14} over traditional methods of construction. Additionally, the cost of on site labor is generally lower due to the prefabricated nature of mass timber. Within certain construction types, exposed structural elements could lead to overall cost savings in materiality. Finally, users could benefit from the warmth, relaxation, and direct connection to nature that an exposed mass timber structure brings, which increases user satisfaction and wellbeing.⁷

Prototype Case Study

Approach
Methodology



PROTOTYPE II INTERIOR (MASS TIMBER)
CORGAN

Prototype Design

Structural Design
Open-Office Layout
Mechanical Systems
Flooring
Structural Detailing
Acoustics

Impact

Prototype II Aesthetics
User Experience
Strategic Sourcing
Embodied Carbon Comparisons
Costing Exercise

Conclusion

Prototype Findings
Limitations

Acknowledgements

Additional Resources

References



Approach

As engineered wood becomes a more widely considered construction type in the Southeastern U.S., understanding its impact on the design process is key. Disciplines must coordinate fully before fabrication, meaning less waste, increased accuracy, and reclamation of time and fee as compared to other construction methodologies.

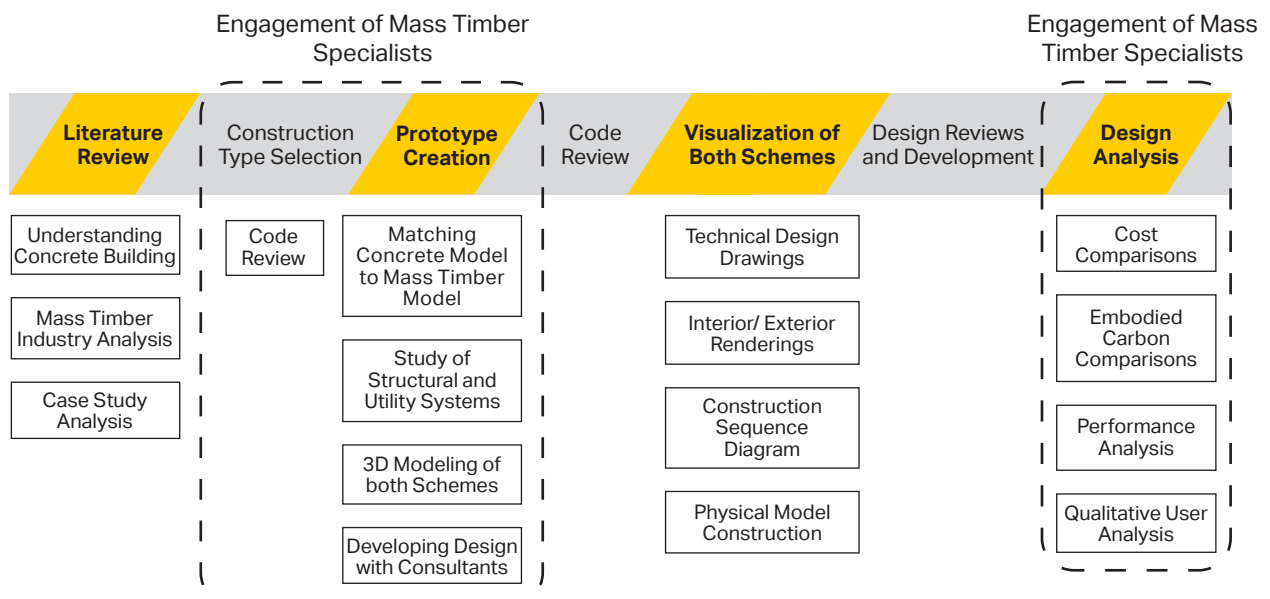
To better understand and directly compare the differences between concrete and mass timber construction, we designed two prototypical buildings. Our goal was to understand variability in cost, schedule, performance, aesthetics, and user experience between the two types of construction. This study also compared embodied and sequestered carbon, subassembly design, fire protection requirements, and material mass for either mass timber or concrete.

Methodology

This prototype investigation took a theoretical 216,000-square-foot, six-story office building in Dallas, Texas to understand the various implications of using mass timber structure as opposed to the same building design, but with concrete structure. The prototype design method involved a process of elimination, where all possible options were considered to inform decisions regarding occupancy, code, cost, and experience. Working with our expert collaborators, we identified optimal wood species, structural design, efficient operations, and mechanical systems to create

a mass timber prototype that meets the client's design goals for the existing concrete building with which we are comparing metrics. These partners also helped examine building codes and standards for each construction type.

In addition to design comparisons and optimizations, other areas of impact such as embodied carbon, material cost, sourcing, construction timeline, and user favorability were evaluated.



Prototype Design

The prototype design is based on an existing Corgan office building located in Austin, Texas, that is five-floors and the same materiality and composition. We took this design and created two six-story prototypes to maximize mass timber code requirements – a concrete design (Prototype I), and a mass timber design (Prototype II) – to directly compare their differences.



PROTOTYPE I - CONCRETE

PROTOTYPE II - MASS TIMBER

6 stories

6 stories

98' - 0" - No Max Height

85' - 0" Max

No Columns in Work Space
Core and Shell Only

Type B Structure
Fewer Columns in Workspace

24" x 36" Columns

12" x 24" Columns

30' - 0" Column Spacing at Perimeter

25' - 0" Column to Core and Column to Facade Spacing
30'-0" Column Spacing Perimeter

Type I-B
Fire Resistive Non-Combustible

Type IV-HT
Heavy Timber

4 ¾" C.I.P. Concrete Slab Flooring
Raised Access Floor, Concrete Tile
Carpet Tile Flooring

3.07" 3-Ply Cross-Laminated Timber Panel Flooring
Raised Access Floor, Concrete Tile
Under Floor Air Distribution

7" x 24" C.I.P. Pan Joist System
2'4 3/4" x 4' C.I.P. Concrete Beam System
Reinforced Concrete

6.75" x 24" Glulam Girder System
12.25" x 33" Glulam Beam System
Concealed Steel Connections

Gyp, Interior Walls and Ceilings
Lay-In Ceilings

Southern Yellow Pine Species
Exposed CLT Ceilings

Structural Design

To determine the mass timber structural system, we compared multiple species of timber and engineered wood by examining any code implications, spans and limitations, impacts to delivery, and overall cost. Ultimately, Southern Yellow Pine was identified as the ideal species for the CLT panel flooring and glulam beams.

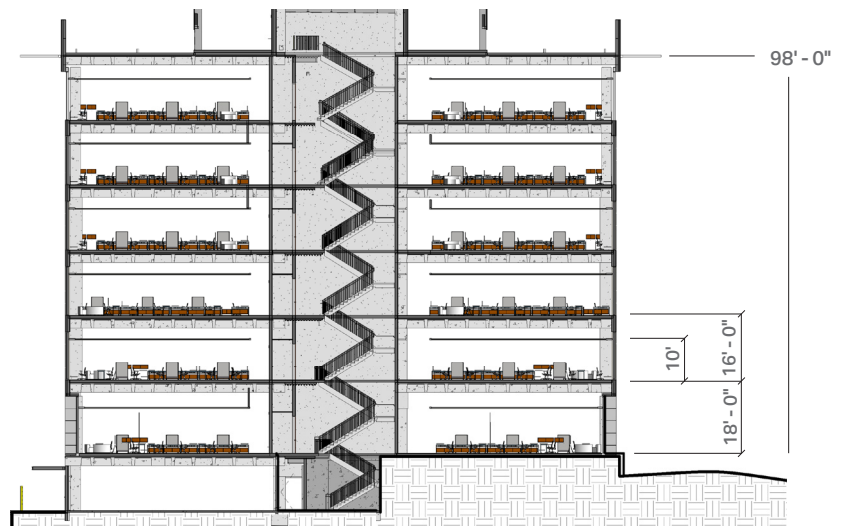
Cross-laminated timber has many advantages — it provides dimensional stability for the wood product, which allows for long prefabricated wide floor slabs, and long, single-story walls. CLT properties also include high in-plane, and out-of-plane strength and stiffness, giving it two-way shear strength like those of reinforced concrete. This increases the splitting resistance of CLT for certain types of connections. CLT panels can reach up to 10 feet wide and up to 60 feet long in panel dimensions, which are governed by truck transport limitations.

13'

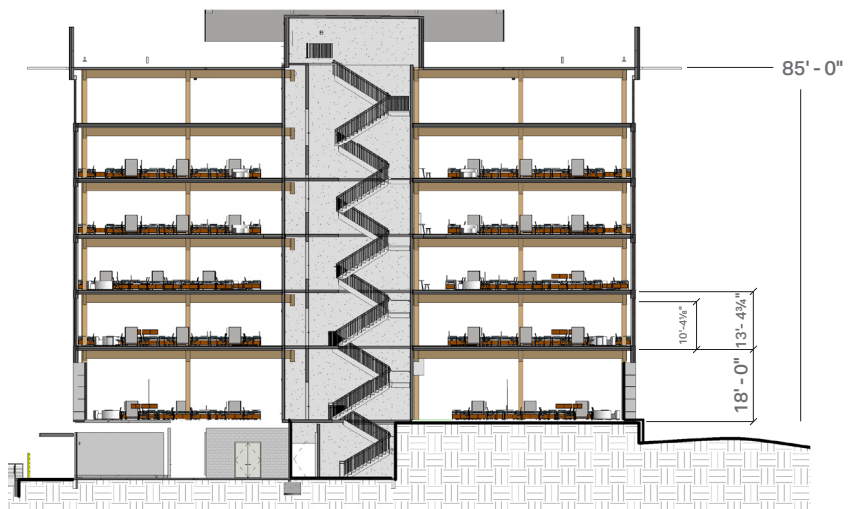
of building height were saved through mass timber construction

Amendments to the Dallas building code enable mass timber buildings to go beyond the Type IV heavy timber designation and be labeled as Type IV -A, -B, or -C. In alignment with IBC 2021, each designation has various fire resistance ratings and surface protection requirements due to their taller height allowances for exposed timber. The 2024 Dallas building code is anticipated to allow for Type IV-B 12 story buildings to have 100% exposed timber, testifying to the direction that code councils are heading towards in increasing tall timber building allowances. For the purposes of this study, Type IV-HT construction was used.

Both designs incorporate an 18'-0" ground floor height. However, to achieve a floor-to-ceiling height of 10'-0" in the upper levels of the building, Prototype I required a 16'-0" floor-floor height, while Prototype II only requires a 13'-4 3/4" floor-to-floor height to achieve a 10'-4 1/8" floor-to-girder height. As compared to Prototype II, the increased floor-to-floor height necessary for the concrete construction of Prototype I adds an additional 13'-0" of height.



PROTOTYPE I SECTION : CONCRETE



PROTOTYPE II SECTION: MASS TIMBER

15'-0" SPACING FROM CORE

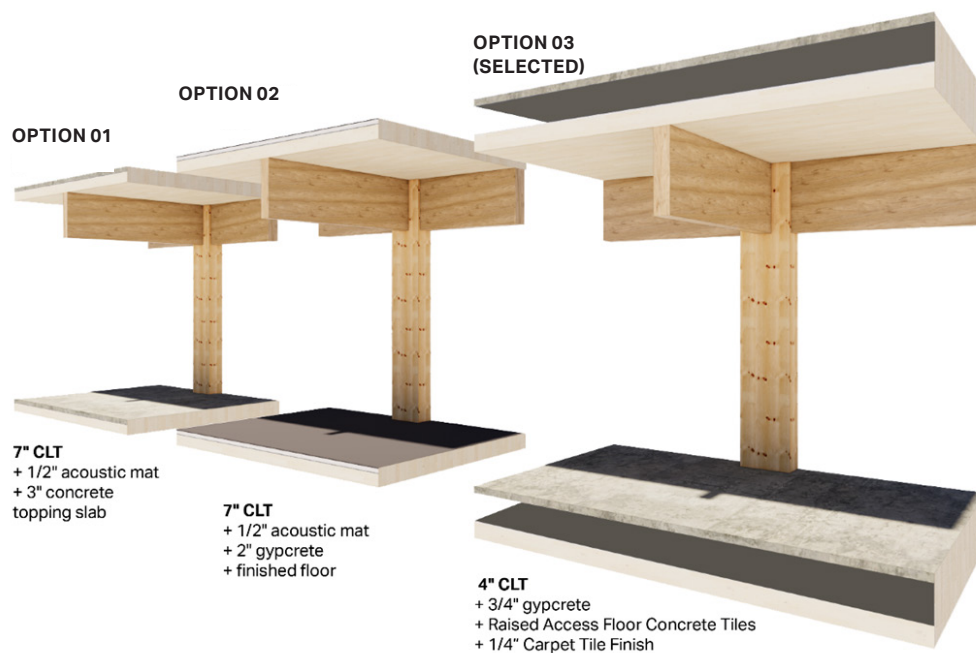
20'-0" SPACING FROM CORE

25'-0" SPACING FROM CORE



When designing Prototype II, center columns were required throughout the 50' -0" span as compared to the open floor plan possible in Prototype I. Various structural sizing and spacing options were studied alongside furniture plans to determine ideal spacing. After examining how 15'-0", 20'-0", and 25'-0" column spacing affects furniture layouts and beam depth — which ultimately influences maximum head clearance for users — the centered 25'-0" spacing was determined as ideal for an enhanced user experience, optimized seat count, and consistent structural members.

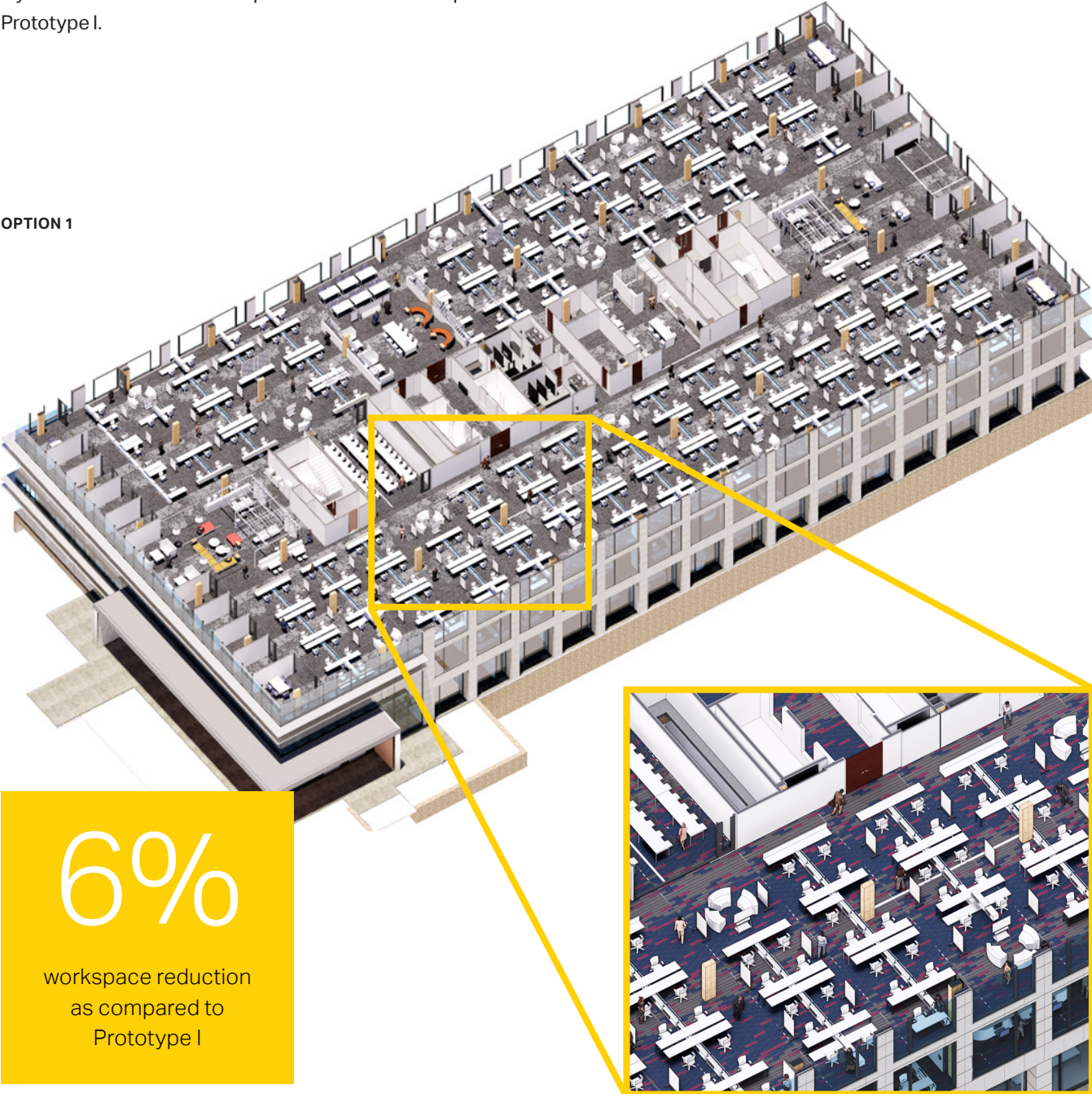
Next, the study examined floor assembly components, their itemized-layered, and overall-aggregated thicknesses, each crucial characteristics to calculating accurate floor-to-floor heights, impacting the overall building height. In this design, we selected "Option 3" — a raised concrete tile floor over CLT panels.



Open-Office Layout

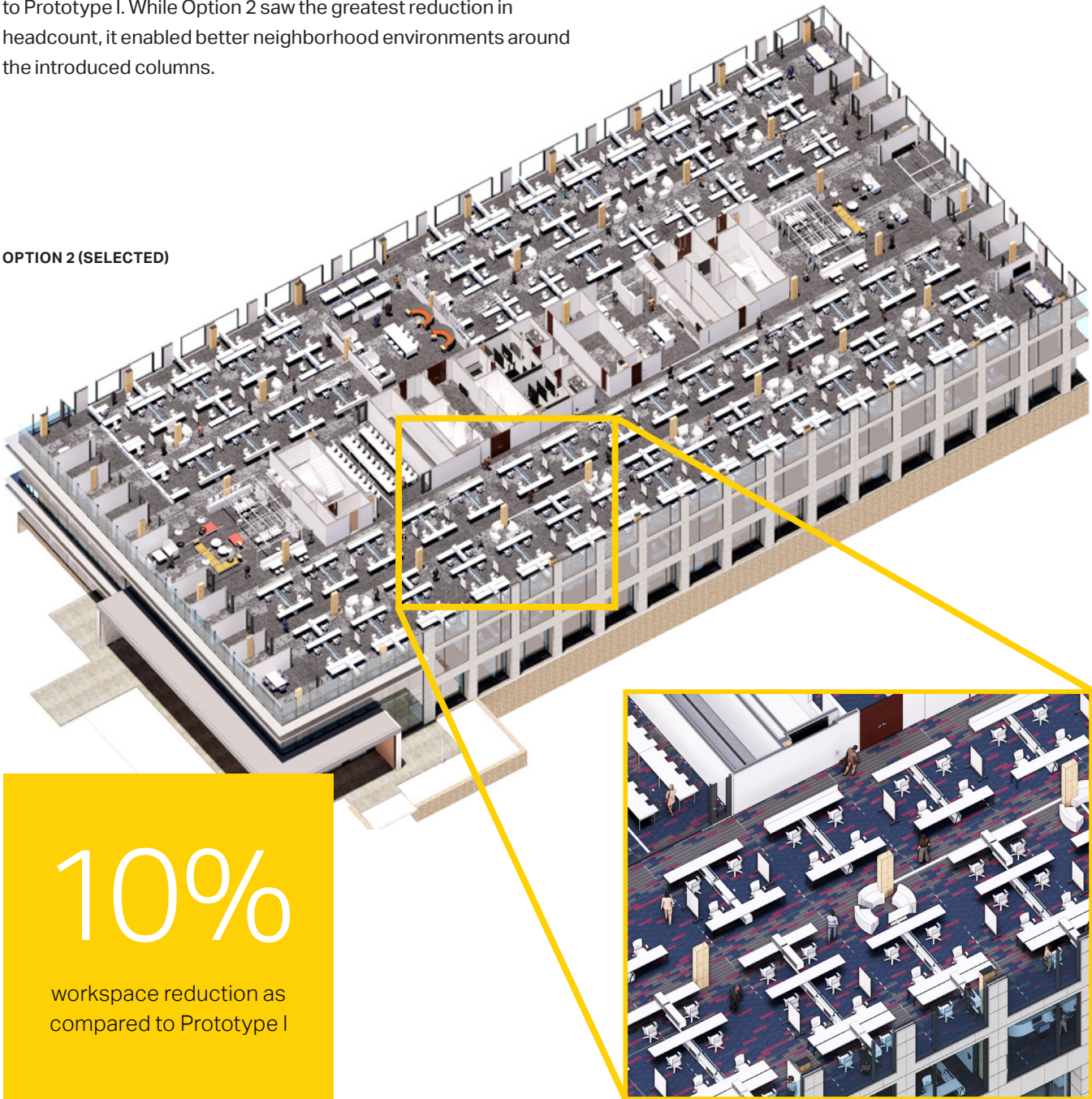
When designing the furniture layout in Prototype II, we aimed to keep the schemes as similar as possible and minimize head count reduction due to the interfering structural layout. In our first option, which focused on maximizing headcount, the modified furniture layout resulted in a 6% workspace reduction as compared to Prototype I.

OPTION 1



The second option for Prototype II's furniture layout aimed to still maximize headcount as much as possible, while creating a better employee experience by providing additional adjacent break out space, that served as a buffer between quiet and active zones. The resulting layout sees a 10% workspace reduction as compared to Prototype I. While Option 2 saw the greatest reduction in headcount, it enabled better neighborhood environments around the introduced columns.

OPTION 2 (SELECTED)



10%

workspace reduction as compared to Prototype I

Mechanical Systems

Of the three floor assemblies compared, a raised floor assembly provided optimal air distribution through an underfloor air distribution system (UFAD) along with combined data and electricity.

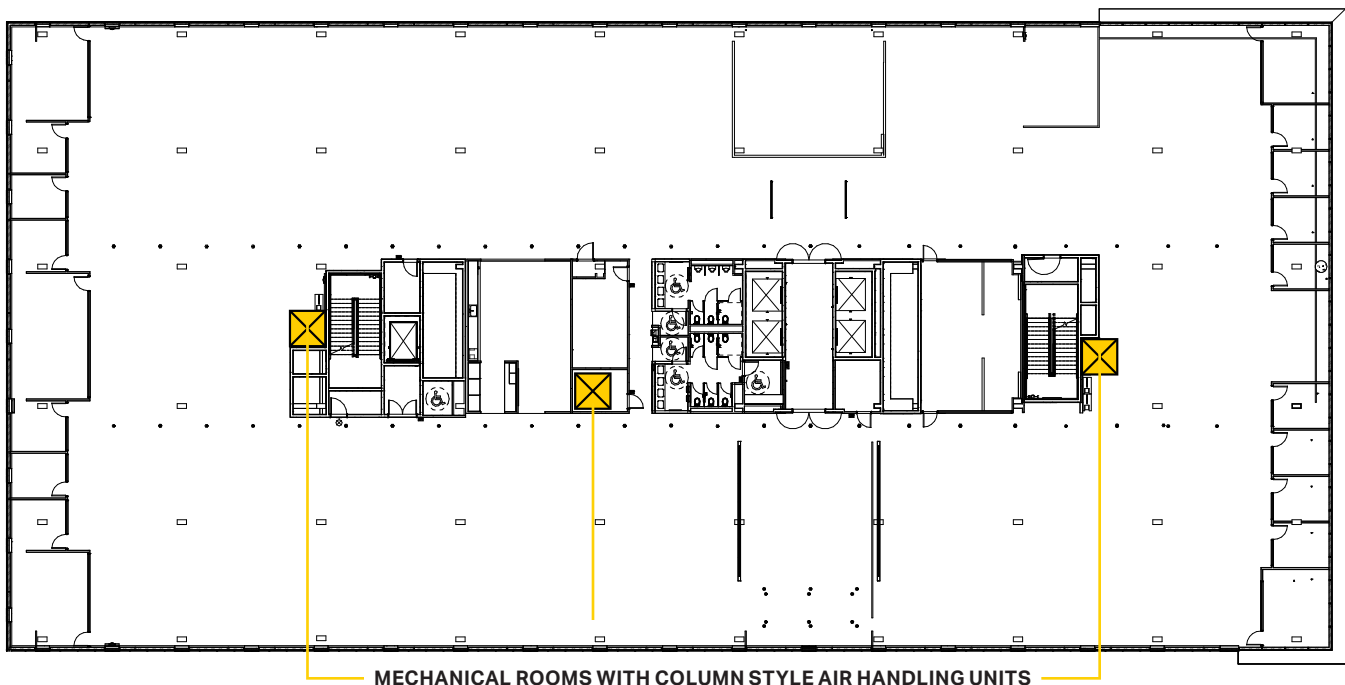
Each of the building's floor plates is about 37,000 square feet of UFAD x 1.25 = 46,250 total CFM (cubic feet per minute). The use of perimeter electric troughs with non-condensing cooling coils using the "Leaving cold water temperature" (LWT) from the air towers (55-57 °F) as "Entering hot water temperature" (EWT) to the perimeter troughs is recommended.

For this design, our partner, Texas Air Systems, recommended the following mechanical equipment: (3) towers at 15,500 CFM Each (QT-35E-72-150 model) per floor (72" W x 72" L x 149"H — this sizing could change).

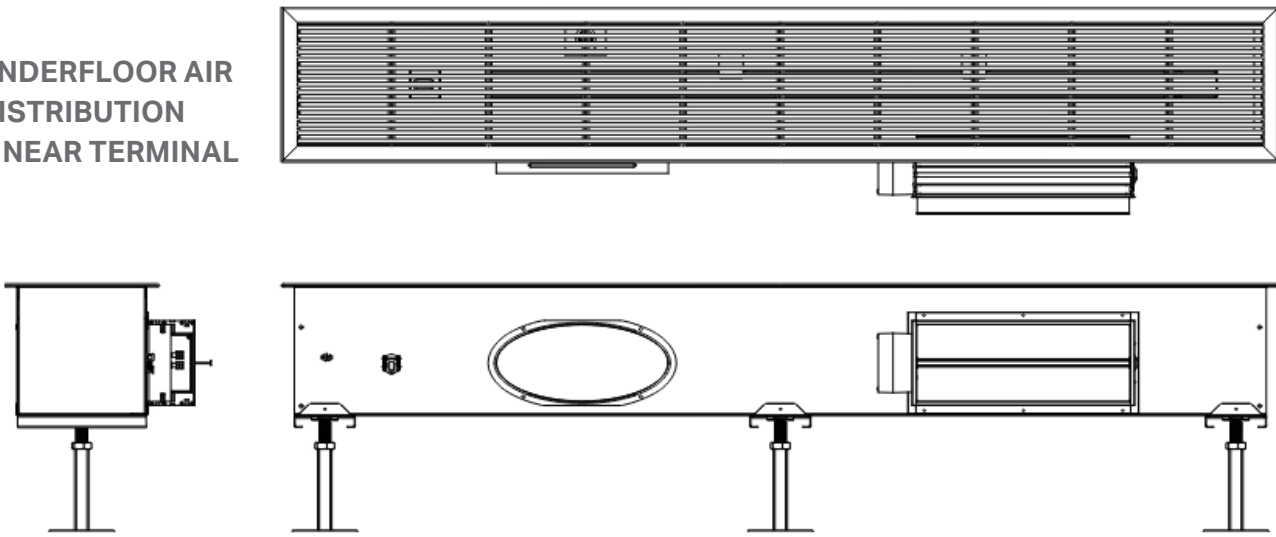
OTHER RECOMMENDED EQUIPMENT:

1. **Interior 8" Wireless VAV diffusers**
 (265) 8" round wireless VAV (Variable Air Volume) aluminum diffusers and associated T-stats and wiring per floor. 8" rounds cover 140 SF of UFAD so 37,000 SF/140 SF = 265 diffusers per floor.
2. **Perimeter Linear Terminals with Electric Heat and Supplemental Cooling Coils**
 (70) CLEMIT and CLE aluminum VAV cooling perimeter troughs with hydronic cooling (cooling for about 50% of the troughs) per floor. Perimeter is 285 x 135 = 840 LF. 60% active or ~ 500 LF of active trough which would be ~70 active troughs per floor (non-continuous grille).
3. **Ventilation Unit(s)**
 Located on the roof and serving each mechanical shaft vertically.
4. **Chillers**
 VSD air-cooled chillers would be the most probable for this size building.

TYPICAL MECHANICAL ROOMS



UNDERFLOOR AIR DISTRIBUTION LINEAR TERMINAL

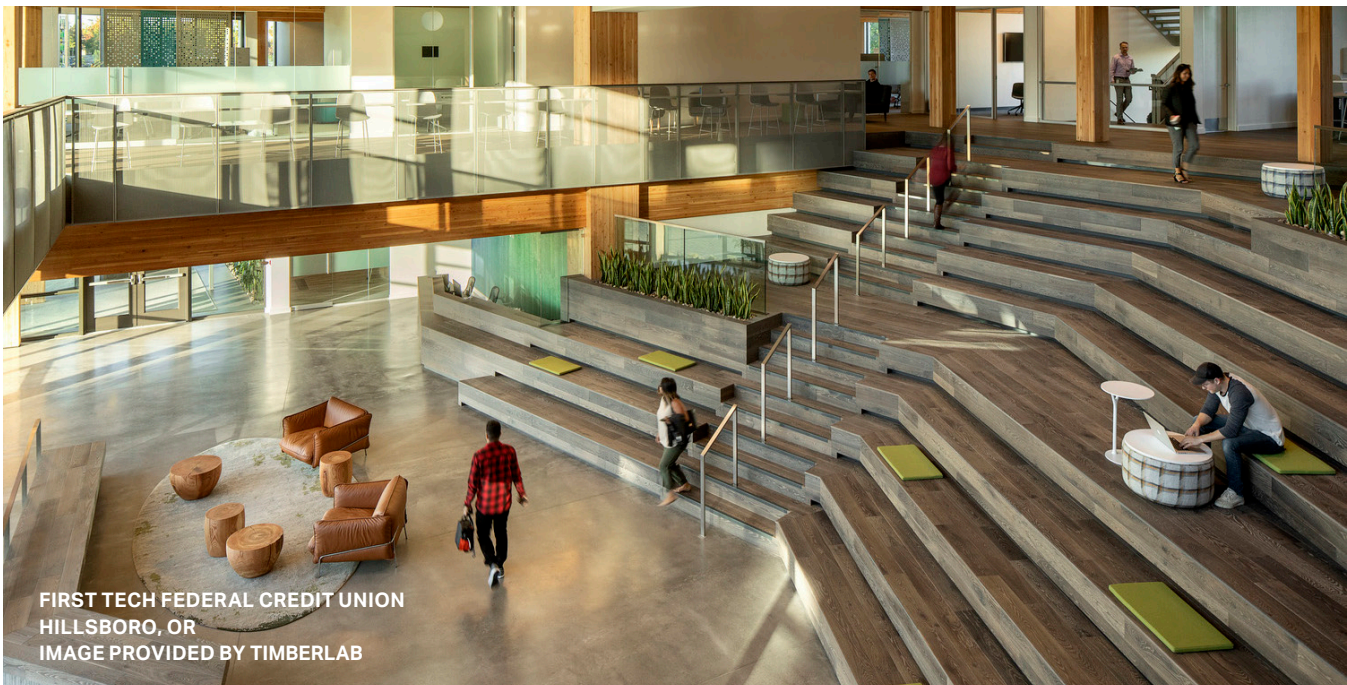


Source: AirFixture Underfloor Air Distribution Linear Terminal Specification

Flooring

For Prototype II's raised floor system, Tate's ConCore® 1,000 raised access floor panel is intended for commercial applications and is engineered to meet Tate Standards per CISCA testing methods. Each 2' x 2' panel is drilled directly onto the 4" CLT panel, topped off with carpet tile. The tiles are adjustable to accommodate the underfloor air linear terminals and the personal comfort diffusers as well.

The key performance characteristics of these raised access floor tiles include steel welded construction filled with a cementitious core material, protected from corrosion by an epoxy paint finish, made of non-combustible material (Class A flame spread rating), and weighing 7.5 lbs/SF per panel.



FIRST TECH FEDERAL CREDIT UNION
HILLSBORO, OR
IMAGE PROVIDED BY TIMBERLAB

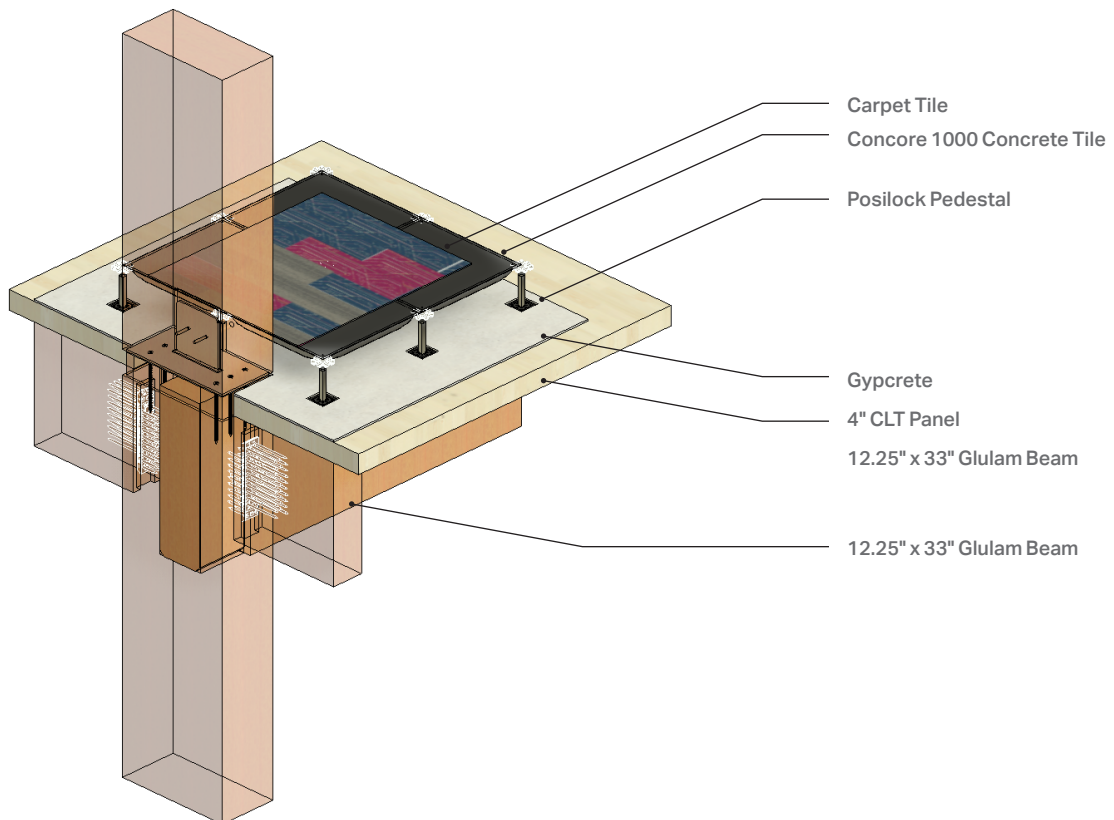
Structural Detailing

The typical floor-to-floor column and beam/girder-to-column connections in Prototype II are designed to be either steel or notched connections. The column sits on a splice plate at the CLT panel level, and the girders use a Ricon S Beam Hangar. The beam is notched into the column, however connections vary based on location in the building and proximity to the core. Connections nearest to the core utilize a custom steel splice plate/ beam flange combination piece.

In reference to IBC 2021 code 602.1 and 704.1, structural members and assemblies shall have a fire-resistance rating not less than the requirements of the type of construction highlighted in Table 601.¹ Exposed connections (Class 2 and Class 3-exposed) require additional protection to meet fire-rating requirements.² Class 1 and Class 3-concealed steel connections are inherently fire resistant, and do not need additional fire protection, creating costs savings for owners.² Each of the various structural connections in the project across multiple locations were studied.



CLT FLOOR ASSEMBLY AT COLUMN, BEAM, AND GIRDER CONNECTION



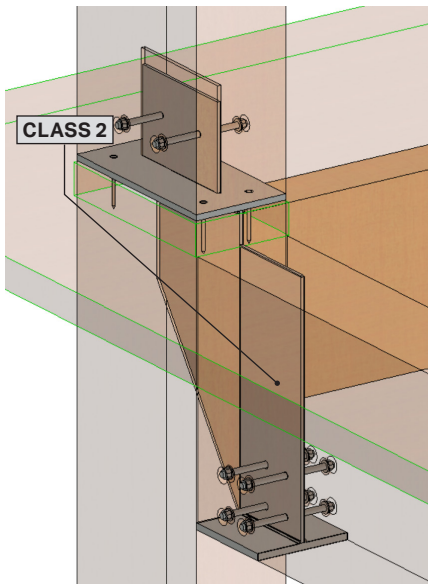


CONNECTION CLASS IN RELATION TO FIRE RATING

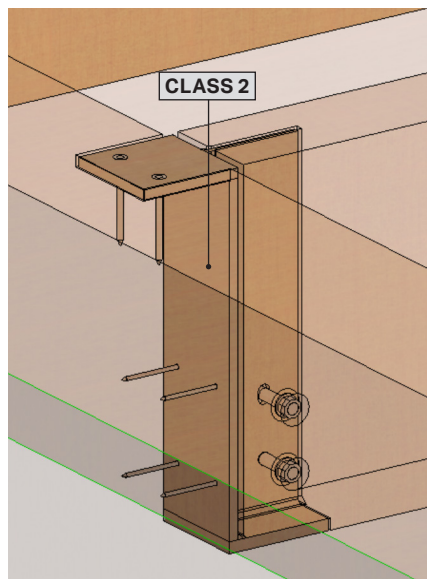
CONNECTIONS CLASS	FIRE RESISTANCE
CLASS 1	May be inherently fire resistant according to NDS calculations
CLASS 2	Requires additional protection to meet fire-rating requirements
CLASS 3	Tested fire-resistance rating (as specified by manufacturer)
CLASS 3 PROPRIETARY	Requires additional protection to meet fire-rating requirements

Adapted from Woodworks - Mass Timber Connections Paper²

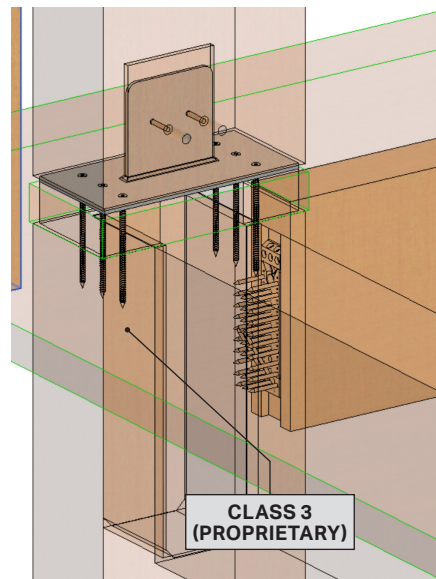
CLASS 3-CONCEALED STEEL CONNECTIONS IN PROTOTYPE II



Concealed column splice plate with custom beam flange connection



Concealed flange beam to girder connection

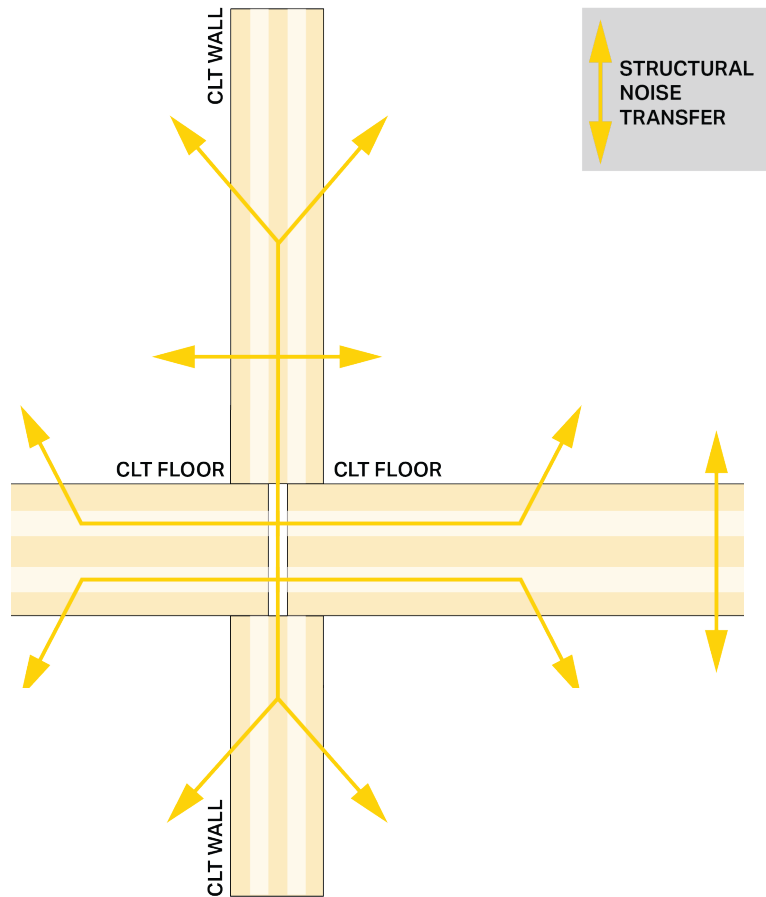


Concealed column splice plate over notched beam

Acoustics

Using CLT panels in design introduces some acoustical challenges, as they exhibit low STC (sound transmission class) and IIC (impact insulation class) ratings. In spaces where acoustical privacy is extremely important, such as office and educational environments, reaching an STC of 45-50 is most desirable.

The raised floor system enables the concealment of conduit and utilities; however, the exposed wood means that additional sound absorption panels would hide the CLT. By introducing a layer of gypcrete or a layer of acoustical matting topping the CLT panel, in addition to carpet tiles, the desired sound absorption could be achieved.



Adapted from: Pliteq® – Mass Timber Acoustical Design Guide³

Type IV-C/HT

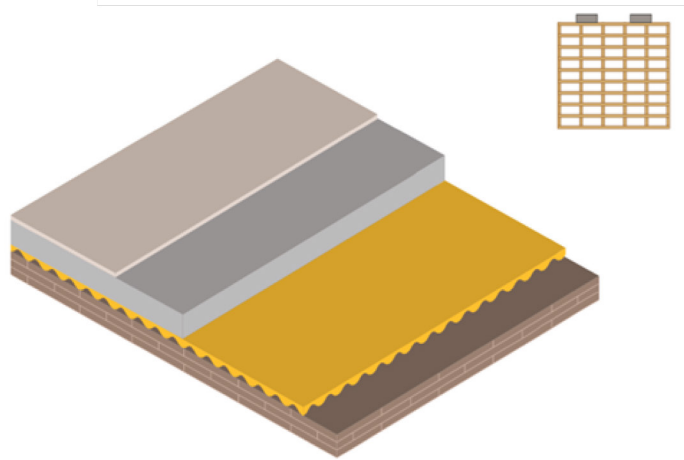
3-Ply CLT

- Carpet Tile
- 2" Concrete Tile
- GenieMat Acoustical Pad
- 4" CLT (3-Ply)

52
STC

50
IIC

K7453.05



Adapted from: Pliteq® – Mass Timber Acoustical Design Guide³

SOUND TRANSMISSION CLASS (STC) RATING — OFFICE FUNCTIONS

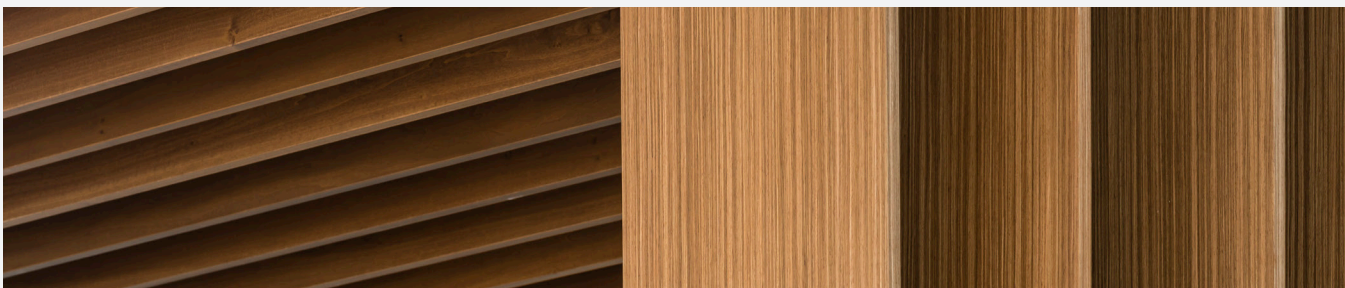
TYPE	ADJACENCIES	STC
Standard Office	Standard Office	45
Executive Office	Executive Office	50
Conference Room	Conference Room	50
	Admin, Admissions	45
Office or conference Room	Corridor	50
Mechanical Room	Occupied Area	60

Adapted from: Target STCs —Recommended STC Ratings on Demising & Corridor Walls⁴

ACOUSTICALLY TESTED MASS TIMBER PANELS

MASS TIMBER PANEL	PANEL THICKNESS	STC RATING	IIC RATING
3-ply CLT Wall	3.07"	33	NA
5-ply CLT Wall	6.875"	38	NA
5-ply CLT Wall	5.1875"	39	22
5-ply CLT Wall	6.875"	41	25
7-ply CLT Wall	9.65"	44	30
	3 - 1/2" bare NLT	4-24 bare NLT	29
2 x 4 CLT Wall	1/4" with 3/4" plywood	with 3/4" plywood	NA
	5 - 1/2" bare NLT	6 - 22 bare NLT	31
2 x 6 CLT Wall	1/4" with 3/4" plywood	with 3/4" plywood	NA
2 x 6 NLT floor + 1/2" plywood	6" with 1/2" plywood	34	33

Adapted from: Inventory of Acoustically Tested Mass Timber Assemblies⁵



Impact

Prototype II Aesthetics

Exposing the Mass Timber structure dramatically enhances the look and feel of the interior space in Prototype II. Additionally, concealed steel connections were used to meet fire codes while least impacting overall aesthetics.

While there is a cost saving benefit to exposing the mass timber construction due to reducing overall floor-to-floor height in comparison to Prototype I, the added warmth also enhances the occupant experience. Additionally, views remain unobstructed, even with the additional center column-line.

The sense of warmth continues throughout from large open spaces to compartmentalized from conference rooms and executive offices. Even the kitchen benefited from the addition of mass timber by bringing warmth to communal space. Carpets and acoustic padding helped bring the STC rating to 50.

In Prototype I there were no columns located in the middle of the floor. By adding a secondary walking corridor along the middle column line, the columns land in non-workspace areas. To further enhance this corridor, communal lounge meeting pods were relocated to buffer between the secondary pedestrian path and quiet workstations.



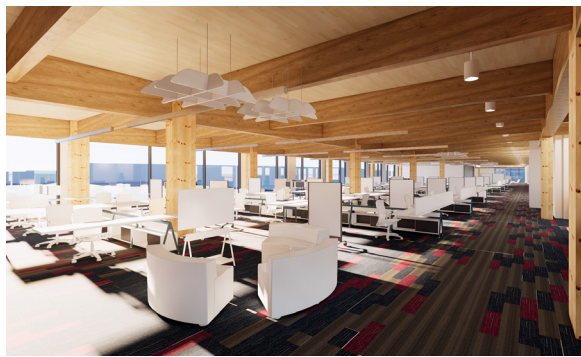
User Experience

To better understand user preferences in the office environment, we deployed a series of qualitative studies to compare our two prototypes. Each study led 15 participants through a virtual tour of one of the prototypes, providing comparative data from 30 total participants.

Participants shared feedback on their willingness to work in the space, and overall favorability of the design. They also ranked spatial qualities such as lighting, openness, color, warmth, and design aesthetic for their specific prototype. Each group of participants were also asked to rank eight different wood species in order of preference.

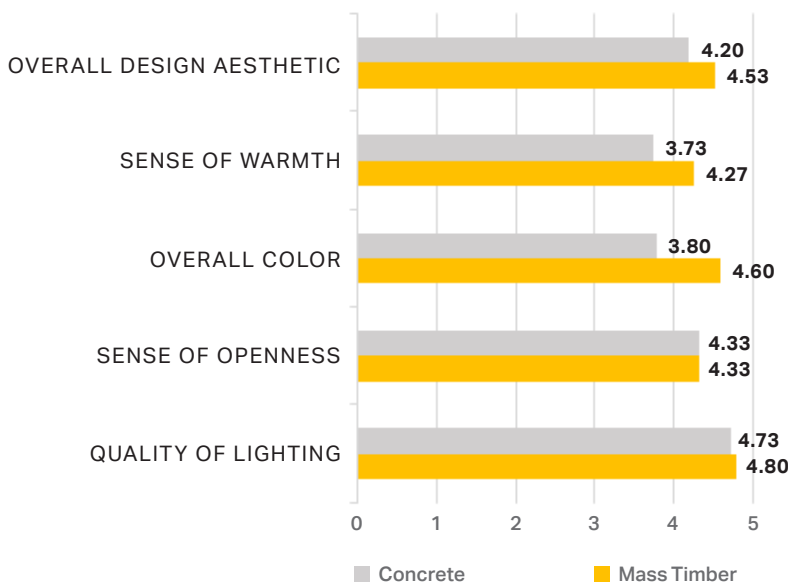


PROTOTYPE I
(CONCRETE)



PROTOTYPE II
(MASS TIMBER)

WOOD TYPE PREFERENCE

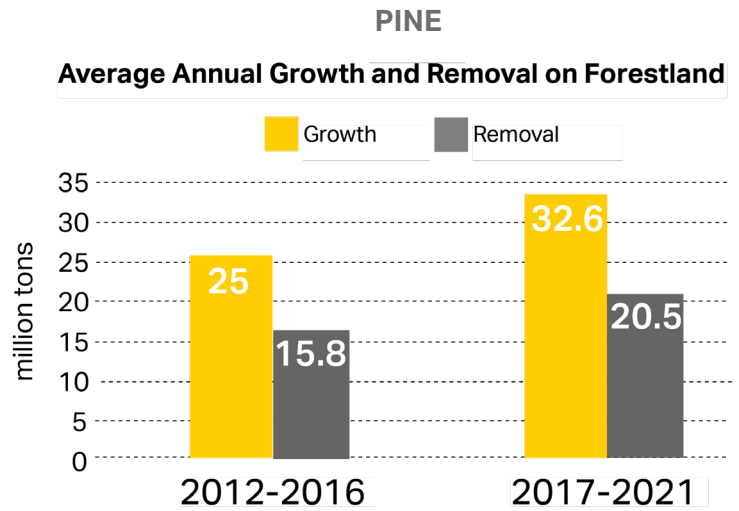


Top Takeaways

1. User willingness to work in the office space increased in Prototype II compared to Prototype I.
2. Users prefer the overall design of mass timber – especially for its sense of warmth and overall color.
3. While Prototype II required additional beams, it did not impact users' sense of openness in the space.

Building Performance

A top concern of using mass timber in construction is the potential impact on forest regrowth. Considering Prototype II is located in Dallas, Texas, the best and most likely source would be Arkansas Pine. When we look at the annual growth and removal in Arkansas forestland, we see that growth outpaces removal annually.



Adapted from: Arkansas Department of Agriculture 2023⁶

By sourcing material from a forest in Arkansas, the timber used in this prototypical design will regrow across the forest in:

32 minutes

AT A RATE OF 1,987 TONS / 62 TONS PER MINUTE⁶
(MASS/RATE OF GROWTH)

CARBON SEQUESTRATION POTENTIAL

In Prototype II, an analysis of the structural mass concluded that the potential carbon sequestered throughout the design was 901,288 kgCO₂e. This includes carbon sequestered in the timber columns (151,500 kg), CLT floor panels (929,864 kg) and structural framing (721,212 kg).

PROTOTYPE II

1,802,757
kg

Total Timber Mass

901,288
kgCO₂e

Total Carbon Sequestered

Embodied Carbon Comparisons

To understand both prototypes' embodied carbon, material baselines from the Carbon Leadership Forum 2021 (CLF) were considered and the Revit plugin, EC3, was used to transfer 3D model elements from Revit into a live carbon calculation tool. The CLF baselines (high, medium, and low) are intended to give a rough order of magnitude of embodied carbon impacts per category reflecting the significant variability of product manufacturing and uncertainty of life cycle assessment (LCA) data available.

"The CLF Baseline — the only figure of the three that currently applies to the EC3 tool — represents a "conservative" or "high" estimate for embodied carbon in building elements. This value is intended to give a rough order of magnitude of embodied carbon impacts and represents a high estimate of the embodied carbon footprint of an element if no effort is made to choose a low-carbon alternative. This CLF Baseline number can be considered a good starting point for developing carbon caps or reductions. For categories in which there are sufficient product-specific EPDs, the CLF Baseline is tied to the 80th percentile value of the category (i.e., the point where 80% of the results have values below this number) as represented in the EC3 database of published, peer-reviewed EPD results. The CLF Baseline is shown within the EC3 tool for all public categories."

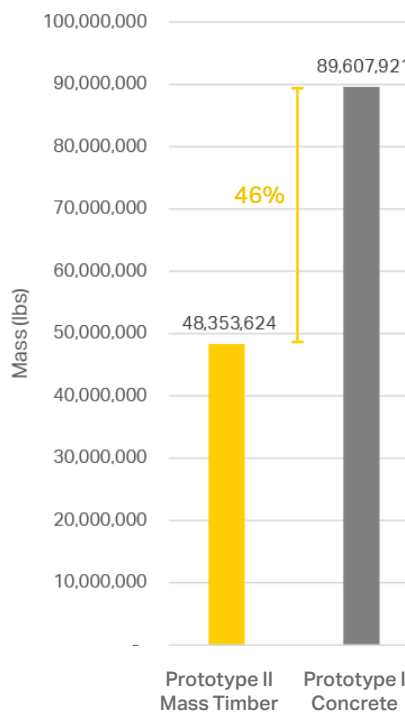
- EC3 Material Baselines⁷

An analysis of the total embodied carbon for each of the two prototypes showed a 19% lower amount of embodied carbon in the mass timber design and a 46% lower amount of material weight.

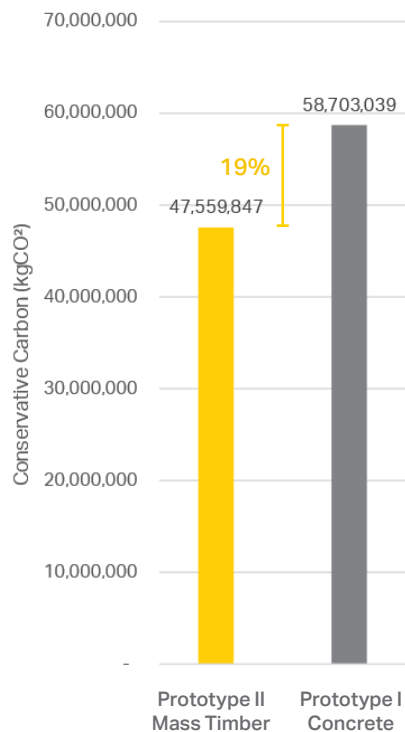
For Prototype II, the mass was 214 lbs/ft² and the embodied carbon was 210kg CO₂e/ft².

See Study Limitations on page 51 for information on current carbon calculation practices.

TOTAL MASS OF MATERIALS



TOTAL EMBODIED CARBON



When looking at embodied carbon compared across both prototypes overall, and by material and subassembly divisions, we see the difference between each with a per-unit understanding. The great difference in mass was found in the structural framing, with the mass timber beams and girders being 93% lighter than the concrete pan joists.

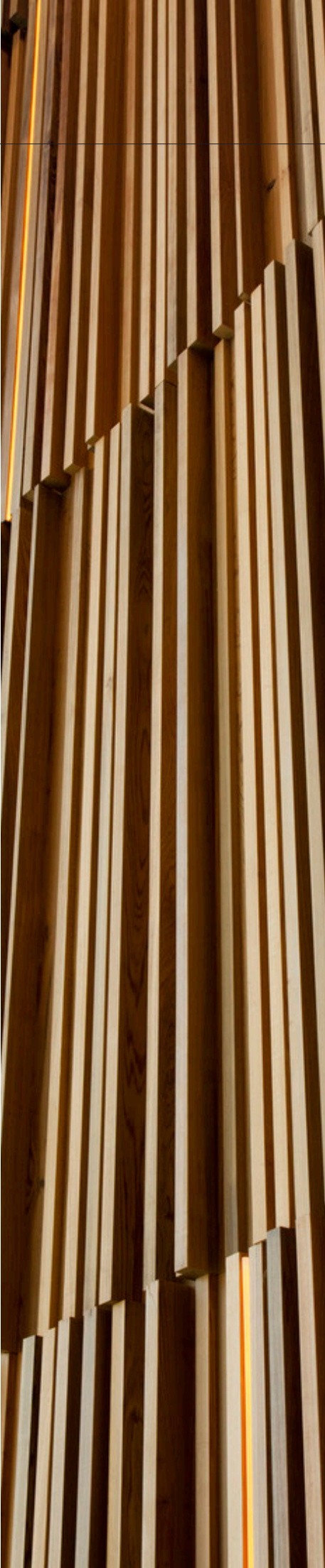
SUBASSEMBLY REDUCTIONS	MASS REDUCTION	CARBON REDUCTION
STRUCTURAL FRAMING	93% lighter	94% less carbon
STRUCTURAL COLUMNS	66% lighter	85% less carbon
STRUCTURAL FLOORING	54% lighter	48% less carbon

By comparing the various subassemblies, their materials, and their embodied carbon properties, it is evident that walls with steel stud framing and the steel rebar in concrete shear walls and foundations contributed the highest amounts of embodied carbon, due to the manufacturing process.

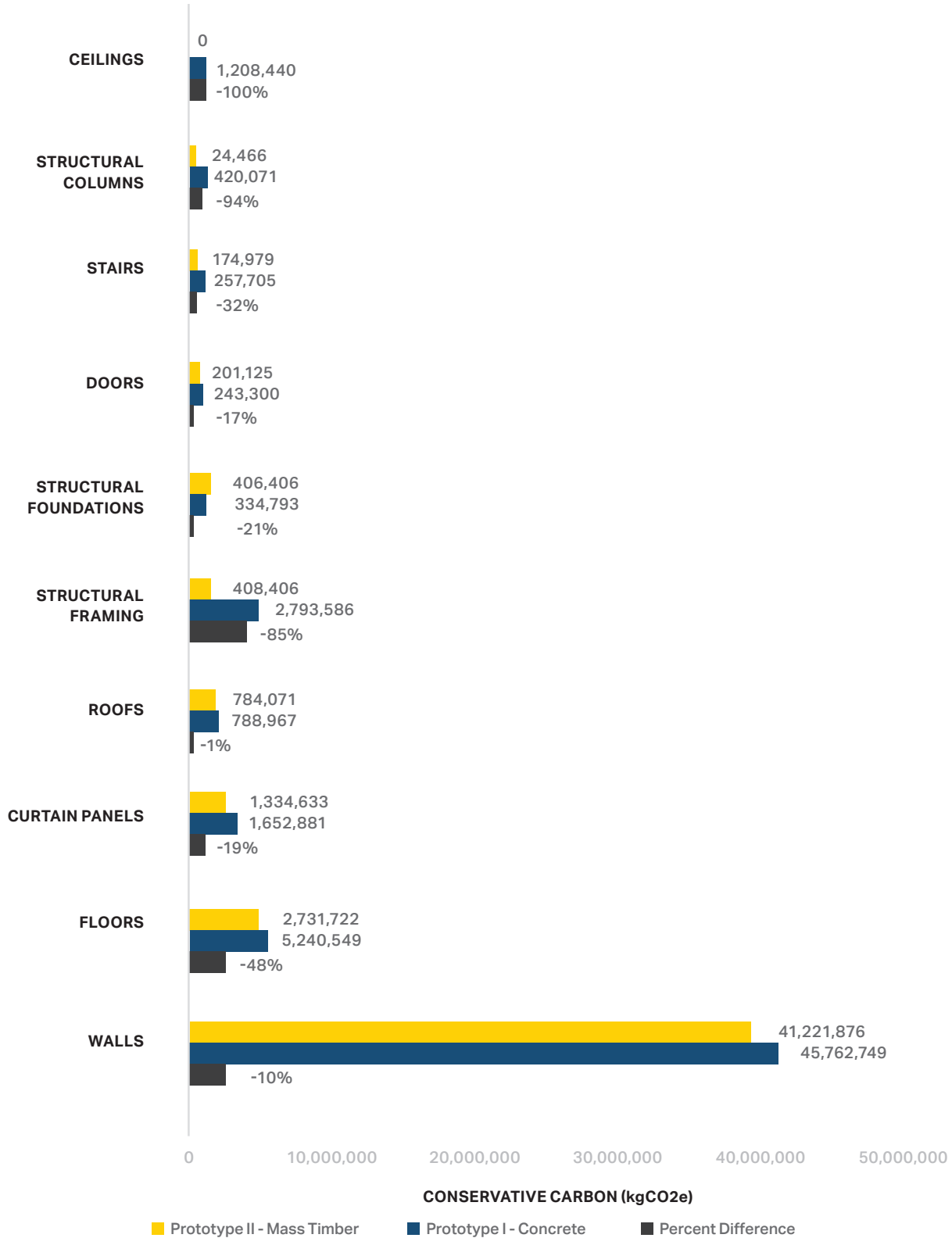
When analyzing each material separately, the highest amount of embodied carbon was seen in the cold-formed steel elements (38,674,283 kgCO2e), which was significantly larger than other materials. Ready Mix concrete was the second-highest carbon exhibitor among the prototypes, due to its manufacturing process.

Looking at the material mass of building elements per prototype resulted in the highest difference in Ready Mix concrete, Cast-In-Place concrete decking, and steel rebar.

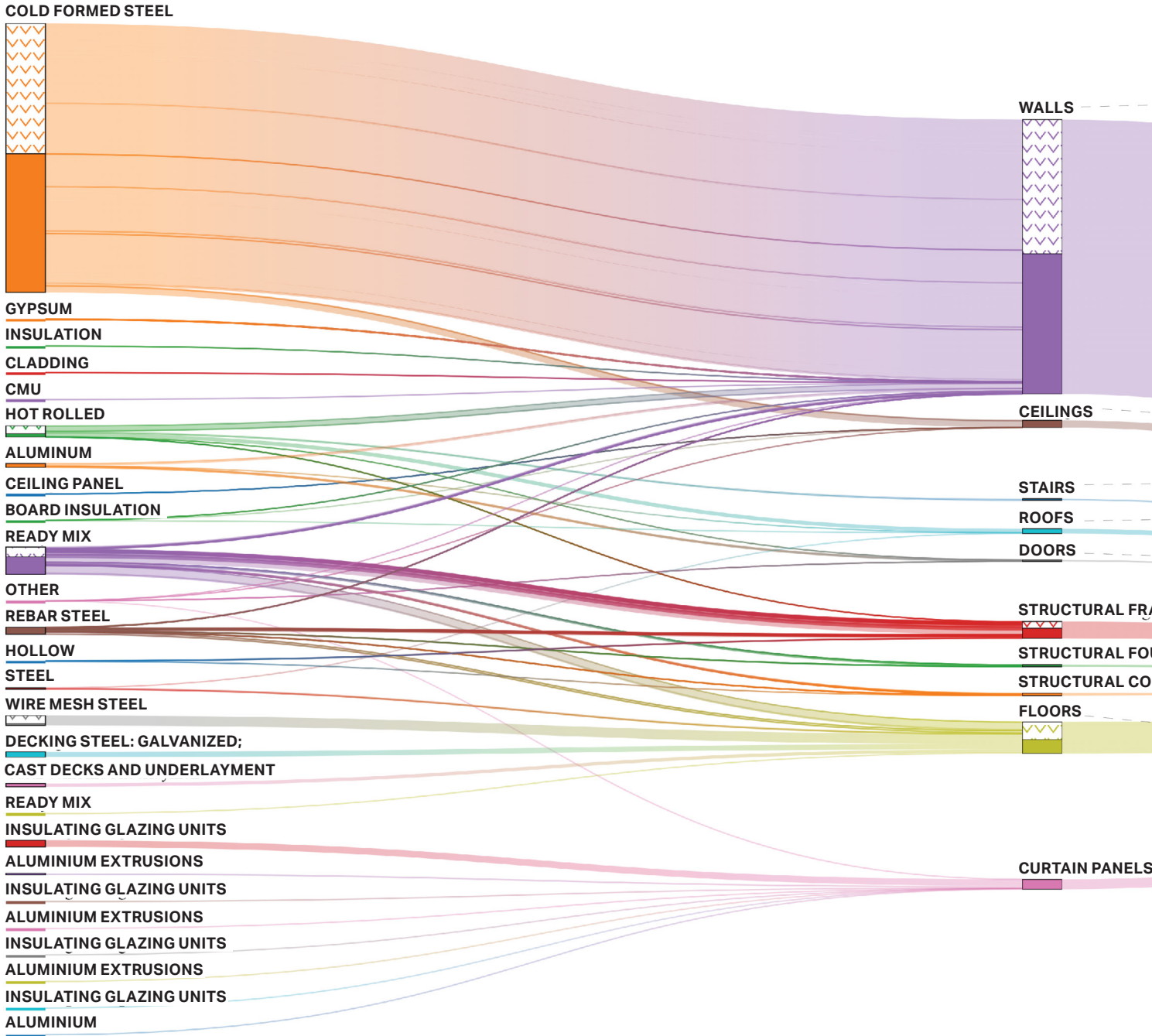
By comparing the hierarchy of subassemblies by magnitude of abundance, Prototype II showed the largest variation in the walls, structural framing, floors, and structural column weights, respectively. This is due to the use of steel or concrete in those subassemblies, which drive up the mass of those elements. The differential between each prototype is due to the reduction in building height in Prototype II, since mass timber did not need as much clearance for floor assemblies on each floor.



EMBODIED CARBON COMPARISON PER SUBASSEMBLY

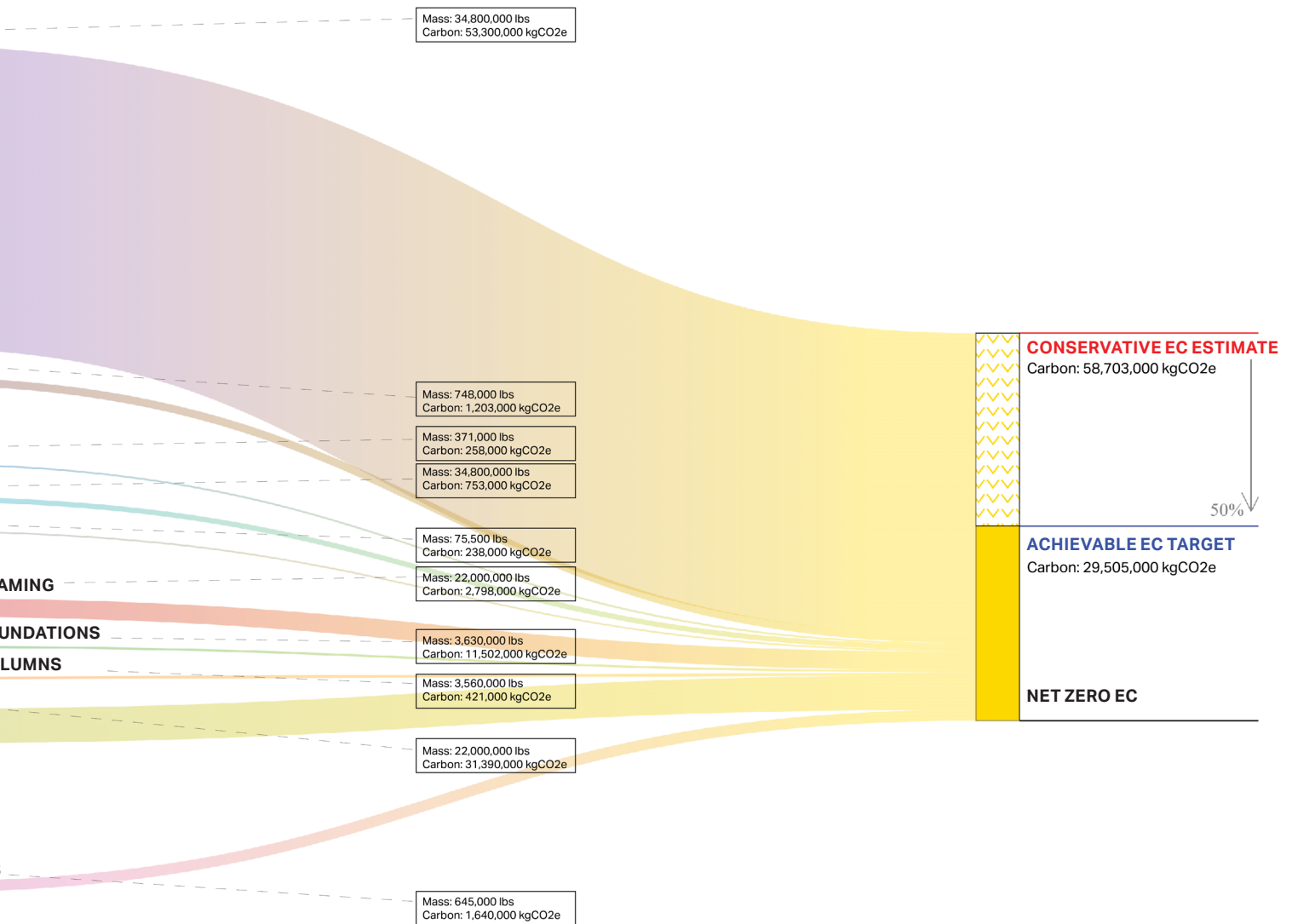


PROTOTYPE I (CONCRETE)

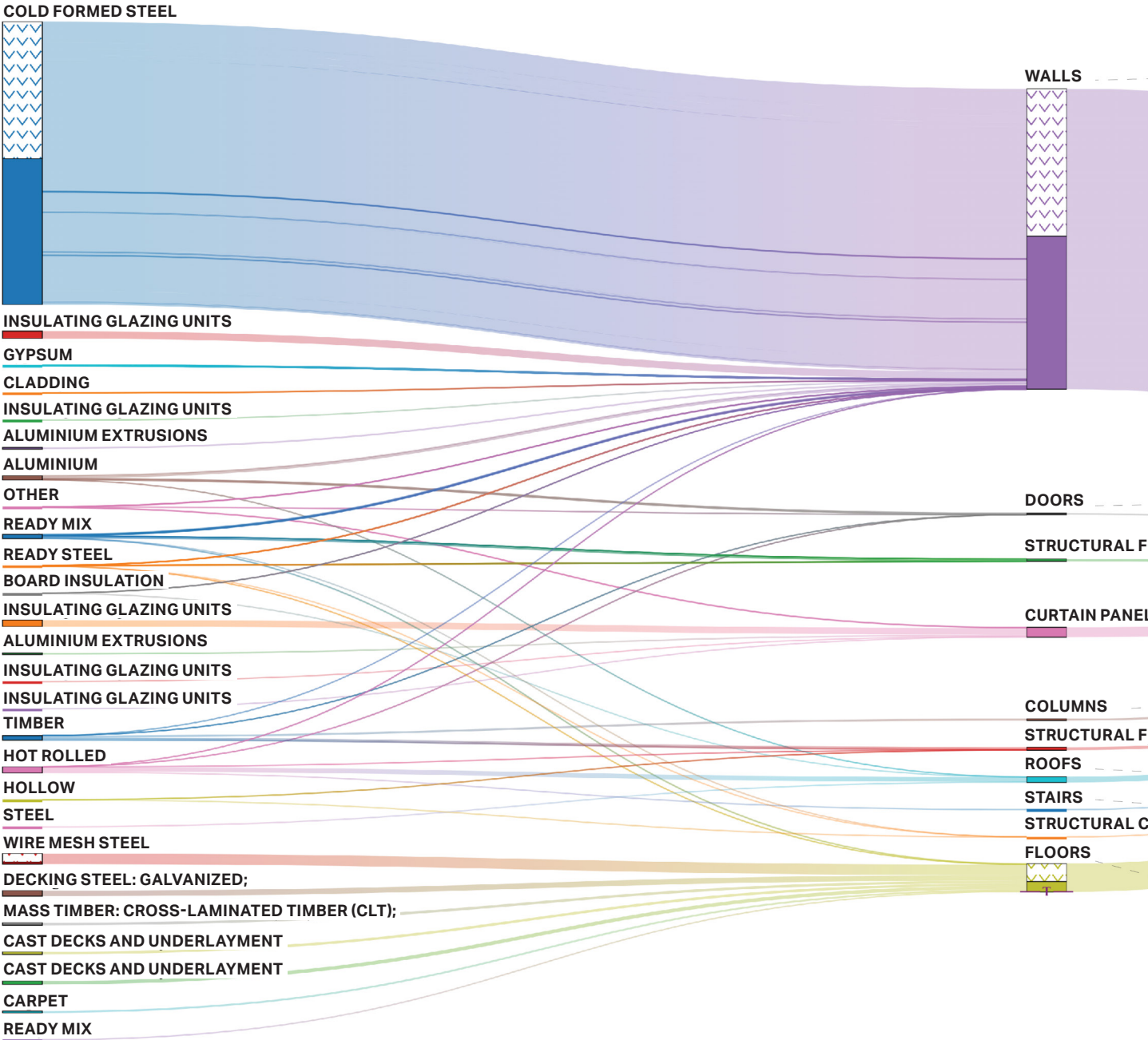


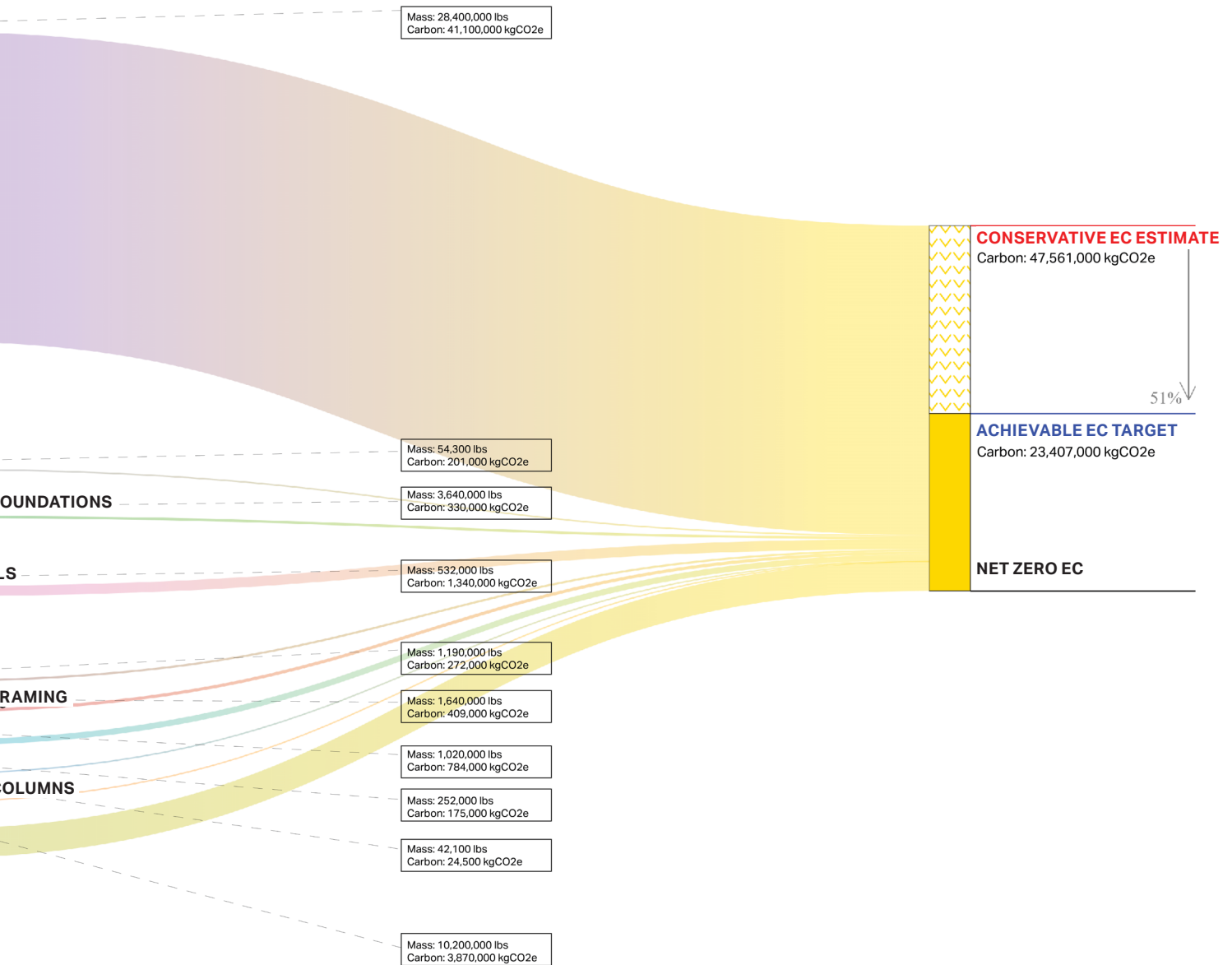
CARBON SANKEY CHART

Sankey Charts helped show how the carbon flows from material to assembly type, and then how that compares in overall construction. In both prototypes, the highest amount of carbon originates from cold formed steel studs in wall construction, which contribute to 45.7 million kgCO₂e in concrete and 41 million kgCO₂e in mass timber.



PROTOTYPE II — MASS TIMBER CONSTRUCTION





Costing Exercise

As advised by partners at Timberlab, schedules for mass timber typically are more efficient (15-25%) based on their most recent projects. This is caused by the front-end, multidisciplinary coordination in the prefabrication process. For this specific prototype comparison, whose schedule was determined for Dallas, Texas in early 2023, there is an expected 6% timeline savings.

Our study found that designing with mass timber is advantageous for speed of installation and reduced on-site labor requirements, as it's mostly crane-based construction. Concrete, on the other hand, is more time and labor intensive and requires creating cast-in-place formwork. Pouring concrete is a time-sensitive process that requires the curing of the material, which may not occur at the same rate depending on the season, humidity, and temperature of the climate on site.

Swinerton's costing experts conducted a full financial analysis of both Prototypes I (concrete) and Prototype II (mass timber) to investigate price and timeline differences

for this scenario. This evaluation discovered that Prototype II (mass timber) would see an increased cost due to several compounding factors. According to Timberlab's estimate, the mass timber structure was estimated to be 69\$/SF as of February 2023. The more expensive structural system was the mass timber system, totaling \$15.7 million, while the concrete amounted to \$12.6 million.

Areas that may see additional material cost savings in Prototype II (mass timber) include procurement and contracting, general requirements, concrete, masonry, thermal and moisture protection, and openings. Prototype II also did not require as much concrete, reducing formwork costs and had a reduced building height (13 feet total). The required foundations would also likely be less, since the weight of mass timber framing is much lighter than concrete. Additionally, the mass timber core was designed to be composed of steel moment frames with gypsum board shaft walls, while the other scheme would be composed of concrete shear walls, increasing the finish costs as compared to the other design scheme.



COSTING

	BUILDING COST	STRUCTURAL COST	TIMELINE
CONCRETE	\$55.4 mil	\$12.6 mil	18.3 months
MASS TIMBER	\$62.2 mil	\$15.7 mil	17 months
	+12.3% than concrete		-6% time savings



Conclusion

Findings from Prototype Comparison

BENEFITS OF MASS TIMBER CONSTRUCTION

- Updates in code are allowing for the exposure of structural wood in taller buildings. This study focused on Type IV-HT (**85 feet max. height for up to six stories**), to maximize current mass timber code (IBC 2021) with concealed steel connections.¹
- Combining building systems through a raised access floor with under floor air distribution allows for both an exposed CLT panel ceiling (reduced cost and improved aesthetics) and creates a more efficient floor-to-floor height (**16' to 13'-4 3/4" floor-to-floor height**), reducing overall building height (**13.3% reduction**).
- Required structural materials can be regrown quickly (32 minutes in an Arkansas forest) and help to reduce the overall building mass (**46% reduction**).⁶
- The impact of mass timber materials also reduces the total sequestered carbon and embodied carbon (**19% reduction**) of the overall construction.
- Due to multidisciplinary coordination earlier in the project, there is often a quicker construction timeline when building with mass timber (**6% reduction**).

LIMITATIONS OF MASS TIMBER CONSTRUCTION

- Mass timber is more limited compared to concrete on how far it can span, requiring additional columns. Comparison of beam depth for headroom needs to be considered to determine best column spacing (**25' in Prototype II**).
- Additional columns in a space also reduce potential head count by limiting furniture layouts (**6-10% reduction in office seats**).
- The cost of using mass timber is variable based on when it is purchased and owner design decisions, it can be more expensive than other structural materials (**12.3% more expensive overall than concrete in comparison**).
- While mass timber projects are becoming more common across the U.S., there is still a lack of wide-spread skilled mass timber labor to construct projects. This often leads to increased project budgets and schedules when estimating.



Study Limitations

In this prototype comparison analysis, we focused on design development and overall performance and impact. Other areas for future exploration could include insurance considerations, hybrid structural schemes, and periodic updates to the rapidly changing code for mass timber.

While our report uses industry-wide accepted values, methodologies, and tools to calculate embodied carbon for mass timber, we recognize that there are also larger questions around carbon accounting processes for wood harvesting and manufacturing and the assumption that mass timber is inherently carbon neutral. These accounting methodologies require further assessment and validation. It is not the intent of our study to address such issues.

Insurance considerations were not deeply studied in this case; however, it is a major influence in the policies created around the adoption of mass timber. These considerations may include, EoW (escape of water/flooding), mold, glue denaturing, fungus, delamination, combustible voids, swelling, toppling of structure, rot, and endangerment of surrounding areas.⁸ However, design interventions can help address some of these considerations. For example, having concrete core/shaft walls and a second-floor concrete slab can significantly help limit the spread of fire within a mass timber building during construction. Additionally the use of gypcrete in floor assemblies helps prevent the spread of fire from floor to floor as well.

We anticipate over the next decade that as the popularity of mass timber increases, this construction typology will become increasingly affordable and attractive as an option for the industry. We also foresee a rapid evolution in the mass timber industry, with increased leasing velocity from prospective tenants, increased ESG alignment of goals through its usage, and resiliency in market downturns.

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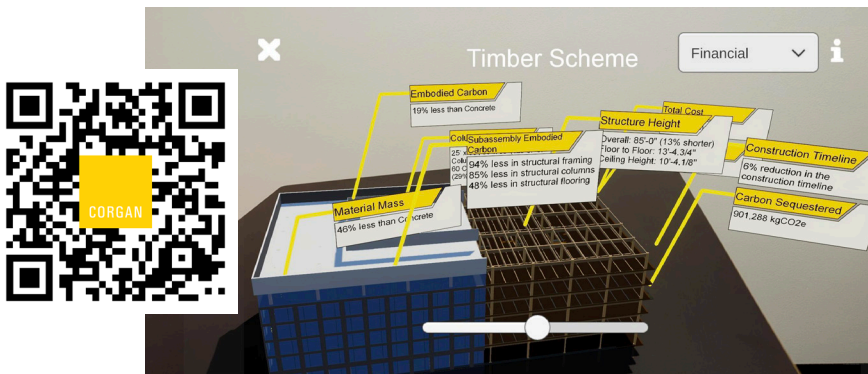
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Additional Resources



AR TABLETOP MODEL

In our Corgan AR app, we have added an AR tabletop model where viewers can experience both our mass timber and concrete prototypes, use the slider tool to take a section view, and read information pop-ups to share financial, sustainable, and experiential outcomes from this comparison analysis.

PROTOTYPE VIRTUAL TOUR

Through an internet browser on any device, jump into the interior of both our mass timber and concrete prototypes to experience the different design qualities and read information pop-ups to share outcomes from this comparison analysis.



PHYSICAL MODEL

To study the mass timber structural system of our prototype, we designed and built a half scale physical model of the connection. The model will serve as an educational tool for designers and clients to understand how elements work in the primary structure and how connections occur. The model is located in Corgan's Dallas headquarters.

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