Sustainable Parking Garages in Wood

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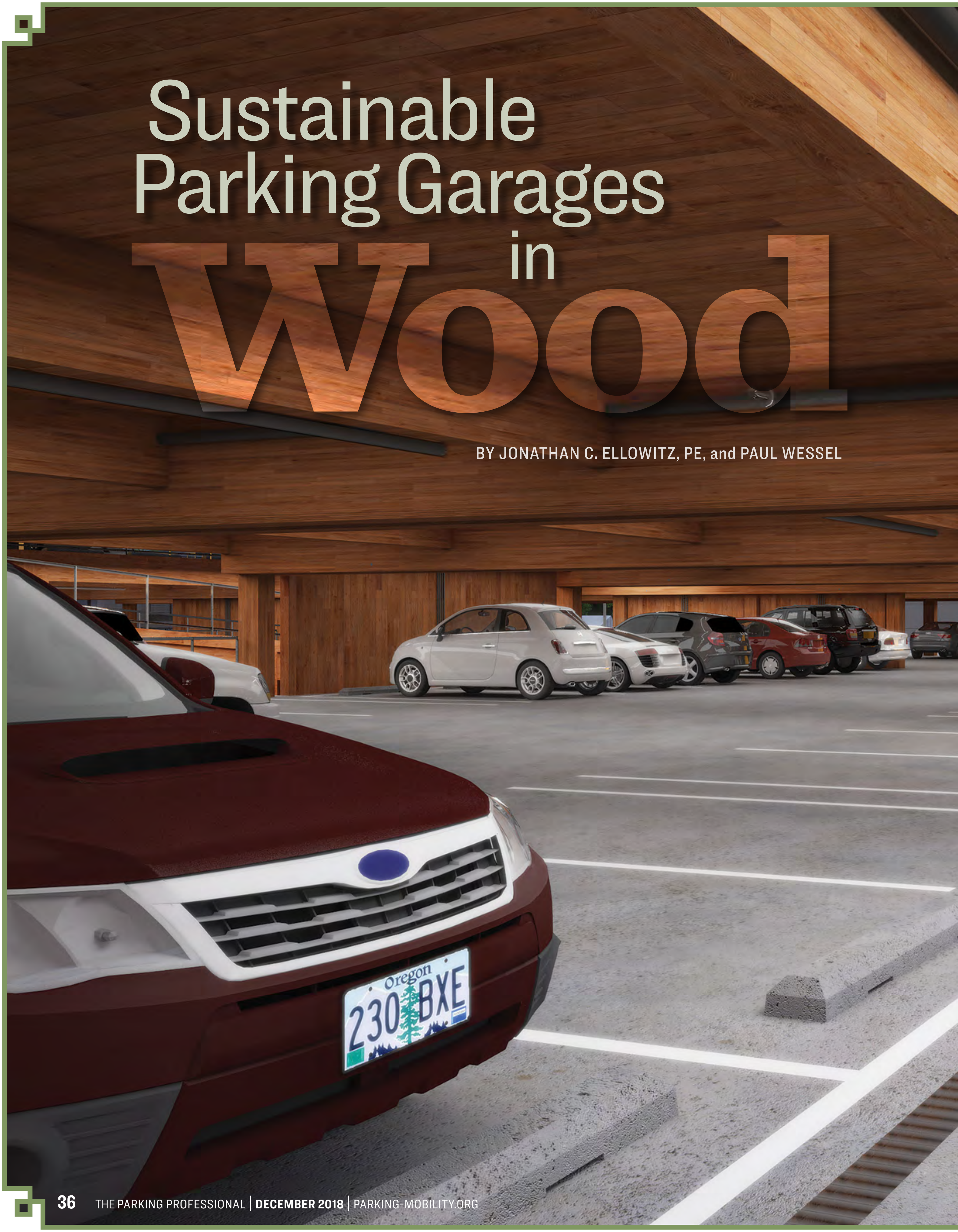


RENDERINGS BY: **H3D** (www.h3dviz.com)
CLIENT: **City of Springfield, Oregon**
ARCHITECT: **SRG Partnership, Inc**
STRUCTURAL ENGINEER: **KPFF**

The Intergovernmental Panel on Climate Change (IPCC) recently issued a report on the startling extent of worldwide climate change.[1] It presents serious challenges, but also opportunities for innovation. Construction activities contribute to greenhouse gas emissions, and building industry professionals are positioned to help mitigate the causes of climate change. Manufactured wood products such as cross-laminated timber (CLT) and glued-laminated lumber (glulam) can be used effectively to render parking garage construction more sustainable.

Typical parking garages are built of steel and reinforced concrete, leading to high embodied carbon profiles. Manufacturing and transporting reinforced concrete and steel members produces greenhouse gas emissions that contribute to climate change.

In contrast to steel and reinforced concrete, engineered lumber building materials sequester carbon, and their fabrication and transport produce a significantly lower magnitude of greenhouse gas emissions. The carbon emissions offset by using sawn lumber and manufactured wood products in a single building project could counter the effects of hundreds of cars from the road or power a home for hundreds of years.[2]

Engineered wood such as CLT and glulam rival typical building materials for strength while removing carbon from the atmosphere and reducing greenhouse gas emissions during the construction process. Their engineering properties are appropriate for parking structures with spans and ceiling heights, competitive with typical concrete or hybrid concrete-steel parking deck systems.

Engineered wood takes center stage in this structure, softening the look and performing vital functions at the same time.

The Carbon Footprint

Concrete is the product of cement mixed with water, sand, gravel, and other admixtures. Cement is manufactured and is the primary contributor to the embodied carbon of concrete. The cement production industry contributes to 5 percent of global CO2 emissions. Burning fossil fuels accounts for 40 percent of CO2 emissions from cement production when numerous natural materials are heated in a kiln at approximately 2700 degrees.[3] A chemical process results during which the cement ingredient calcium carbonate undergoes calcination, generating CO2 and accounting for 50 to 60 percent of CO2 emitted from cement production. The Environmental Protection Agency and the Portland Cement Association have found that approximately one ton of CO2 is emitted in the production of each ton of Portland cement[4]. Consideration should also be given to the embodied carbon of the mining and shipping of raw materials, concrete placement, and transportation of precast members—all processes that currently require the burning of fossil fuels.

Steel, for its part, is a highly recycled material. Like concrete, however, steel manufacture produces considerable greenhouse gas emissions. According to the American Iron and Steel Institute, 69 percent of steel in North America is recycled annually, and 95 percent of the water required for steel production is recycled[5]. Nonetheless, steel requires extreme heat for production; blast furnace emissions prevail as the main source of greenhouse gas emissions of steel production worldwide.[6] Like concrete, the steel industry contributes about 5 percent of global anthropogenic greenhouse gas emissions. Nearly two tons of CO2 are emitted in the production of a single ton of steel. A primary component of steel is the production of iron, which accounts for 90 percent of the steel industry's greenhouse gas emissions.[7] As with concrete, consideration should be given to the embodied carbon of the mining of iron ore necessary for steel production and of the transportation energy (emissions from fossil fuel burning) inherent in shipping steel to fabricators and construction sites.

Alternative Garage Construction

Parking garages benefit from diverse structural systems but largely experience a lack of variety in building materials. However they are popularly constructed, garages are normally reinforced concrete or steel, endowing them with an unfortunate carbon footprint and high embodied energy profile. As engineers, architects, constructors, developers, and governments imagine ways to transform the built environment to mitigate climate change, they should consider alternative materials and building methods for parking garages.

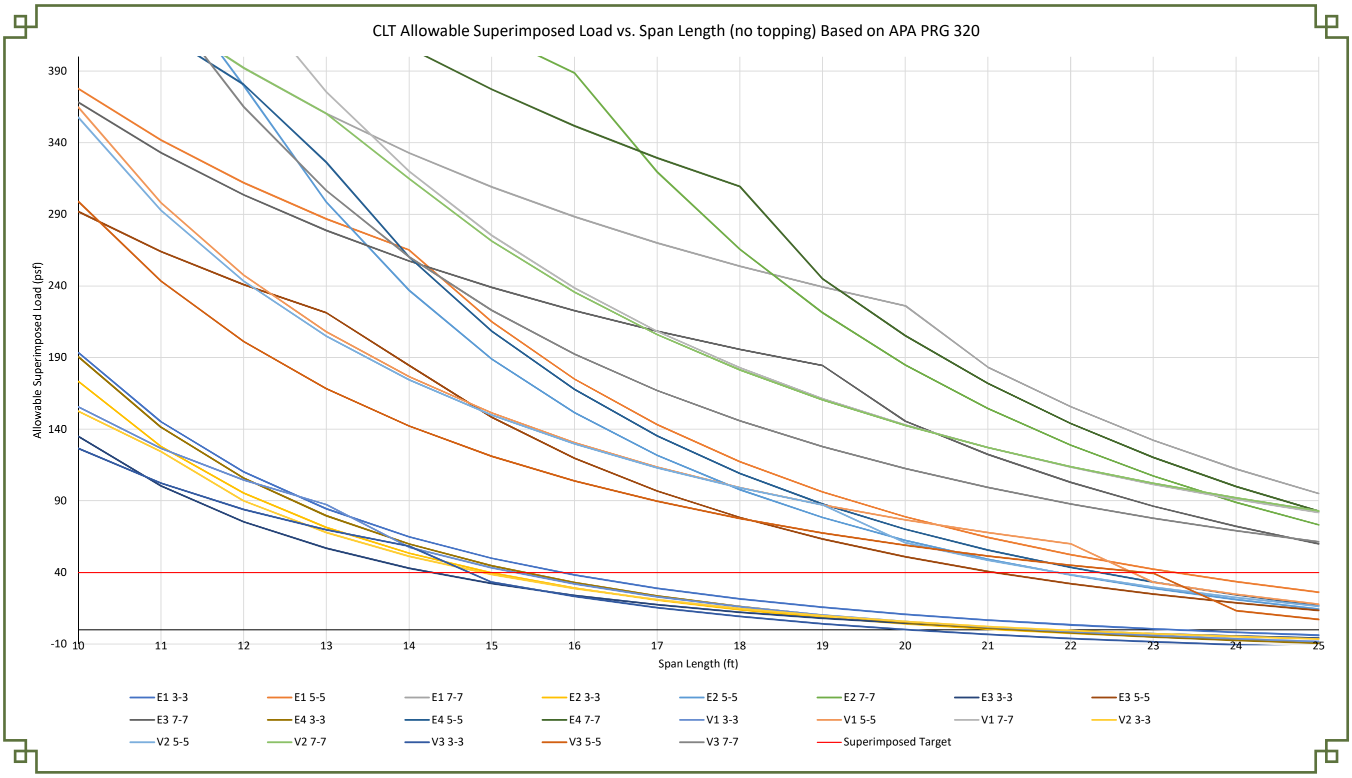


Figure 1: Superimposed Load vs. Span for CLT Layups

Engineered wood such as CLT and glulam presents the opportunity to greatly diminish a parking structure's embodied carbon emissions. The spans achieved with CLT and glulam beam floor-framing systems are competitive with typical hybrid steel and prestressed concrete garage systems. These wood products by their nature sequester carbon, and their wood is sourced from sustainable forestry. These characteristics can offset or negate the carbon footprint of wood-built garages, and constructing garages from wood could serve as part of a CO2 removal effort to mitigate climate change.

Wood sequesters carbon as it grows—trees absorb CO2 and release oxygen. Younger trees more aggressively store CO2, and the rate of storage decreases as trees age, culminating in the release of stored CO2 when mature trees die and decay. In the U.S., forests annually add new wood from young trees at twice the rate as the loss of wood from trees dying naturally. This results in a net carbon storage versus release. The IPCC has indicated that sustainable management of forest populations that increases new stocks while producing a yield of timber for building, energy, etc., can markedly mitigate the effects of climate change. A good use for this timber yield is construction materials. Because 50 percent of the dry weight of wood consists of carbon, building with wood stores carbon that would otherwise be released into the atmosphere.

Wood stores enough carbon to offset the greenhouse gas emissions of its production, transport, and installation. Manufacturing wood products takes significantly less energy than steel and concrete, and little of this energy derives from combustion of fossil fuels.[8]

As standardized, manufactured products, engineered lumber members such as CLT decks and glulam beams offer the benefits of economical installation and connection detailing.

Using Wood in Construction

CLT floor decks and glulam beams are essentially modular. Like precast concrete members, they are fabricated according to specific project geometry and delivered to the job site ready for installation. They can be hoisted via crane into place in a single piece. This decreases field labor time and materials and provides for efficient construction scheduling.

CLT decks and glulam beams can be fabricated to accommodate anticipated connection hardware. CLT panels can be manufactured with internal spines in the layups for panel-to-panel connections, or manufactured with setbacks along their span length to install mounted metal tube-and-screw panel-to-panel

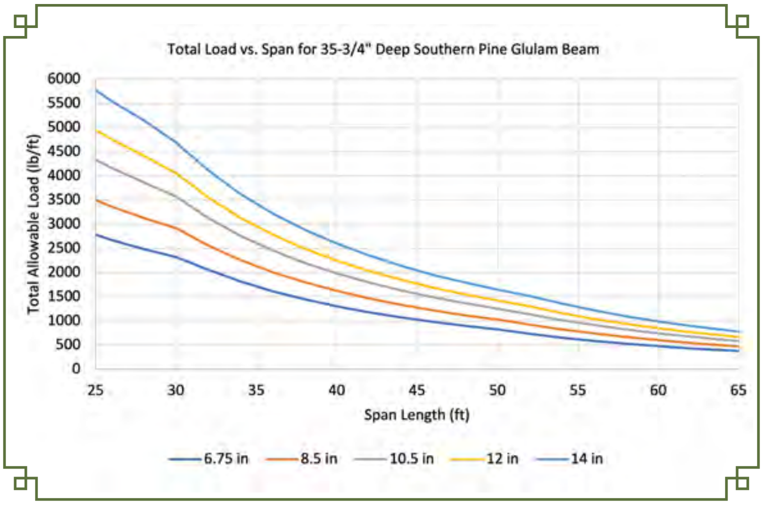


Figure 2: Total Load vs. Span for Glulam Beams

connections. The fabricator can include a slit down the length of CLT panels for installation of connector plates and brackets in the field, where the pieces are assembled without the need for laborious sawing or grinding.[9]

Glulam beams offer a similar benefit. Slits and setbacks in the cross-sections of member ends can accommodate concealed plate connections, and pre-cored holes can provide for sunken bolts. The engineer must adhere to code-prescribed geometrical constraints, such as notch depth, bearing length, bolt spacing, and fastener edge distances, but these limitations do not preclude adequate yet elegant connections.[10]

Case Study: Springfield, Ore.

The city of Springfield, Ore., retained architecture firm SRG Partnership, Inc. to design a CLT parking structure. Its design contains 360 parking spots, occupied interior space on the ground level, and solar panel canopies on the roof. The 200,000-plus square-foot structure consists of five-layer CLT floor decks spanning between post-tensioned glulam beams supported on glulam columns. A curtain wall consisting of a stainless steel wire fabric protects the glulam columns at the perimeter from damage from wind-driven rain. The screens are strategically placed in response to research that identified the direction and magnitude of rain events at the site. The lateral system is a post-tensioned seven-layer CLT shear wall with performance capacity verified by a seismic shake-table test at the University of California at San Diego, and a sprinkler system provides fire-proofing.

Typical structural bays are 30 feet wide by 60 feet

long with 10-foot-wide by 30-foot-long CLT panels spanning between glulam beams spaced at 15 feet on center. This provides CLT panels with intermediate midspan support. Designers incorporated laminated veneer lumber (LVL) for the top and bottom layers of the glulam beams and a post-tensioning system to improve their structural strength and minimize beam depth. This configuration allows for 60-foot beam spans to maximize garage space. The construction schedule is expected to be shorter, and less shoring is expected to be required for the CLT-glulam system than for steel or concrete systems.

Although building officials were appropriately concerned whether a wood parking garage would satisfy code requirements, they were cooperative from the start of the design process. The novelty presented a challenge to building officials tasked with permitting new structural systems requiring testing and review, and a fire marshal was concerned about combustible cars within a wooden superstructure.

Officials required the building to incorporate a sprinkler system for fire protection and continued to work closely with the design team to address other related concerns.

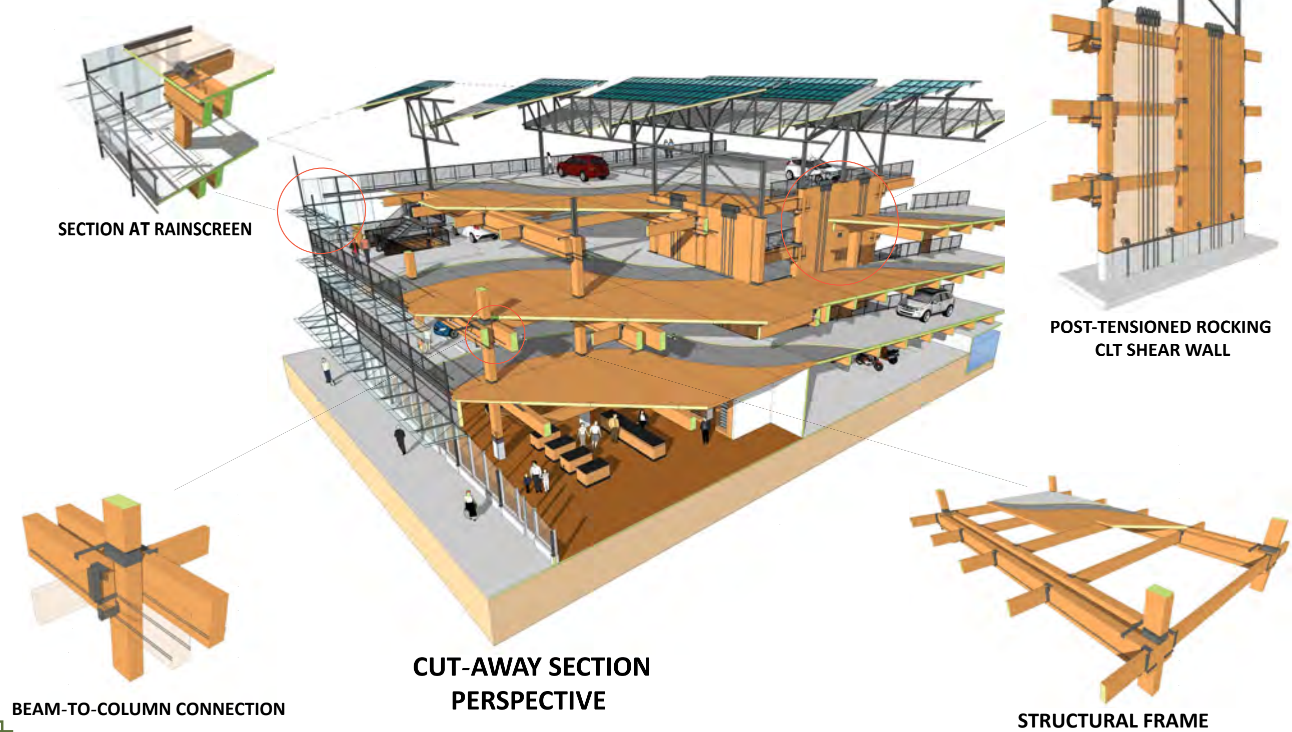
In garages with concrete decks, inadequate weatherproofing can lead to damage from deicing salts, water intrusion from tires and leaking drains, and freeze-thaw cycles. Engineered wood could rot from excessive moisture exposure, leading to section loss from water damage or insect infestations. Research performed at the TallWood Design Institute in Oregon recommended an asphalt topping over a moisture barrier to weatherproof the CLT panels. Of course, adding asphalt detracts from the sustainability profile of the structure and increase its carbon footprint. As of this writing, the authors are not aware of competitive weatherproofing methods of CLT or glulam materials that avoid supplementary toppings such as concrete or asphalt.

Structural Capacity

In 2018, APA-The Engineered Wood Association published "Standard for Performance-Rated Cross-Laminated Timber." The guide, known as PRG 320, describes the structural load-path characteristics of CLT and defines mechanical and geometrical properties for use in design. A few definitions:

- Layup is an arrangement of layers in the CLT panel according to wood grade, number of layers, orienta-

What are the Challenges/Opportunities of a CLT Parking Garage?



tion (parallel and perpendicular to span direction), and thickness per layer.

- Grade of lumber refers to the kind of wood and whether the material is visually graded or machine stress-rated (mechanically graded).

The performance criteria presented in PRG 320 were used to determine superimposed (live load) loading capacity of seven different CLT layups and three total panel thicknesses per layup for a total of 21 different CLT panel members. The layups are denoted E1, E2, E3, E4, V1, V2, and V3. The E-series layups contain mechanically graded layers parallel to the span direction and visually graded layers perpendicular to the span direction. The V-series layups contain visually graded layers in each direction. These grades and layups define the current industry standard, and they are found in available CLT panel products from manufacturers such as Nordic Structures (the Nordic X-Lam is E1 layup) and SmartLam (SL-V4 is V4 layup). Figure 1 shows superimposed loading capacity versus span length for the 21 CLT members. Depending on the member properties and span length, either moment, shear, or deflection will control, and this is reflected in the figure. Maximum deflection under combined dead and live load was taken as L/240.

Like CLT, glulam is composed of layers of mechanically or visually graded wood adhered into a single monolithic member, except the layers are all oriented parallel to the span. Manufacturers generally have freedom to design glulam beam sections using combinations of wood layers—for example, the glulam beams in the SRG wood parking structure where LVL strips form the top and bottom cords, with sawn lumber in between. Glulam capacity depends on the mechanical properties of the wood layers and on the geometry of the section profile. Figure 2 shows total allowable loading capacity versus span length for visually graded southern pine glulam beams of different widths and all 35¾ inches deep. The figure shows controlling values for moment, shear, or deflection. Maximum deflection under combined dead and live load was taken as L/240.

Glulam beams spanning 60 feet are spaced at 12 feet on center, with simply supported 6⅞ inch-deep CLT decks spanning between them. Including the weight of the CLT, glulam beam, miscellaneous dead load, and garage live load of 40psf, and using the heaviest glulam beam evaluated in this article—the 14-inch-wide by 35¾-inch-deep size—the beam is overloaded by 63 pounds per linear foot (lb/ft). Refining the actual clear span based on the width of supporting members may provide a span length reduction to 58 ft, resulting in a beam that works with 43 lb/ft additional capacity beyond the loading demand. Alternatively, the glulam beam could be designed to have stronger top and bottom cord engineered lumber with sawn lumber in the middle, or the beam could be post-tensioned. Although it appears some design intervention is needed to provide the glulam beam with additional capacity, this scenario shows the feasibility of the engineered lumber system.

Spacing 60 feet glulam beams at 10 feet allows use of the 4⅛-inch-deep CLT panels, thereby relieving the system of dead load. The beam is again evaluated under self weight, CLT weight, a miscellaneous dead load, and garage live load. The 12-inch-wide beam works with 56 lb/ft additional capacity, and the 14-inch-wide beam works with 170 lb/ft additional capacity.

Spacing the glulam beams two feet closer together prevents the need for external post-tensioning.

Wood and Parking Structures

Sourced appropriately, wooden building materials can contribute to the storage (and removal from the atmosphere) of greenhouse gas emissions. The net embodied carbon of wood structures—from collection of raw building material through construction and over the service life of the materials—is negative. This is also a function of the lower energy necessary to refine, transport, and install manufactured wood.

The IPCC report suggests that revolutionizing global energy production alone is not sufficient to limit or reverse the effects of climate change. Rather, in concert with such efforts, CO2 removal methods must be implemented. Construction on a wide scale with engineered lumber such as CLT and glulam can simultaneously deliver demanded building projects while sequestering carbon. Expansion of forest growth, sustainable harvesting of wood for building, and large-scale wood-sourced urban development can become a powerful—and practical—tool in the mitigation of climate change.

As engineered lumber manufacturers establish fabrication facilities, design professionals would be wise to prepare for the emergence of these new building materials. As demonstrated above, engineered wood can be adapted for parking garages. Carbon dioxide removal, low greenhouse gas emissions, greater construction efficiency, shorter installation time, and material flexibility are all benefits of engineered wood like CLT and glulam.

Design professionals can anticipate the coming market demand now by performing feasibility studies, forming working groups within firms, and communicating with trusted vendors across the building industry.

When an owner is contemplating a vertical or horizontal addition to a parking facility or a new parking structure, discuss designing it in wood. ℗

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Endnotes

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