TIMBER RISING

Ever-taller buildings made from engineered wood are being proposed and constructed around the world. To meet that demand, designers are being tasked with learning about the new capabilities, attributes, and challenges of working with the newest versions of one of nature's oldest building materials.

BY ROBERT L. REID

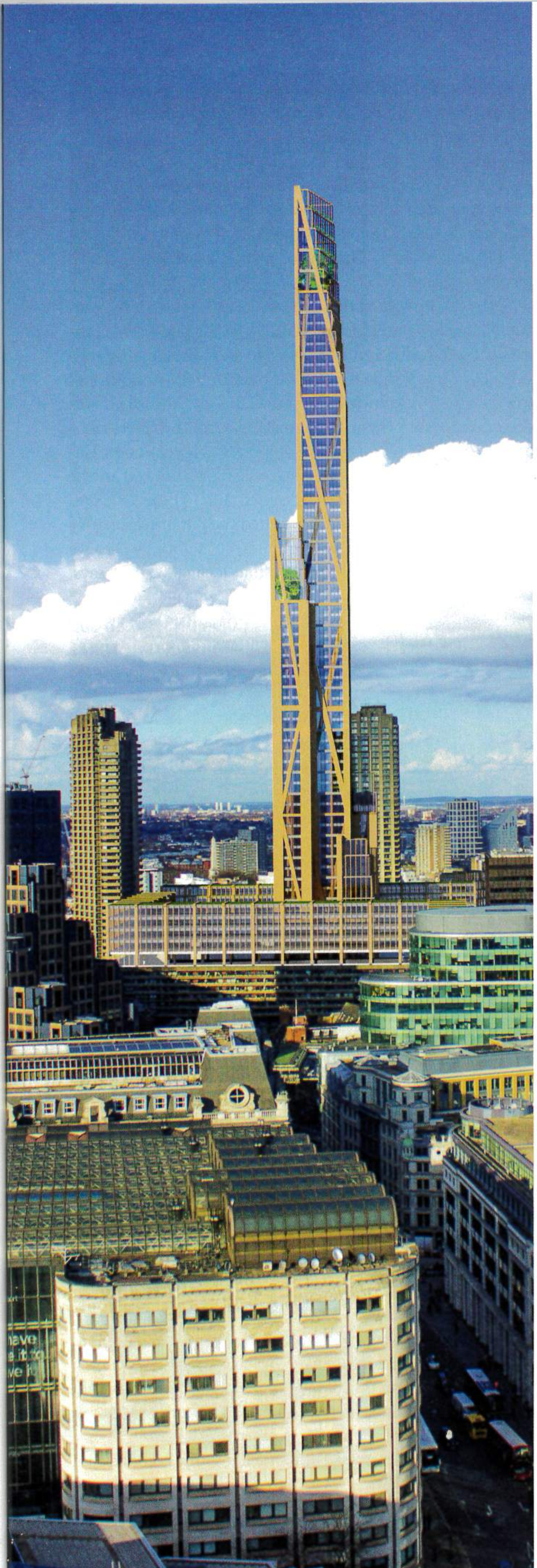
THE USE OF ENGINEERED wood products in the structural systems of tall buildings is, to beg a pun, growing. Since 2008, more than 50 tall timber buildings across the globe have been proposed, been designed as experiments, broken ground, or been completed, according to a study, "Tall Timber: A Global Audit," prepared by the Chicago-based Council on Tall Buildings and Urban Habitat (CTBUH), which appeared in the June 2017 issue of the CTBUH *Journal*. Roughly half of those timber projects have been completed, and one of the most recent—Brock Commons-Tallwood House, a residence hall that opened in July 2017 at Canada's University of British Columbia—is currently the tallest timber building in the world.

Of course, the definition of a "tall" timber building does require clarification. The 100 tallest buildings designed in concrete, steel, or a combination of those materials reach heights of between 300 and 800-plus m, many of them featuring more than 100 stories, according to CTBUH data. By comparison, Brock Commons-Tallwood House rises just 53 m in 18 stories. But those 18 stories make Brock Commons-Tallwood House roughly three times taller than most timber-framed buildings, which are often restricted in height by local building codes to just five or six stories, notes Scott Breneman, Ph.D., P.E., S.E., M.ASCE, a senior technical director in the project resources and solutions division of WoodWorks-Wood Products Council, a Washington, D.C.-based nonprofit organization that provides educational assistance to engineers, architects, and developers who are interested in designing wooden structures.

Many smaller timber buildings, those six stories and lower, are conventionally framed wooden structures called "stick-built" buildings. But Brock Commons-Tallwood House and other buildings in the CTBUH "Tall Timber" study, all of which measure at least seven stories in height, feature the use of so-called mass timber. That's the umbrella term for panelized, engineered wood products, including cross-laminated timber (CLT), nail-laminated timber, glue-laminated timber (glulam), and other such building materials, explains Jennifer Cover, the president and chief executive officer of WoodWorks. Formed from layers of wooden material, mass timber products are used to create large structural el-

Oakwood Timber Tower is a conceptual design that is being used to help design other tall timber buildings. Framed with external mass-timber supports, the proposed tower would rise 80 m into the London skyline, *opposite*.

PLP ARCHITECTURE, *BOTH*



PLP ARCHITECTURE, *BOTH*

ements—for instance, beams, columns, and floor systems—that provide greater strength and fire resistance than traditional wood members, Cover notes.

THIS YEAR should see the completion of the tallest mass timber structure in the United States—a 12-story, mixed-use building in Portland, Oregon, known as Framework. Designed by Lever Architecture, of Portland, and engineered by the Portland office of KPFF Consulting Engineers, the Framework building is also noteworthy for having been one of two winners of the U.S. Tall Wood Building Prize Competition, which was sponsored by the U.S. Department of Agriculture and two trade groups: the Softwood Lumber Board, based in Washington, D.C., and the Binational Softwood Lumber Council, based in Surrey, British Columbia. The other winner was a proposed 10-story residential building in New York City that has since been cancelled. Known as 475 West 18th, it was designed by New York City-based SHoP Architects, international engineering firm Arup, and Icor Consulting Engineers, of Iselin, New Jersey.

Around the globe, several mass timber structures even taller than Brock Commons-Tallwood House are also in the works, have been proposed, or are being researched. In Austria, for example, the 24-story mixed-use HoHo tower, is now under construction in Vienna. Designed by Vienna's Rüdiger Lainer and Partner, this mass timber structure is expected to measure roughly 84 m in height. A 35-story tall mixed-use mass timber building known as Baobab has been proposed for Paris by Vancouver, British Columbia-based Michael Green Architecture. The international architecture and engineering firm Skidmore, Owings & Merrill LLP (SOM) has explored what it would take to design a 42-story building in Chicago that uses mass timber as its main structural system; the firm has also published four reports on mass timber research since 2013, the most recent released late last year. And in a pair of research projects, the Center for Natural Material Innovation at Cambridge University has worked with engineering and architecture firms in the United States and the United Kingdom to conceptualize 80-story mass timber towers for both Chicago and London.

The reasons for the uptick in interest for ever-taller mass timber buildings vary from aesthetics to economics to simply a desire to design something that has never been done before. But one critical point is cited repeatedly by engineers working with mass timber: sustainability. For Benton Johnson, P.E., S.E., an associate director in SOM's Chicago office, the issue centers on the fact that cities "outperform other ways of living in terms of their overall carbon footprint. If you look at the per-capita carbon footprint of people living in cities, it typically is much better" than for people living in the urban sprawl of suburbia or rural settings.

At the same time, the mostly steel and concrete buildings within cities tend to be large emitters of greenhouse gases—which presents a conundrum that mass timber can help resolve. "The design community recognizes the key to a lot of the sustainability goals that we have as a society are geared around living in cities, but if we want to make those cities more sustainable, we need to make the buildings in those cities more sustainable," Johnson explains. "That often means looking at mass timber."

For mass timber structures to be relevant in an urban environment, however, those buildings need to be high-rise structures. "Maybe not forty-two stories tall," Johnson says. "But they need to be in the realm of ten, fifteen, twenty, thirty stories to make a serious impact on the overall sustainability of these cities."

The life cycle of the trees that are harvested to become mass timber products is a critical aspect of that sustainability, says Cover. "As trees grow, they absorb carbon dioxide from the atmosphere and they release oxygen, and they incorporate the carbon into their wood and their leaves and their needles and their roots," she explains. "That carbon stays sequestered within the tree itself, so when that tree is harvested and turned into a wood product, it continues to sequester that carbon over the life of the project itself. And then a new tree is planted in that location which continues to pull carbon dioxide out of the environment."

If the timber comes from a clear-cut site at which nothing was replanted, that lessens the sustainability of the resulting buildings. "But research shows that in communities with a strong market sector for wood products, they tend to protect their forests and manage their forests better than places in the world that do not have a strong forest industry," adds Johnson, "because in those areas there's no value for keeping the forest going."

MASS TIMBER structures often feature hybrid or composite systems that combine steel and/or concrete with the timber elements to provide the structures with the strength, stiffness, fire resistance, and other factors that are making taller timber buildings possible. An essential aspect of the 42-story building designed by SOM was a CLT floor system with a composite concrete topping slab, which underwent extensive testing at Oregon State University, Johnson notes. The floor system and its use in combination with structural steel columns were explored in the two most recent SOM reports on mass timber research.

Brock Commons-Tallwood House utilizes cast-in-place concrete foundations and cores, a concrete podium, and a steel-framed roof, together with steel connections between the CLT panel floor system and the glulam columns, according to the paper, "Structural Design, Approval, and Monitoring of a UBC Tall Wood Building," by Thomas Tannert, Ph.D., PEng, an associate professor of tall wood and hybrid structures engineering at the University of Northern British Columbia, and Manu Moudgil, a research assistant at the University of British Columbia. The paper was presented at Structures Congress 2017, which was organized by ASCE and its Structural Engineering Institute and held in April in Denver.

Brock Commons-Tallwood House was designed by Acton Ostry Architects Inc., of Vancouver. The structural engineer was Fast + Epp, also of Vancouver, and Architekten Hermann Kaufmann ZT GmbH, based in Schwarzach, Austria, served as the tall wood adviser.

Even tall buildings that are considered "all timber" generally have nontimber foundations. Timber piles were commonly used in Chicago a century ago and were initially considered for the Windy City's conceptualized 80-story timber tower, which is known as the River Beech Tower and was designed to use primarily engineered wood products rather than any sort of hybrid or composite systems, notes David Weihing, P.E., S.E., LEED AP, a senior principal in the Chicago office of Thornton Tomasetti Inc. "But we found that [the 80-story structure] exceeded the potential capacity [of wooden piles] substantially—so we abandoned that idea," Weihing says,

BROCK COMMONS-TALLWOOD HOUSE STRUCTURAL SYSTEMS

Exposed wood structure at student amenity space

Encapsulated wood structure at typical floor

Concrete structure and CLT canopy at base

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At 18 stories, the University of British Columbia's Brock Commons-Tallwood House is currently the tallest mass timber structure in the world.

PHOTOGRAPH BY KK LAW COURTESY OF UBC/NATURALLYWOOD.COM, TOP; UBC/ACTON OSTRY ARCHITECTS INC., BOTTOM

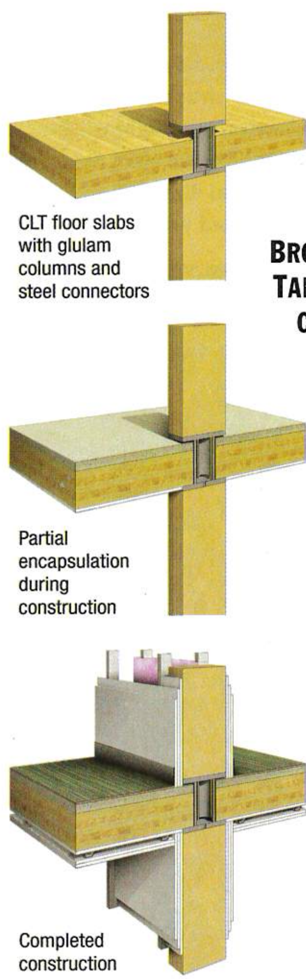
adding that the tower's foundations were designed to use concrete caissons instead.

In addition to Cambridge University, Thornton Tomasetti also worked with the Chicago-based architecture firm Perkins+Will on the River Beech Tower, which actually features two side-by-side towers, one slightly taller than the other. The structures are linked by a multistory atrium and supported laterally via a diamond-shaped diagonal grid system on the facades that utilizes laminated veneer lumber elements, notes Weihing.

The other conceptual 80-story timber skyscraper, known as Oakwood Timber Tower, was designed by Cambridge University, London-based PLP Architecture, and Cambridge-based structural engineering firm Smith and Wallwork. The Oakwood Timber Tower also features exterior wooden supports, although in the London building's case these would be extremely tall crisscrossing elements.

Although both 80-story structures were intended essentially as experiments, rather than as projects anyone was currently planning to build, the towers were designed under the assumption that everything would actually "work," from the ways the buildings handled structural forces to the market forces that would drive rentals in each space, notes Michael Ramage, Ph.D., MIStructE, CEng, the director of Cambridge University's Center for Natural Material Innovation.

BROCK COMMONS-TALLWOOD HOUSE CONNECTIONS



"We went with the premise of 'Let's try to design at scales we haven't seen before, but let's use materials already on the market, [and] work with practicing architects and engineers,'" say Ramage. The resulting designs would therefore demonstrate not only the exciting things that were theoretically possible with very tall timber buildings but also how those designs could apply to smaller timber buildings that might actually be under consideration. "If we can show that it works at three hundred meters, it is much more straightforward to do it at one hundred meters," or even with the roughly 50 m tall timber buildings that are being built these days, Ramage notes.

Some of the ideas learned from the Oakwood Timber Tower project have already been applied via a proposed timber structure in the Netherlands that would have been roughly 120 m tall, notes Simon Smith, CEng, a founder and the director of Smith and Wallwork. A Dutch developer was very interested in a timber structure because of the potential environmental benefits as well as the embedded energy and operational energy costs of wood, Smith says. Moreover, despite a building height restriction of 80 m in the local codes where this project was being considered, an "exemplary building" such as the timber tower might have been allowed to exceed that limit, Smith says. That would then have enabled the developer to provide more floor space than surrounding buildings and thus earn a greater return on investment.

In the end, the relatively low rents available in that regional market persuaded the developer to select concrete as a building material for a shorter tower, Smith says. The cost premium for timber was too great. But in larger markets—say, Rotterdam or Amsterdam—with higher potential rents, "our proposal might have stood a better chance," he says. Ultimately, the exercise proved instructive. "We came away from that experience with some good information on what a tall timber building might look like," Smith explains, "and structurally, in terms of its viability, we got very close, from a strength point of view, to making that one feasible."

LOCAL BUILDING code limitations are one of the key obstacles to taller timber structures, but they are not insurmountable, says Breneman. Exceeding the heights prescribed in local codes involves the pursuit of an alternative means and methods process "that varies dramatically from jurisdiction to jurisdiction," he explains. The design team essentially partners with the local authority to discuss the project and determine what it will allow, as well as what concessions it would like in return, notes Breneman. "To be successful, you have to demonstrate how your proposed design has equivalent or better safety than a code-allowed design and how what you're proposing meets the 'intent' of the code in terms of life safety and other metrics," he explains.

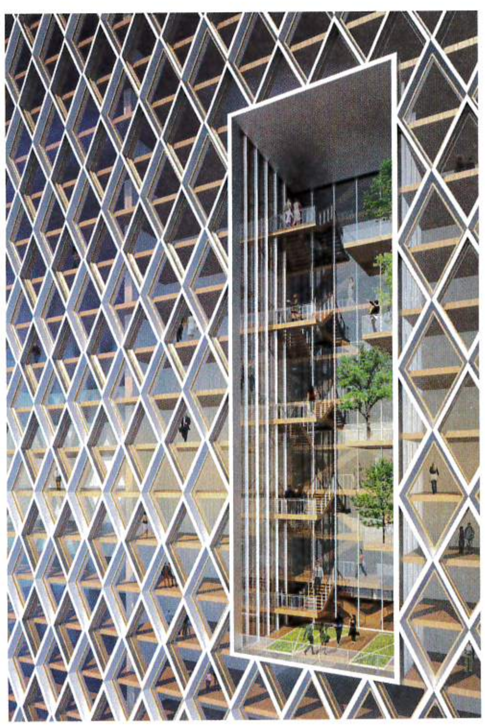
For the Framework building, which will exceed the heights allowed for mass timber in Portland, the project underwent a performance-based design that Eric McDonnell, P.E., M.ASCE, an associate at KPFF Consulting Engineers, described as "a pretty arduous process" that involved "a lot of extra eyes" reviewing the design and considerable testing. This process included a nonlinear analysis of one of the project's signature features: a posttensioned rocking CLT shear wall system that will provide the building's lateral resistance and be one of the first such systems used in the United States. There was also a review by the state of Oregon's building codes division, an international peer review team, and a series of tests on various aspects of the rocking wall system and other components in the design conducted by researchers at Oregon State University, Portland State University, and the University of California, San Diego.

In addition, there was a second performance-based design review of the building's fire protection systems—conducted by Arup—that featured considerable fire modeling, fire tests on the floor assembly to ensure that it could meet a two-hour fire resistance requirement, and fire tests of the typical beam-to-column connections, McDonnell says.

Fire is always a concern in timber structures because of the combustibility of wood. But the mass aspect of the mass timber used in or designed for these wooden towers helps alleviate that problem. One way a mass timber building can resist fire is through charring—as the wood burns "it develops this layer of charred material that actually acts like an insulation, very similar to an insulation on a steel member," notes Johnson. "And what that does is keep that core of the timber member cool and structurally sound." Because oxygen cannot get through this charred layer "it basically suffocates the fire," Johnson explains.

"We've got to be hesitant to say that one thing is safer than another," Johnson adds. "The bottom line is that the codes set the required level of fire resistance to provide, and then

River Beech Tower, another conceptual 80-story mass timber structure, features two side-by-side towers, one slightly taller than the other, *above*. The facades, *below*, feature a diamond-shaped diagonal grid system that utilizes laminated veneer lumber elements.



PERKINS+WILL/CAMBRIDGE UNIVERSITY/THORNTON TOMASETTI, *BOTH* it's up to the designers to satisfy those requirements. What I can say is that timber can meet all of the code requirements necessary for these large buildings in terms of fire."

The rate at which mass timber burns is also quite predictable, adds Carsten Hein, an associate director of structural engineering in the Berlin office of Arup. "If you have a fire in a timber building, you notice that your columns start burning, and you know you have ninety minutes to leave the building because you know the charring process behaves extremely predictably," explains Hein, who participated in the research design of a proposed 20-story timber building known as the LifeCycle Tower; an Austrian developer later constructed an eight-story prototype of the Lifecycle Tower using an Austrian engineering firm, Hein notes.

Mass timber has a charring rate of 0.7 mm per minute, Hein explains, which means that over a 90-minute period, the timber element will lose 6.3 cm of structure. But the remaining timber core is not weakened by the fire and has the same structural properties as before, Hein says, and therefore it has the same load capacity as before. "So after a fire in a timber building the remaining structure will stand up, allowing refurbishment or replacement of damaged elements," Hein explains.

Another way to protect a timber tower from fire is simply to fireproof the material with a fire-resistant gypsum drywall—the same material sometimes used to fireproof steel columns, notes Johnson. Intumescent paints and coatings for timber structures are also under development, Hein says. And a tall timber building will need to have a sprinkler system like any high-rise building, notes John W. van de Lindt, Ph.D., F.ASCE, the George T. Abell Distinguished Professor in Infrastructure within the Department of Civil and Environmental Engineering at Colorado State University.

PERKINS+WILL/CAMBRIDGE UNIVERSITY/THORNTON TOMASETTI, *BOTH*

KPFF CONSULTING ENGINEERS, *BOTH*

A wooden model, *left*, assisted in the design of the Framework building in Portland, Oregon. The 12-story, mixed-use building, *above*, will be the tallest mass timber structure in the United States when completed this year.

ONE ASPECT OF MASS TIMBER that is both an advantage to the product as a building material and a potential fire concern involves exposed timber. The environmental conditions within a wooden building "feel much healthier because the timber controls the humidity, so the room climate is better," Hein notes. The timber also provides additional insulation, which makes it easier to control the rooms' temperatures. Moreover, there is a tactile benefit to wood—"it's nicer to touch a smooth wooden surface than a cold concrete one," says Hein. Such aspects are difficult to measure, he adds, "but still enjoyed by most tenants or occupants of a timber building."

(Continued on Page 76)

Timber Rising

(*Continued from Page 51*) At the same time, exposed timber and the threat of fire require more research, Hein says. Numerous tests have been conducted regarding the amount of exposed timber surfaces, especially in a building with extensive use of CLT, Hein notes. Such buildings might face an enhanced fire risk "because at a certain point the construction material turns into the fire load itself," he says. "When it all starts burning, it can attract oxygen and burn even faster."

For the timber buildings designed by Arup's Berlin office—including the study for the LifeCycle Tower—timber columns and timber-concrete composite slabs with glulam beams were used, Hein notes. "This proved to be a huge advantage," he adds, because the danger of a fire spreading was significantly reduced.

Thus, designers might have to limit the amount of exposed mass timber in buildings, encapsulating some elements as noted above or using fire-protected steel or concrete composite materials strategically to block the spread of a fire from one section of exposed mass timber to another, Hein says.

Because mass timber elements are relatively lightweight and flexible they can deflect more than concrete or steel, which potentially limits the spans of timber systems, Johnson notes. But again, the use of hybrid or composite elements can help mass timber designs meet the same capabilities of other building materials, as demonstrated during the tests that Oregon State University performed for SOM, he says.

Hybrid systems might also help solve one of the issues identified but not yet resolved by the current research into mass timber: how to transfer loads through the timber elements in very tall structures, notes Ramage. "We can show that from a stability perspective, [mass timber] works as a structural system and a material," Ramage explains. "But when we get to a specific connection, we don't know all the answers."

In steel, he explains, when you weld various sections together the resulting steel element acts as if "it's basically one piece of steel from the bottom to the top—but we don't know how to connect wood like that yet," at least not for the conceptualized 80-story timber buildings. It is less of a problem in the midsized mass timber buildings—those in the 20- to 40-story range—and probably not a problem at all for smaller timber buildings, Ramage adds. But he hopes that hybrid connections will help solve the issue someday even for the tallest designs.

To help protect tall timber buildings in high-seismic zones, van de Lindt and other researchers have been testing wood-framed structures on various shake tables, including two- and four-story wooden buildings that were tested at the University of California, San Diego; the two-story building was subjected to a simulated 6.7 magnitude event comparable to California's Northridge earthquake of 1994. In Japan, van de Lindt also subjected a six-story wooden structure to a simulated 7.5 magnitude temblor.

The wooden buildings have all performed well, van de Lindt notes. In 2020, he will also be part of a shake-table test involving a 10-story CLT-framed building that will feature a large rocking wall system similar to that designed by KPFF Consulting Engineers for the Framework building.

In the Framework building, the rocking wall will feature a posttensioned steel rod in the middle of a rigid CLT panel, explains McDonnell. In the event of an earthquake, the base of the wall will want to lift up but the posttensioning will become elongated and pull it back down. "A beauty of the system is that it's actually self-centering," McDonnell notes, adding that the system will also eliminate the cracking and other damage that shear walls generally experience during an earthquake. "You can end up, through this system, with a very resilient, low-damage system that's much easier to repair following an earthquake," McDonnell concludes. In particular, the Framework structural systems will feature a series of structural steel plates, dubbed "fuses," that are designed to dissipate energy during a seismic event and then be easily replaced if necessary, McDonnell adds.

The speed of construction with mass timber is impressive, especially compared with concrete. "These [systems] go up lightning fast because you're bringing panels in that are preassembled," notes van de Lindt. "And you're literally setting them in place and connecting them so [the contractor] can put up whole stories in a day," he explains, as opposed to concrete construction that can take weeks to cure.

Brock Commons-Tallwood House is a perfect example. "The structure was completed less than 70 days after the prefabricated components were first delivered to the site," according to a September 15, 2016, press release from the University of British Columbia titled "Structure of UBC's tall wood building now complete."

Although the use of mass timber is certainly on the rise, there is one more major obstacle that prevents many engineers from even considering wood when they design a new building: they've never learned how. "Wood is not taught across the board" at engineering schools in colleges and universities, notes van de Lindt. "If you're a structural engineer coming out of school, at almost any university, you've had a steel class, you've had a concrete class, you might even have had a masonry class—but not always a wood class," he says. That's what various groups are trying to correct, including WoodWorks and ASCE's wood-related committees—among them the Wood Technical Administrative Committee, which is part of ASCE's Structural Engineering Institute and oversees four committees related to wood. Van de Lindt previously served as chair of the Wood Technical Administrative Committee.

Going forward, predicts van de Lindt, "as taller wood buildings become more and more engineered and become large structural systems that essentially thousands of people can work in or live in, that's when we'll start to see more and more university classes being offered." After all, he adds, "wood is one of the oldest construction materials in the world, so in a way we're kind of coming back around to what we know works well." **CE**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