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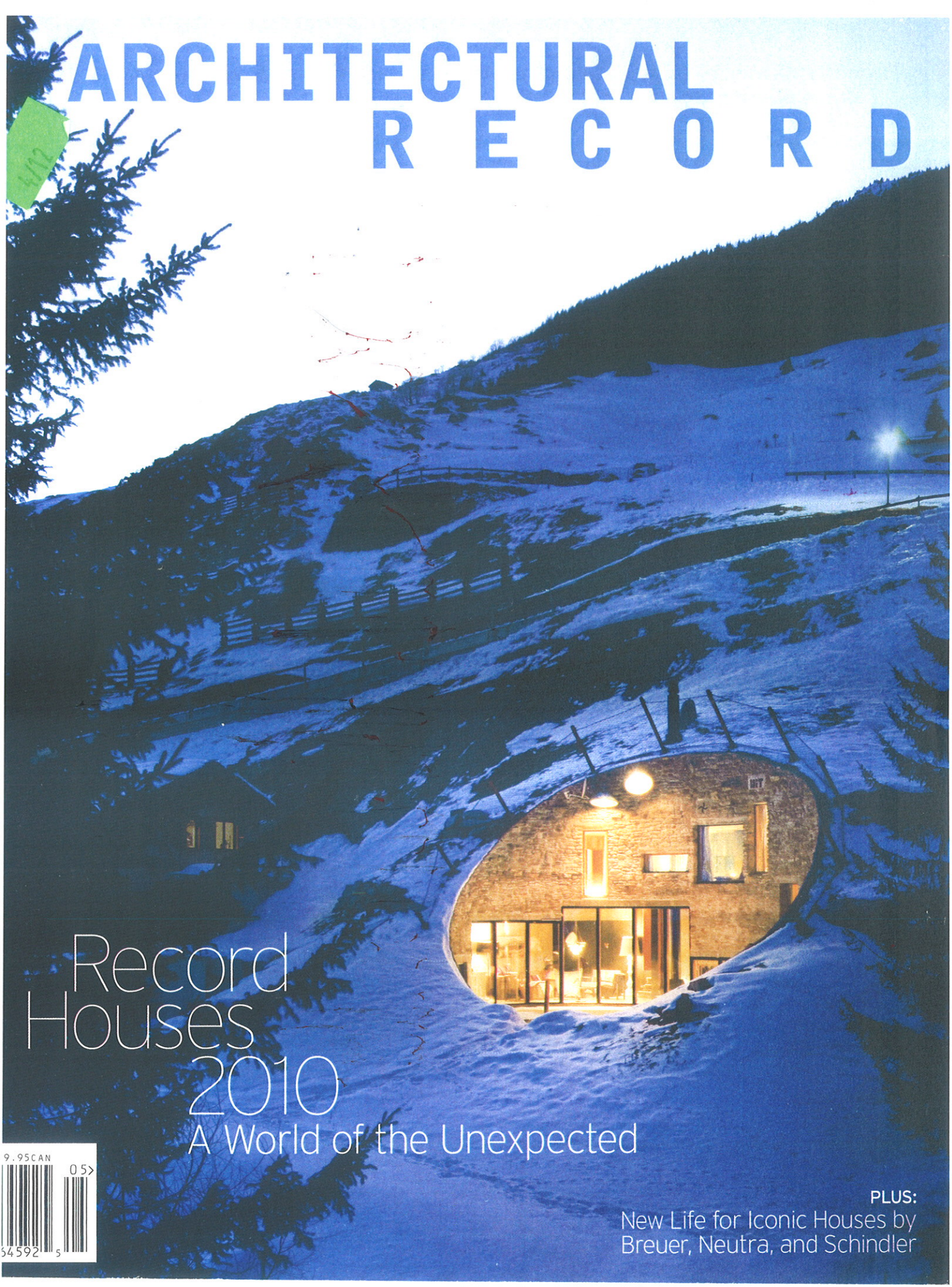

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Testing Timber's Limits

Designers push a traditional material to create longer spans, reach new heights, and find unconventional applications.

By Joann Gonchar, AIA

THERE WAS PLENTY OF EXCITEMENT at the long-track speed-skating events during this winter's 2010 Vancouver Olympic Games. And television cameras caught it all, including the shocking disqualification of Dutch competitor Sven Kramer from the 10,000-meter event after he followed the instructions of his coach and illegally changed lanes, and the German women's stunning win of the team pursuit, even though one of their skaters stumbled and fell right before the finish line. But in between shots of these surprising moments, viewers at home could catch occasional glimpses of another kind of drama at the Richmond Olympic Oval – that provided by the $173 million arena's vaulted timber roof.

The 512,000-square-foot building's impressive structure includes massive poured-in-place concrete buttresses from which spring 15 curved beams of steel and glue-laminated Douglas fir, each 7 feet deep and 328 feet long. The arches are the longest-spanning composite members in the world, according to the project team, which includes architects from the local office of Cannon Design, and two Vancouver-based structural engineering firms – Glotman Simpson, for the concrete base structure, and Fast + Epp, for the timber roof.

Spanning the 47 feet between arches is a secondary system made from dimensional lumber, primarily from pine-beetle-infested trees. Here, sophisticated analysis and computer numerically controlled (CNC) milling have been deployed to transform a material normally used only in stud-wall construction into 450 wavelike ceiling panels with acoustic and structural properties.

Before beginning the project, the team toured other Olympic speed-skating venues. They found that almost all had exposed ducts. "These diminished the quality of the space," says Paul Fast, Fast + Epp principal. To get rid of such visual clutter, designers configured both primary and secondary structural systems to conceal building services. The arches, V-shaped to prevent buckling, house air distribution within their hollow cores, while voids within the ceiling panels hide sprinklers and conduit.

PHOTOGRAPHY: © ANDREW DORAN (1); HUBERT KANG (2)

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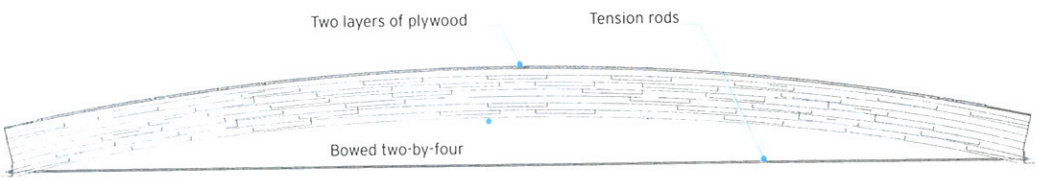
1. **The Vancouver Olympic Oval's largely wood-framed roof encloses more than 6 acres and springs from reinforced-concrete buttresses.**
2. **Mechanical services are hidden within the oval's roof structure.**

Continuing Education

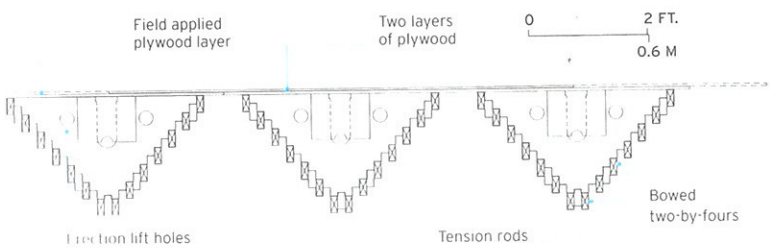
Use the following learning objectives to focus your study while reading this month's ARCHITECTURAL RECORD/AIA Continuing Education article. To earn one AIA learning unit, including one hour of health, safety, and welfare/sustainable design (HSW/SD) credit, turn to page 99 and follow the instructions. Another opportunity to receive AIA/CES credit begins on page 101.

Learning Objectives

1. Explain how wood components sequester carbon.
2. Describe how wood can be used in long spans and tall structures.
3. Discuss engineering challenges involved in using wood in such structures.
4. Discuss code-compliance issues that relate to using wood in such structures.

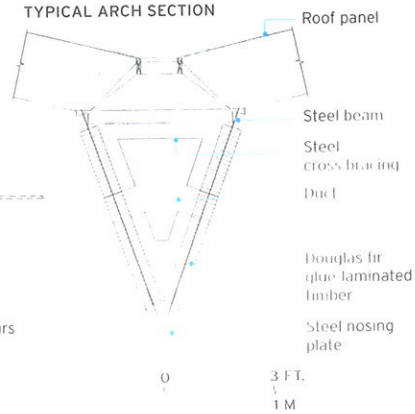


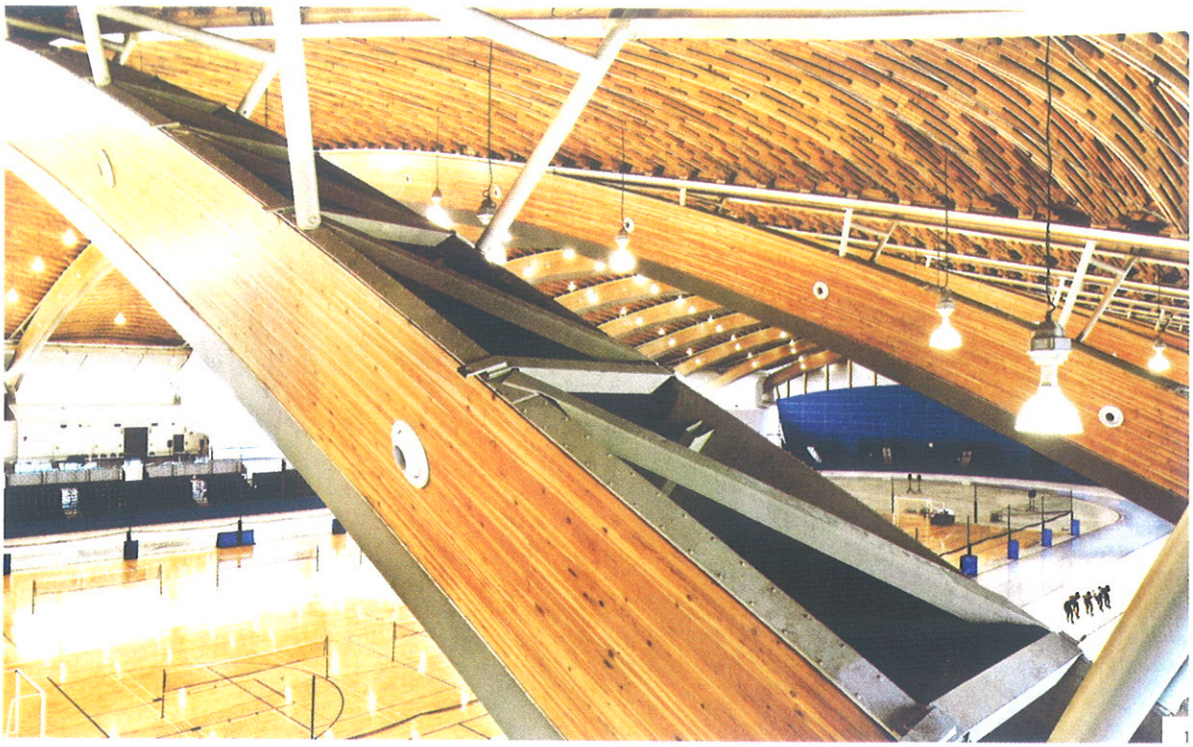
WAVE PANEL ELEVATION



WAVE PANEL SECTION

TYPICAL ARCH SECTION

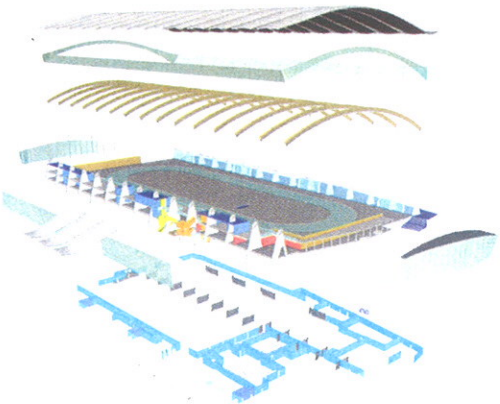




1. **The oval's V-shaped arches are constructed of two slabs of glue-laminated Douglas fir connected by a steel blade at the bottom and steel bracing at the top. The secondary roof structure of wavelike dimensional-lumber panels lifts off the arches at the building's north end.**

2. **During the Olympics, the building housed a 400-meter track and seating for 8,000 spectators. The full basement below the ice level contains parking, offices, and changing rooms.**

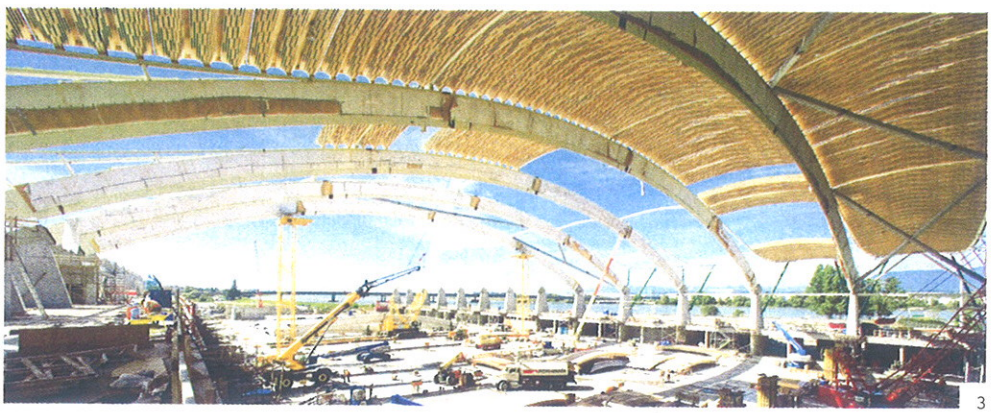
3. **The oval's 450 ceiling panels were fabricated off-site and installed at a rate of about 30 per day.**



2 EXPLODED AXONOMETRIC

The oval, with its long, clear spans, inventive use of dimensional lumber, and clever integration of building services, is part of a group of recent larger institutional and commercial projects that deploy timber as a significant structural element, where steel or concrete might have seemed the more obvious choice.

Designers and clients cite a variety of reasons for incorporating wood. In the case of the oval, the timber – about a million board feet each of dimensional lumber and glue-laminated stock lumber – is the project team's response to a requirement that the building act as a showcase for products from British Columbia, where the timber industry is an important sector of the economy. The designers suggested using the pine-beetle wood as a way of drawing attention to the infestation, which by some estimates has affected two thirds of the province's forests. Although the wood has a slight blue or "denim" tinge and is often discarded, its structural capacity is undiminished if the tree is harvested soon after it is attacked.



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Warming it up

For some projects, the decision to go with wood is based solely on the material's visual warmth. That is the case for a $570 million terminal under way at North Carolina's Raleigh-Durham International Airport, which will have 32 gates and accommodate up to 11.4 million passengers per year when the second phase of construction is complete in 2011. The curved metal roofs of the facility's 90-foot-wide concourses and its 160-foot-wide ticketing halls, intended to evoke the silhouette of the surrounding hilly landscape, are supported by hybrid bowstring trusses of steel and glue-laminated Douglas-fir members. "The clients told us they didn't like the industrial look of most airports," says Curtis Fentress, whose eponymous Denver firm is the project's architect. The project team believes Raleigh-Durham is only the second major airport with a roof structure that makes significant use of wood. Another, built in 1998, is at Gardermoen, near Oslo, Norway.

Timber's ability to sequester carbon is cited with increasing frequency as a motivation for using it to replace construction materials with energy-intensive production processes. Forests with healthy ecosystems act as carbon sinks by absorbing carbon dioxide (CO_2) from the atmosphere. As part of photosynthesis, the trees' trunks, branches, leaves, and root systems store carbon in the form of sugars, while the oxygen is released back into the atmosphere. Eventually,

1. At London's Stadthaus, each level's load-bearing CLT walls and floors support the floor above. The panels, arranged in a cellular fashion, are installed by the panel supplier's own crew of workers using a mobile crane.

2. The facade material also contains wood. It is clad in a rain-screen siding of fiber cement and wood pulp.

3. At the supplier's factory in Austria, the Stadthaus CLT panels were fabricated and cut to size, with door and window openings included.

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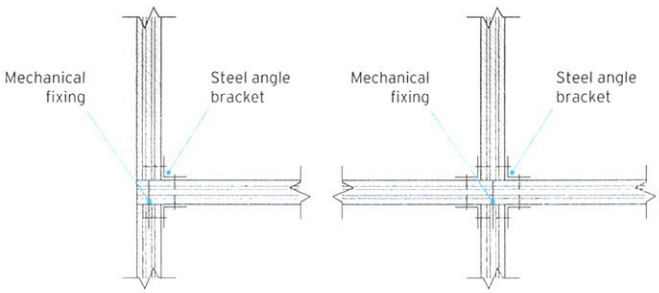
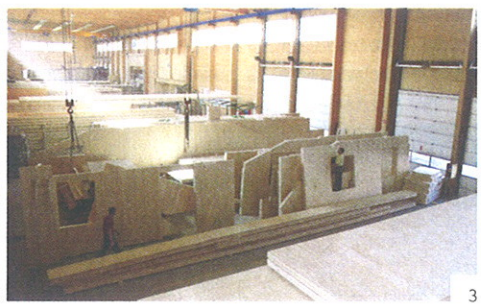
loads. But the behavior of the oval's ceiling panels was inherently more difficult to understand with simulation alone since each has a slight camber held in place by tension rods and a stressed plywood upper skin and is assembled from hundreds of stepped and staggered two-by-fours. Because of this complexity, the panels' design-builder, StructureCraft (a company owned by the partners of Fast + Epp) conducted load tests, piling full-scale prototypes with weights equal to several times the design capacity. The engineers monitored deflections and used the results to refine the design and calibrate computer models.

For London's Stadthaus project, structural analysis was relatively straightforward. However, one complicating factor was the lack of technical design guidance for multistory CLT or timber-framed buildings, especially with respect to the U.K. regulations that safeguard against disproportionate collapse – a type of collapse caused by abnormal loads, such as accidental impact or explosion, which precipitates a sequence of failure out of proportion to the original event. The official guidelines regarding this phenomenon only relate to reinforced concrete, steel, and masonry, explains Matt Linegar, project director for Techniker, Stadthaus's structural consultant.

In the absence of official guidance specific to timber and CLT, Techniker sought advice from two timber industry associations and designed the Stadthaus structure so that any individual wall



TYPICAL WALL-TO-FLOOR CONNECTION DETAILS



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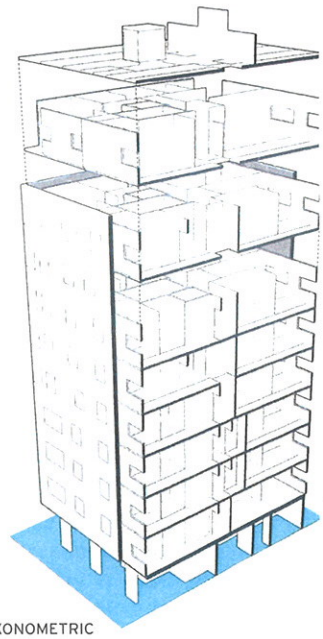

CUTAWAY AXONOMETRIC

can be removed without causing the floor or wall above to fail. The engineers made floor panels continuous over a minimum of two supporting walls or configured them to cantilever under accidental loads. In addition, they tied building elements together with standard angles and plates to resist a horizontal force of 156.6 pounds per square foot, relying on only two anchorage details and two types of screws. "We kept the connections simple and off-the-shelf," says Linegar.

Acoustical performance is another key area of concern for designers deploying timber in unconventional ways. This was especially the case at the oval, given the possibility that the arena's rever-

1. **Stadthaus's timber construction allows electricians to easily install conduit and locate switches and outlets.**

2. **Standard finishes, such as drywall and hardwood floors, conceal the building's unusual frame.**

berant open volume would make announcements unintelligible. But the void above the sculptural ceiling, slot-shaped spaces between the individual two-by-fours, and mineral-wool insulation all help absorb sound. The team commissioned lab tests to compare the panels' effectiveness against conventional perforated metal deck and found that the custom solution matched the performance of the more standard one for sound at upper frequencies and surpassed it at lower frequencies.

The Olympic oval's ceiling also presented a fire-protection conundrum, since the use of small dimensional lumber was not allowed by the prescriptive code. Although the panels cleverly conceal sprinklers, these are intended to protect the space below the ceiling. But with the inclusion of the mineral-wool insulation, and through modeling, consultants proved that panels have the required resistance.

Solid timber elements, such as glue-lam beams and CLT panels, take longer to burn than dimensional lumber. So for Stadthaus, Waugh could readily demonstrate to local officials a resistance of 90 minutes, based on the charring rates of the CLT and two layers of drywall. But he maintains that actual performance would be even better, since the calculations are conservative and do not take into account timber's ability to "self protect" once a layer of char forms on its surface.

One hopes the robustness of Stadthaus's fire resistance won't ever be needed or tested. But in other areas, especially with regard to financial practicality, the project has already proved a success. In part because of the panels' off-site fabrication, contractors were able to compress construction into 49 weeks, versus the 66 that would have been needed for an equivalent concrete-framed building. However, an even better indication of the construction method's commercial viability may be the speed at which the apartments sold. When they went on the market in October 2007, according to Waugh, all were bought in just an hour and 15 minutes.

Building on their achievement with Stadthaus, the team is already exploring the feasibility of going taller. According to Linegar, a CLT tower can reach 25 stories before the panels' compressive strength becomes the limiting factor. But no doubt, he and fellow timber innovators will continue to push the world's oldest building material, not only to reach new heights, but also to span longer distances, and find new applications. ■

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