GOING TO NEW HEIGHTS

Building the World's Tallest Mixed-use Wood Structure

By Roxane Ward

When architect Andrew Waugh received the various approvals necessary to build the nine-story Stadthaus building in London's east end, it gave him an opportunity to utilize an innovative building product he had long wanted to try – cross-laminated timber (CLT) – and for his firm, UK-based Waugh Thistleton Architects, to create the world's tallest mixed-use wood structure.

A partnership between Telford Homes and the Metropolitan Housing Association, the building consists of 19 private for-sale apartments, 10 social housing units and a resident's office. The upper eight stories are made from CLT panels that form a cellular structure of load bearing walls, including stairways and elevator cores, and timber floor slabs. The ground floor is made from cast concrete with short pile foundation, though Waugh now says he could have used timber and will likely do so in the future.

The world's tallest mixed-use wood structure, the nine-story Stadthaus building, was created with cross-laminated timber panels.

Building Code Challenges

The Stadthaus building uses a platform configuration, with each floor set on the walls below and joints secured with screws and angle plates. Stresses are generally low throughout, but additional screws have been added to reinforce the timber locally where pressures exist due to compression perpendicular to grain. The building also has sufficient redundancy that any single element can be removed without causing progressive collapse.

This, according to the project engineer, was the greatest engineering challenge. The UK has stringent disproportionate collapse regulations which, at present, only consider concrete, steel and masonry buildings. "To simply apply the methods and accidental loadings for these materials to a timber building would have been very onerous," said Matthew Linegar, BEng, MIstructE, project director for Techniker Ltd., who has worked with CLT on a variety of projects over several years. "We sought independent advice from the Timber Research and Development Association and the UK Timber Frame Association, which suggested the application of ties to resist a horizontal force of 7.5kN/m (514 plf) of wall and the theoretical removal of these walls. This advice was based on timber-framed construction up to six stories, but it provided a more realistic and rational approach."

Because the panels are cross-laminated, loads can be transferred in one direction (for supports or girders, for example) or on all sides, creating unique design opportunities.

To realize the hypothetical removal of walls, "floor panels were designed to double span or cantilever under accidental loading, and effective ties between floors and walls were achieved using simple 'off-the-shelf' brackets and screws," said Linegar. "The high in-plane stiffness and cross-lamination process provided additional 'built-in' redundancy within the panels themselves."

One of the selling points of CLT is that cross-wise gluing at high pressure reduces the potential for expansion and shrinkage to insignificant levels. In the Stadthaus building, the potential for creep shortening due to compression under load is negligible for the walls and 0.6 millimeters (0.02 inches) for the floors. Likewise, the potential for moisture expansion is negligible for the walls and 2 millimeters (0.07 inches) for the floors, resulting in maximum settlement for the entire building of less than one inch.

Although frequently asked about fire protection, Waugh said meeting building code requirements for fire was relatively straightforward. Timber is self-protecting in the sense that it will char on the outside, preventing heat build-up at the center and allowing it to retain its strength during fire for longer periods than steel or even concrete. As such, the CLT panels were designed to resist fire by calculating charring rates.

"Generally, the panels were designed for fire resistance of 30 minutes and sized to retain their structural integrity with this loss of section," said Linegar. "Disregarding fire, the panels could have been thinner, perhaps three layers instead of five." However, the existing thickness

combined with a layer of drywall allowed the design team to achieve fire resistance ratings of 60 and 90 minutes.

Acoustics were a greater issue because, while the CLT has European certification for acoustics, the UK has its own more stringent requirements. "Part of the solution was progressive build-up, which we tested in a lab before construction started," said Waugh. This included a thin timber floor with just over 2 inches of screed overtop, followed by a layer of compressed insulation, 5 ¾-inch floor slab, 3-inch void, another 2 inches of insulation and a layer of drywall – for a total of about 14 inches overall.

Vertical sections in the elevator and stair cores isolate them both structurally and acoustically from the rest of the building, and the external construction includes 3 inches of insulation, an air gap and rain screen cladding to reduce noise from outside.

Speaking of which, even the cladding is made from timber – a combination of wood pulp and cement tile that includes 5,000 individual panels in a pattern that mimics the shadows on the site, thus providing texture without the use of brick.

Cross-laminated Timber: A Solid Approach

Supplied by Austrian manufacturer KLH Massivholz GmbH through KLH UK, the CLT is made from industrial dried spruce boards stacked together at right angles and glued over their entire surface, much like jumbo plywood. Pre-fabricated at the factory, they arrived at the building site in panels of approximately 40 x 12 feet, in configurations that included three board layers for the walls and five board layers for the floors. Wall panels were pre-cut for windows and doors based on the project specifications.

Although CLT is not currently sold in North America, interest has been piqued by the Stadthaus building and plans are afoot to make it available in the United States and Canada. "KLH is exploring its options with regard to a North American office," said Dwight Yochim, national director of the WoodWorks program for non-residential construction, which introduced Waugh to US engineers and architects in a recent series of workshops. "We're in discussions with a developer who wants to build three buildings out of CLT in the southeastern US – likely with Andrew's participation – and another who's looking at the possibility of modular homes, which could be especially useful in post-emergency situations and for low-cost, high-density housing."

The existing thickness of the cross-laminated timber panels combined with a layer of drywall allowed the design team to achieve fire resistance ratings of 60 and 90 minutes.

The Stadthaus building at seven stories. According to the project engineer, the greatest challenge was achieving sufficient redundancy such that any single element could be removed without causing progressive collapse.

Because the panels are cross-laminated, loads can be transferred in one direction (for supports or girders, for example) or on all sides, creating unique design opportunities. KLH offers panels as large as 16.5 x 2.95 x 0.5 meters (54.1 x 9.7 x 1.6 feet), in configurations of 3, 5, 7 or more board layers, and all of the timber used comes from forests that are certified as being sustainably managed.

Environmental Goals Bring Economic Gains

When Waugh proposed to build the Stadthaus out of wood, his reasons were environmental. Between the emissions avoided by not using steel or concrete, and the fact that wood keeps greenhouse gases out of the atmosphere by storing the carbon absorbed by growing trees, he estimates that the savings are equivalent to about 300 tonnes of carbon – which is the amount the building is projected to emit over 21 years of operation.

This message worked strongly in his favor with local building authorities, who at the time were stipulating that new buildings achieve energy reduction targets of 10 percent compared to benchmark levels. (According to Waugh, the savings achieved by using timber were equivalent to meeting this target for 210 years.) However, the developers – who were used to building the area's typical concrete structures – were far more interested in wood's speed of construction and cost.

"Our clients didn't set out to be environmental heroes," said Waugh. "For us to persuade them that we were going to build a nine-story building very similar to the ones they build all over the area, but in timber instead of concrete, was initially quite a hard sell. But the efficiencies were a real eye opener."

For comparison, he presented concepts for two almost identical structures, one in wood and the other in concrete. The wood structure was estimated to cost £1,420 per square foot (approximately $2,130 USD at today's exchange rate) compared to £1,750 a square foot ($2,625 USD) for concrete, a savings at the time of 15 percent. In addition to lower material costs, the building was projected to weigh four times less than its concrete counterpart, which lowered transportation costs, allowed the design team to reduce the foundation by 70 percent and eliminated the need for a tower crane during construction. Particularly

impressive to the developers was the fact that Waugh proposed to shave five months off the typical construction process for this type of building – a goal he managed to exceed.

"The electricians estimated the job at eight weeks, spent four days on site and announced they'd be back in six weeks," he said, providing an example of the savings. "Imagine the difference walking around with a cordless drill compared to a concrete building where you're using hammer drills to drill into structural concrete soffits. It's massive."

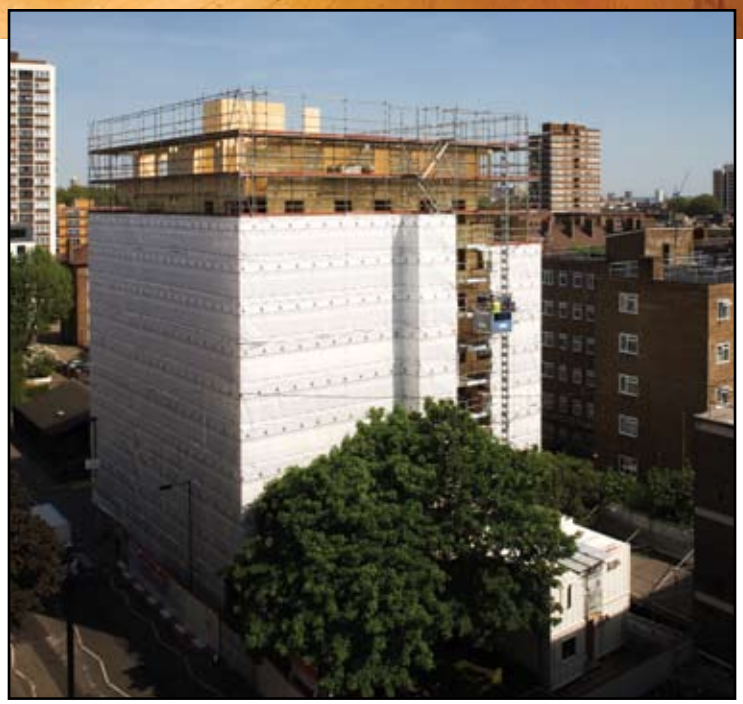
In the end, four carpenters erected nine stories in nine weeks – arriving every Tuesday with materials and completing a story on Thursday – and the entire building process was reduced from 72 weeks to 49.

Aiming Higher Still

According to Linegar, an all-timber structure is feasible up to 25 stories, but changes to the Stadthaus design would make a building that high more efficient. He and Waugh are currently working on a 15-story building made from CLT that incorporates a decreasing floor plate, starting with a larger grid and getting progressively smaller on the higher floors – a design that adds stability and, unlike steel or concrete, is simple to achieve with timber construction.

Although both Waugh and Linegar believe that taller wood structures are achievable, Linegar says p-delta effects become significant beyond the 25-story mark due to the relatively low modulus of elasticity of timber compared to steel or concrete. However, he says even that is surmountable. "Introducing a concrete core would allow us to go higher still, perhaps up to 50 stories!"▪

All graphics courtesy of Waugh Thistleton Architects.



It took four carpenters nine weeks to erect nine stories, and the entire building process took just 49 weeks.

Roxane Ward is a Vancouver, Canada-based writer who has written extensively on sustainability, forest and wood-related issues for more than 15 years.

For more information, a book on the subject – Stadthaus: A Process Revealed *by Henrietta Thompson – is available via* ***amazon.co.uk****. A webinar presentation by Andrew Waugh is also available on the WoodWorks website (****woodworks.org*** *under presentations), and technical information on cross-laminated timber can be found on the KLH UK website (****klhuk.com****).*