Performance Testing: Cross-Laminated Timber

The strength, resilience, and efficiency of an exceptional modern building material

Catalyst, Spokane, WA.
Katerra + Michael Green Architecture

Introduction: Tall Wood Building

In Ikaruga, Japan, stands the world's oldest surviving wood structure, Horyuji Temple, a vital piece of world history, and a testament to the incredible endurance—and beauty—of wood structures. Horyuji Temple's magnificent tiers, entasis columns, and cloud-shaped brackets were built from 2,000-year-old cypress in 607 A.D.

This ancient pagoda is one of several ancient heavy timber monuments throughout the world that highlight the potential of modern mass timber structures. Mass timber continues to build steam as a viable option for large commercial buildings, thanks in part to vital code changes, like revisions to the Tall Wood Building Code in late 2018, and ever-impressive modern mass timber builds, like Mjøstårnet, a 280-foot-tall tower in Norway constructed entirely out of cross-laminated timber.[12]

Mass timber was first commercialized in Austria and Germany in the early 2000s and has been instrumental in changing how regions of the world design, build, and manufacture commercial buildings. North America is in the early stages of a mass timber construction boom, driven by increasing demand and expanded building code acceptance of mass timber structures.

Horyuji Temple, Ikaruga, Japan

CLT has been used widely in Europe since its commercialization the early 2000s.

Katerra opened its first CLT manufacturing facility in 2019.

On the forefront of this early adoption in North America is Katerra. For the last three years, Katerra has helped to drive growth of the mass timber market in the North America, working to counter misconceptions and demonstrate the performance of mass timber by developing and testing the composite engineered wood product—cross-laminated timber (CLT). Katerra CLT is a prefabricated, engineered solid wood building material composed of Katerra-specified lumber, or laminations, stacked crosswise at 90-degree angles in multiple layers (plies) and bonded together under high pressure using structural adhesives.

In 2019, Katerra opened its first CLT manufacturing facility, the largest in North America, in Spokane Valley, WA. Later that year, Katerra's CLT factory reached a major milestone and produced its first certified CLT panel. That panel was delivered for project use on the Catalyst Building in Spokane, WA, a 150,000 square foot office building, and the first building of its kind to be constructed with CLT in the state. Katerra put over two years of focused effort into the development of its product and manufacturing process and underwent substantial independent laboratory testing to ensure Katerra CLT met the requirements of the International Building Code in the US and the Canadian Building Code in Canada.

Despite this significant effort, lingering perceptions remain that timber structures are less structurally-sound, less serviceable, more fire prone, or more environmentally costly.[3]

Accordingly, Katerra's mass timber product development and testing team is working to correct these misperceptions about the performance of mass timber structures by enabling developers, designers, and builders to transcend traditional construction tradeoffs, delivering performance-tested durable, safe, comfortable, cost-effective, and environmentally-preferable building solutions.

Katerra's Spokane Valley, WA, CLT manufacturing facility is the largest in North America.

Catalyst, Spokane, WA.
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21st Century Steel: The Strength and Durability of CLT

For centuries, timber was the only way to build—and it still is the primary structural material of choice for residential dwellings in the US. But, according to Pat Layton, Director of Clemson University's Wood Utilization + Design Institute, timber fell out of favor for commercial buildings when the Eiffel Tower went up.

When architects built the Eiffel Tower, building tall with steel and iron became the new, trending way to build. Then, in the 1960s going tall in precast concrete became a very popular choice, according to Layton.

Even as one hundred-year-old post-and-beam wood structures outlive concrete buildings from the '70s, concrete and steel endure as the most ubiquitous 'modern' building materials for commercial construction.

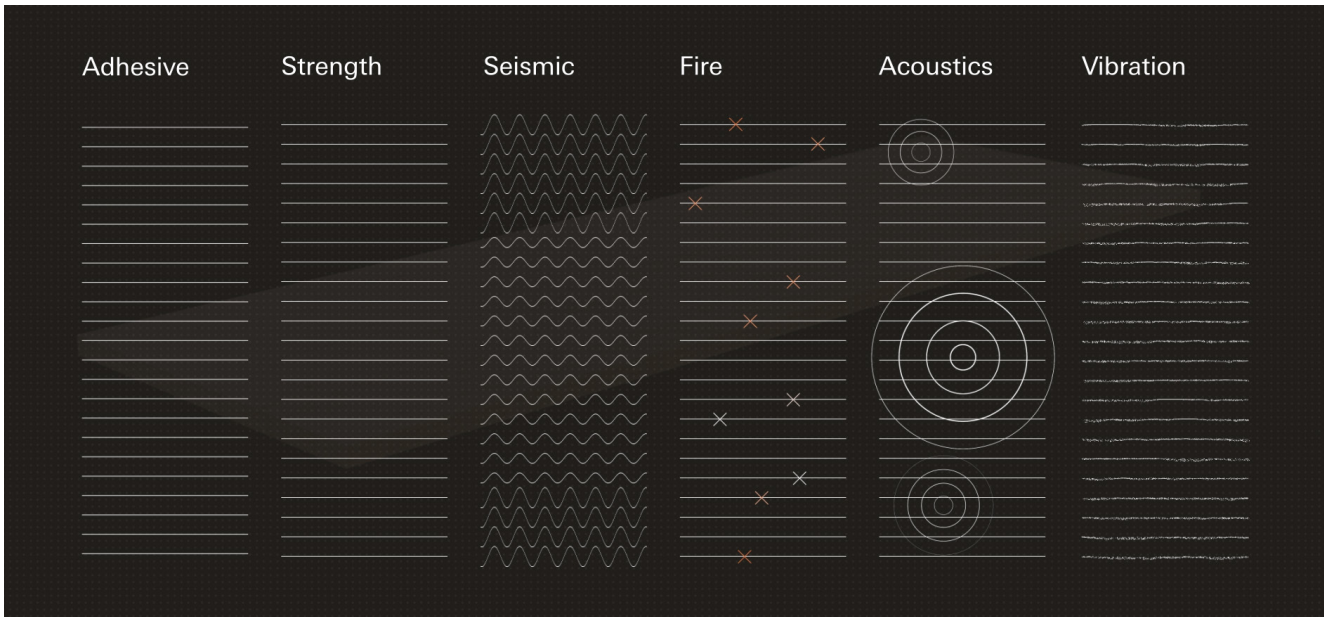
"The idea that we're going to build a ten-story building out of what someone just built a backyard shed out of doesn't seem believable. But then you can show them about the massiveness of the wood—the old buildings like the pagodas in Japan that are 700 years old and have withstood earthquakes. Wood is durable.

Wood can perform in large scale buildings" said Hans-Erik Blomgren, Katerra's director of testing and certification for structural products.

> "Despite some outdated misconceptions about building with wood, CLT is predictable, safe and reliable."

Nick Milestone
Director, Mass Timber, Katerra

Wood buildings can be built as tall and large-scale as steel and concrete with CLT and other mass timber products. CLT advocates point to Norway's "Mjösa Tower," which recently nabbed the title of world's tallest wooden building.[4] At 18 stories, it is constructed from European glued-laminated timber (Glulam), CLT, and laminated veneer lumber (LVL), all mass timber products.



Katerra's CLT has been performance tested to ensure compliance with the International Building Code (IBC) and relevant reference standards.

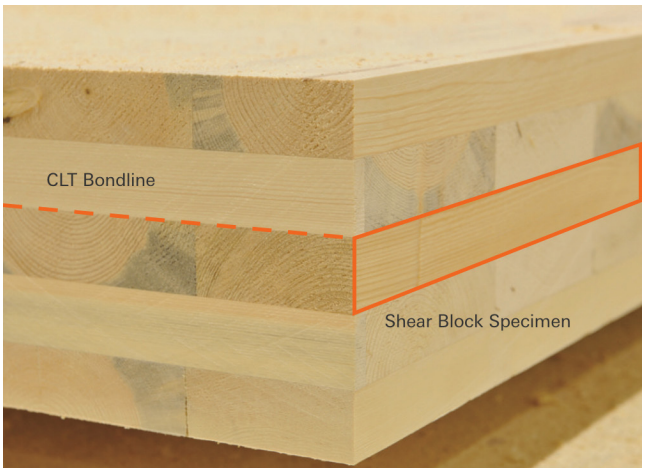
What's more, Katerra CLT is performance tested to ensure compliance with the International Building Code (IBC) and relevant reference standards including the ANSI/APA PRG 320 (2018) manufacturing standard, to underscore CLT as a sturdy, cost-effective, and sophisticated alternative to steel and concrete for market-rate apartments.

Adhesive Bondline Integrity

Because Katerra CLT is made from lumber plies, which are glued together and then pneumatically-pressed, the integrity of adhesion is vital to the overall durability of the material. For that reason, Katerra uses a face bonding adhesive that benefits the manufacturing process. This adhesive is certified by third-party agencies to meet the requirements of the ANSI 405 Standard for Adhesives for Use in Structural Glued Laminated Timber.[5]

Katerra strives to ensure bondline quality—both for face bonding and end joints. The CLT panels Katerra produces are regularly sampled in Katerra's Quality Assurance laboratory for small scale shear block testing. These tests destructively fail the bondline of the specimen in shear, and the resulting failure surface is visually evaluated to ensure the majority of the failure plane is through the wood fiber and not the adhesive itself.

Samples are then subjected to repeated rapid water impregnation and drying in our lab. A visual evaluation of the samples is then conducted to ensure there is limited to little-to-no separation at the adhesive bondline. This procedure ensures the adhesive has appropriate moisture durability, guaranteeing the overall strength of the CLT.



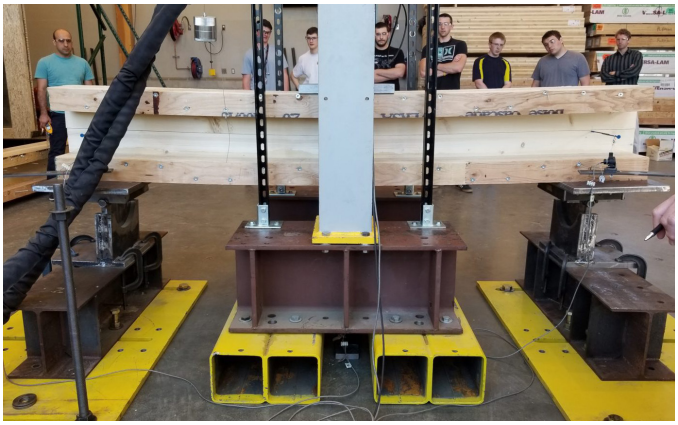
To assure bondline quality, the CLT panels we produce are regularly sampled in our factory's Quality Assurance laboratory for small scale shear block testing.

Mechanical Strength and Stiffness

Katerra CLT is produced in 3-, 5-, 7-, or 9-ply panels, pressed, and manufactured to a maximum panel size of 12 feet by 60 feet for floor, roof and wall applications. The lumber utilized in Katerra CLT is made from the Spruce-Pine-Fir species combination in accordance with the V2 CLT layup of ANSI/APA PRG 320-2018.[6] Plans to expand into Douglas-fir species offerings are in the works.

To ensure each panel has reliable strength and stiffness, Katerra CLT undergoes comprehensive destructive testing to recognized American Society for Testing and Materials (ASTM) standards. For instance, Katerra CLT's major axis flexural and shear strength and stiffness, minor axis flexural and shear strength and stiffness, and edgewise (in-plane) shear strength are all tested to ensure greater than or equal to the reported third-party product research reports 0126 and 0126 CAN.[7] These results are then used by design professionals for each specific CLT building application. As a part of this certification effort, over 400 specimens of Katerra cross-laminated timber products have been individually tested to ensure they are structurally-sound.

Flatwise flexural strength testing (top) and edgewise shear strength testing.



Over 400 specimens of Katerra cross-laminated timber products have been individually tested to ensure they are structurally-sound.

In 2017, a two-story seismic shake table test validated the performance of Katerra's patented CLT shear wall system.

CLT and Building Code Life Safety Performance

The strength and durability of Katerra CLT has significant advantages for the safety of those who build with and inhabit mass timber structures. The performance of Katerra CLT panels in a seismic environment and in fire testing has paved the way for its growing desirability in the tall buildings market.

Seismic Advantages

In 2017, Katerra was a key industry sponsor and collaborator in a two-story seismic shake table testing that validated the performance of Katerra's patented CLT shear wall system. These panels, which stand vertically, have been designed and detailed with the capacity to rock and sway while maintaining their strength to prevent building collapse.

CLT has a higher strength to weight ratio than concrete or steel, providing lighter buildings that reduce demands from gravity loads placed on the foundations and supporting soils, as well as the lateral loads introduced by seismic shaking.

CLT as a quality retrofitting material for seismic has been verified by other industry players, as well. In fact, Andre Barbosa of the Oregon State University College of Engineering teamed up with Cascadia Seismic Strategies on a $150,000 study of the use of cross-laminated timber panels for seismic retrofits on unreinforced masonry buildings.

Two-story seismic shake table test.

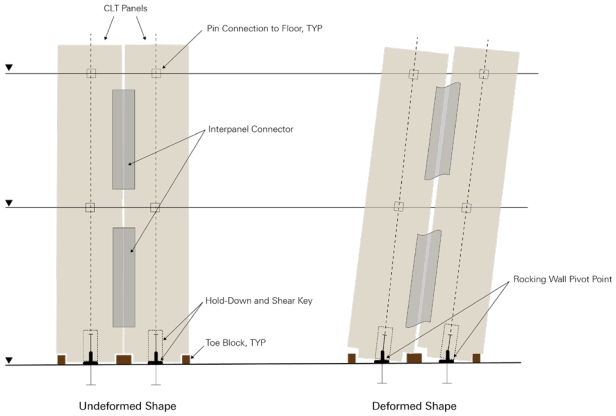
According to project manager and historic preservation architect Sue Licht, this project identifies seismic retrofits for historic buildings that improve their safety performance without compromising their historic integrity.

A forthcoming 10-story shake table test by Colorado School of the Mines with Katerra acting as the industry sponsor, the NHERI Tall Wood Project, is slated for 2021.[8]

Additionally, Katerra is serving as an advisor to the University of Utah whose testing is funded by US Forest Products Lab. This project has another progressive idea for filling current gaps in the code for a building's lateral system with timber buckling-restrained braces. In this

method, mass timber components are used to construct braced frames that make a structure more ductile under wind and seismic forces.

"Buckling Restrained Brace Frames (BRBF) are a proven and reliable method for providing an efficient lateral force resisting system for new and existing structures in earthquake prone regions. The fuse-type elements in this system facilitate stable energy dissipation at large load deformation levels. Currently, the new trend towards mass timber vertical structures creates a need for a lightweight compatible lateral force resisting system," wrote Blomgren in his paper for the International Network on Timber Engineering Research conference.



Katerra's patented CLT shear wall system has been validated by rigrous seismic testing.

Fire Protection

Concrete and steel structures' popularity grew not just because of the success of the Eiffel Tower's construction, but also in-part due to fallout over the Great Chicago Fire of 1871, in which 17,000 buildings—commercial and residential—were destroyed and 300 people were killed.

Fire protection became a chief concern of architects and engineers, particularly when it comes to multifamily dwellings and buildings with a large number of occupants. The Great Fires of history have steered many developers, engineers and architects of tall buildings away from timber.

However, CLT exhibits an innate fire resistance, contrary to the belief that wood structures are less fire safe. According to a report by Woodworks, "Numerous ASTM E119 assembly tests have been performed with CLT showing how wall and floor assemblies, both exposed and covered with noncombustible materials, can provide up to a 3-hour fire-resistance rating (FRR) [Osborne, 2012].[9]

Still, the perception persists that wood buildings, easily combust—stemming, in many cases, from city code changes inspired by the destruction Chicago's Great Fire. Wood is indeed combustible, but it is still *extremely fire resistant*. While steel is non-combustible, it has almost no fire resistance at high temperatures, and when it fails due to heat, it rapidly loses strength. When these codes were established many years ago, officials didn't have the knowledge and technology we do today to test and verify the safety of mass timber buildings.[10]

In addition to passing the required furnace testing, Katerra CLT is tested for spread of flame and smoke index ratings.

A load is applied for large scale horizontal furnace fire-resistive rating testing..

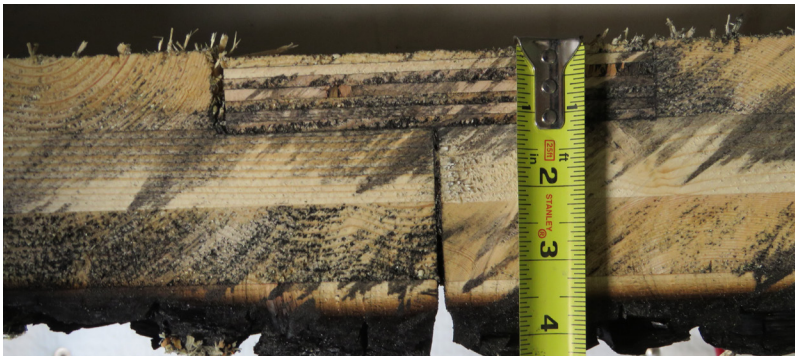
The recently published 2021 International Building Code Tall Wood Building provisions are informed by a better understanding of fire-resistant construction gained through testing, and now permit CLT to be used for an exposed floor or roof element in construction types that allow combustible construction requiring one or two-hour fire-resistive ratings. This was determined through large-scale horizontal furnace testing of Katerra CLT panels per ASTM E119 *Standard Test Methods for Fire Tests of Building Construction and Materials*.

Katerra has successfully completed this testing, which requires the product to endure furnace temperatures of over 1,500F (815C) for one to two hours in an independent lab, with our fully loaded Floor Assembly Layup K5-0540 (1hr FRR), Roof Assembly Layup K5-0540 (1 hour FRR), and a Floor Assembly Layup K-0630 (2 hour FRR).

In addition to passing the required furnace testing, Katerra CLT is tested for spread of flame and smoke index ratings, verifying it performs up to the standards outlined by ASTM E84 in different building applications and meets the same ASTM E84 testing requirements for other materials in non-combistible buildings.

> "Our additional testing demonstrates that if a fire happens the ignited CLT surfaces don't develop too much smoke, and that fire can't develop along the surfaces too rapidly. This is a key criteria of fire safety because if a fire advances too quickly, occupants often can't exit the building in time."

Hans Erik Blomgren
Director, Testing and Certification, Katerra



Visual examination of floor spline joint testing cross-section post-fire test.

Katerra Mass Timber Office Concept

User Experience and Comfort

Beyond the demonstrated strength, durability and life safety attributes of mass timber, Katerra's CLT benefits the commercial construction industry by delivering one-of-a-kind structures that people want to live and work in.

Acoustics and Vibrations

When designing market-rate apartments, acoustic separation provided by the walls and floors that separate living units are vital to creating desirable residences. Katerra is continuously developing and measuring the acoustic performance of its CLT floor assemblies, keeping the comfort of occupants in mind.

Beyond using innovative designs to enhance its acoustic rating, Katerra CLT has undergone several tests to quantify its acoustic and vibration performance.

Katerra CLT has been tested at the accredited Intertek acoustic laboratory in York, PA to ASTM standards recognized by the building code—Airborne Sound Transmission Class (STC), which measures how sound travels through air, as well as elements like partitions, and Impact Insulation Class (IIC), which measures how sound is transferred through floor assemblies and the rest of the structure.

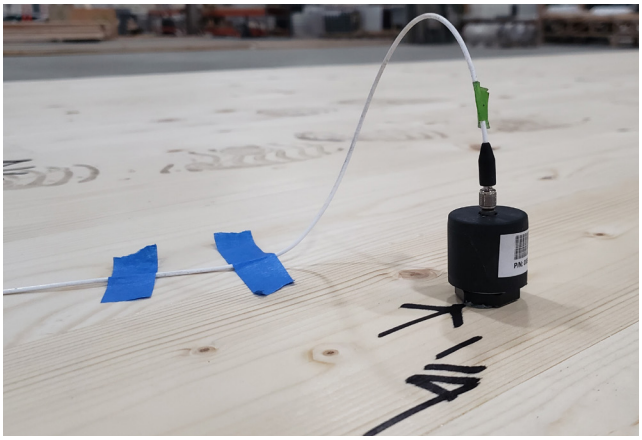
In 2017, Katerra constructed full scale multifamily housing unit mockups with CLT floors at its CLT facility in Spokane and brought in internationally recognized acoustics and vibrations consultants from ARUP to measure the airborne and impact sound transmissions of a custom topping assembly. The floors were also tested for the perceptibility of their vibration response to the frequency of occupants walking within the apartment unit.

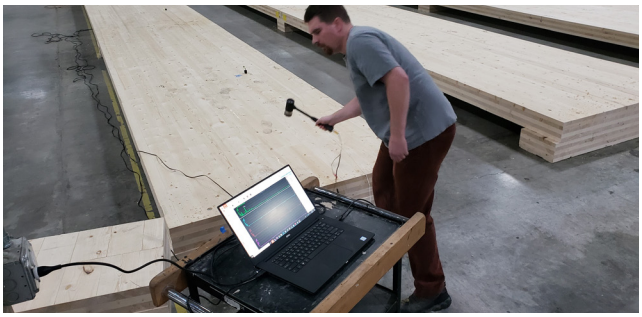
"The acoustic and vibration performance of flooring or any building environment is really important to how we perceive comfort in the building environment," said Peter Dodds, Acoustics AV Theater Consultant from ARUP.

Katerra's CLT performed so well, the company was able to move forward on its first market-rate apartment projects using CLT.

Katerra subsequently completed an extensive floor vibration testing program to support the company's multi-story CLT office projects. This test data is used to accurately assess the vibration performance of up to 30-foot Katerra CLT floor spans.

"A developer can't undercut acoustic performance because you end up with a building people don't want to live in. The walls and ceilings must have a classification through testing measurements at an independent lab," said Blomgren. "When we design CLT exposed ceilings we attain the acoustic rating by designed and engineered assembly of materials on the top side."





Katerra CLT is tested at the accredited Intertek acoustic laboratory in York, PA

Project Highlight: The Postmark

The Postmark will include 243 apartment units in two 5-story buildings above a two-level below-grade parking structure. This project is the first of its kind using Katerra's CLT. Its performance in Katerra's rigorous acoustics testing make it an ideal material for this exceptionally performing multifamily building.

LOCATION

Shoreline, WA

TYPE

Mid-Rise | Multifamily Market-Rate

SERVICES

Architecture and Engineering, Design Coordination, Materials, Construction Management

The Catalyst Building in Spokane, WA, uses Katerra CLT.

Thermal Response

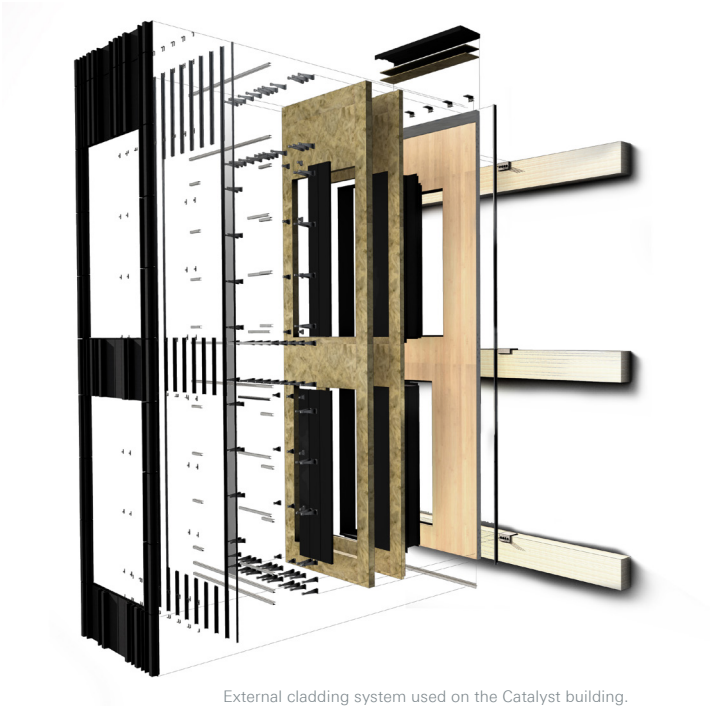
CLT can be advantageous to use as the structure for external wall assemblies in commercial buildings. According to an article in The American Wood Council's magazine, reThink Wood, CLT provides thermal mass because it is a solid wood panel, is quite airtight and as a result, requires less insulation.[11]

CLT responds particularly well in cold climates and is quick to construct due to its prefabrication, making it a favorite of builders and architects in climates with a shorter construction window, like parts of northern and eastern Canada, according to Journal of Commerce.[12]

"All the insulation goes on the outside and there is no thermal break — it is like putting a jacket on," technical adviser Bill Billups for Wood WORKS! B.C. told the Journal.

Bearing this in mind, Katerra CLT was implemented for external cladding on the Catalyst building. The Catalyst project uses a 3-ply CLT curtainwall system, which offers numerous improvements in thermal and acoustic performance than an insulated cold-formed steel wall. It also provides a monolithic substrate for fastening exterior insulation and finishes.

The Catalyst building was tested for air leakage, and the results were among the best the testing agency had ever seen in a large commercial building. The Catalyst measured an air leakage rate of 0.035 cfm per square foot, a remarkably low result, even below that of the requirements for Passive Haus rating, the highest of green-building standards. Low air leakage translates to high energy performance. CLT panels are proving to be a superior substrate for building envelopes as well.



External cladding system used on the Catalyst building.

Katerra Mass Timber Office Concept

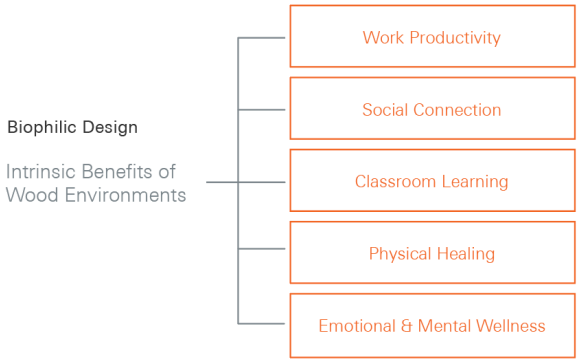
Aesthetics and Biophilic Properties

CLT also expands an architect's pallet, which is traditionally limited to steel, concrete, and masonry, because it can be left exposed due to its innate fire resistance. This not only creates a pleasing aesthetic effect but also prevents the need for framing, decking, topping, fire proofing, and final finish.

"Developers can market a building type that is distinctly different than the status quo. In a typical market-rate apartment, all of the walls and ceilings have to be covered with sheetrock, but with CLT you can expose the wood structure in the living unit. In the right markets, there will be demand for these living units because the customer is going to love the wood feel," said Blomgren.

Exposure to natural materials like wood has been linked to many positive benefits for commercial and residential inhabitants. This phenomenon, called biophilia, is also linked to a building's long-term ROI. Hundreds of studies corroborate that biophilic elements like sunlight, views, vegetation, air quality, and use of natural materials can have beneficial impacts on health, wellbeing, and productivity.

Exposed CLT as an alternative to conventional, less durable finishes can also increase building longevity. The patina of visible wear and aging is often seen as a positive factor in wood materials, reducing long-term capital and operational expenditures stemming from renovations, upgrades, and redesigns.



Cirrus, Denver, CO

Additional Performance Benefits: Construction Efficiency and Environmental Impact

The nature of cross-laminated timber as a prefabricated, engineered wood building material means it has unique and often superior environmental and efficiency attributes.

"Mass Timber is creating disruption in the construction industry by improving the vertical integration roadmap," said Nick Milestone, director of Mass Timber at Katerra. "For example, Katerra can own the in-house supply chain and deliver it more effectively with offsite technology. Mass timber is absolutely intrinsic to a vertically integrated approach based on its design for manufacture characteristics."

Construction Speed and Safety with CLT

A prefabricated material, weighing about 75 percent less than concrete with comparable strength, Katerra CLT moves construction labor upstream and offsite to our Spokane Valley factory's controlled environment, speeding site-build times, improving safety, and mitigating many of the risks associated with traditional construction sites.

Installation of Katerra CLT at Cirrus, a 292-unit multifamily mid-rise building in Denver, CO. Five- and seven-ply CLT panels will be used for five stories of exposed ceilings.

350 ribbed panels were prefabricated offsite and delivered to Catalyst.

Take for instance, Katerra's rib panels on the Catalyst building. Using its internal team of engineers and manufacturing, Katerra developed a long-span mass timber floor solution – the Katerra Rib Panel - during the project design phase. The rib panel is comprised of 10 foot by 30 foot CLT panels with two glulam compositely bonded to serve as 'ribs' to strengthen and stiffen the panels. This is the first known application of this technology in North America. The rib panels were designed and tested to satisfy strength and vibration performance for the 30 foot span office building use. Three hundred and fifty of these panels were prefabricated off site and delivered on-site to Catalyst, significantly improving the efficiency of the floor installation and the overall project schedule.

> "When we take each panel to site, it is pre-cut, pre-drilled, for assembly, without any secondary work required on site."

Nick Milestone
Director, Mass Timber,
Katerra

CLT Reduces Carbon Emissions

While the extraction, processing, and fabrication of steel and concrete are significant sources of CO2 emissions, trees sequester carbon as they grow, and that carbon is stored in wood product for the life of the product. The Nature Conservancy has identified expanding markets for forest products from sustainably managed forests, such as building with mass timber, as a "natural climate solution" that can simultaneously help the climate while boosting jobs.

As a 2014 study in the Journal of Sustainable Forestry found,[13] replacing the steel used in construction with timber such as CLT could cut global CO2 emissions by 15-20 percent. According to a report from the USDA, "the near-term use of CLT and other emerging wood technologies in buildings 7-15 stories could have the same emissions control effect as taking more than 2 million cars off the road for one year."[14] An LCA study of the Catalyst building conducted by the Carbon Leadership Forum and the University of Washington found that building with wood will avoid an estimated 1,437 metric tons of CO2 emissions, the equivalent of taking 1,100 cars of the road for a year.

The "embodied carbon intensity" of the Catalyst Building was estimated to be only 207 kgCO2e/m2 (the CO2 emissions associated with extraction, transportation, and manufacturing of building materials). The wood in the building is estimated to store approximately 204 kgCO2e/m2, almost completely offsetting the embodied carbon of the building products used in its construction. With the addition of planned renewable energy systems to meet operational energy needs, a future of Net-Zero-Carbon buildings is within reach.

Catalyst, Spokane, WA. Katerra + Michael Green Architecture

"The emerging interest in mass timber is that it replaces steel and concrete," said Blomgren. "And, if you use CLT in the enclosure, like we did on the Catalyst building project, you've replaced a good amount of aluminum—and the energy-intensiveness for aluminum is off the charts."

Building with CLT can also positively impact operational carbon emissions—largely because of cross-laminated timber's improved thermal response and as evidenced by the remarkable air leakage test results at the Catalyst building.

According to a 2016 study from the Journal of Architectural Engineering, "A 10-story multi-unit residential building model constructed using CLT was simulated and compared with a light-frame metal construction model with the same floor plan. It was concluded that CLT generally provides significant improvement on heating energy efficiency as a heavy and air-tight envelope, but its energy performance efficiency can be affected by weather, building size, internal loading, and HVAC control."[15]

Project Highlight: The Catalyst Building

3,713 Metric tons of carbon dioxide stored in the project's mass timber.

1,437 Estimated metric tons of CO2 emissions avoided.

1,100 Equivalent number of cars taken off the road for a year.

Katerra's Spokane Valley CLT has CoC certification under three major certification programs: SFI®, FSC®, PEFC.

CLT and Forest Protection

Aside from the environmental benefits associated with reduced embodied carbon of wood, Katerra sources all lumber for its CLT from sustainably managed forests. Katerra's CLT factory can provide customers chain of custody certification from three major certification programs: Sustainable Forestry Initiative® (SFI-03536), Forest Stewardship Council® (FSC C156195), and the Programme for the Endorsement of Forest Certification (PEFC/29-31-382. These certifications help Katerra's CLT clients meet green building standards like LEED and Living Building Challenge.

CLT may also contribute to the sustainable management and preservation of timberland in some surprising ways. First, landowners may be more willing to keep and take care of their land if they know they can harvest it for use in CLT more frequently due to the smaller dimensional lumber used in CLT.

"Really, a lot of people would like to see their timberland have a more consistent revenue generated—as an investment," said Pat Layton, Director of Clemson University's Wood Utilization + Design Institute. "So, the idea of being able to harvest some wood off the land every 10-15 years is a really great opportunity to keep people engaged in keeping their lands and forests. If they don't have a revenue stream, then they may be out there selling their land for golf courses and developers."

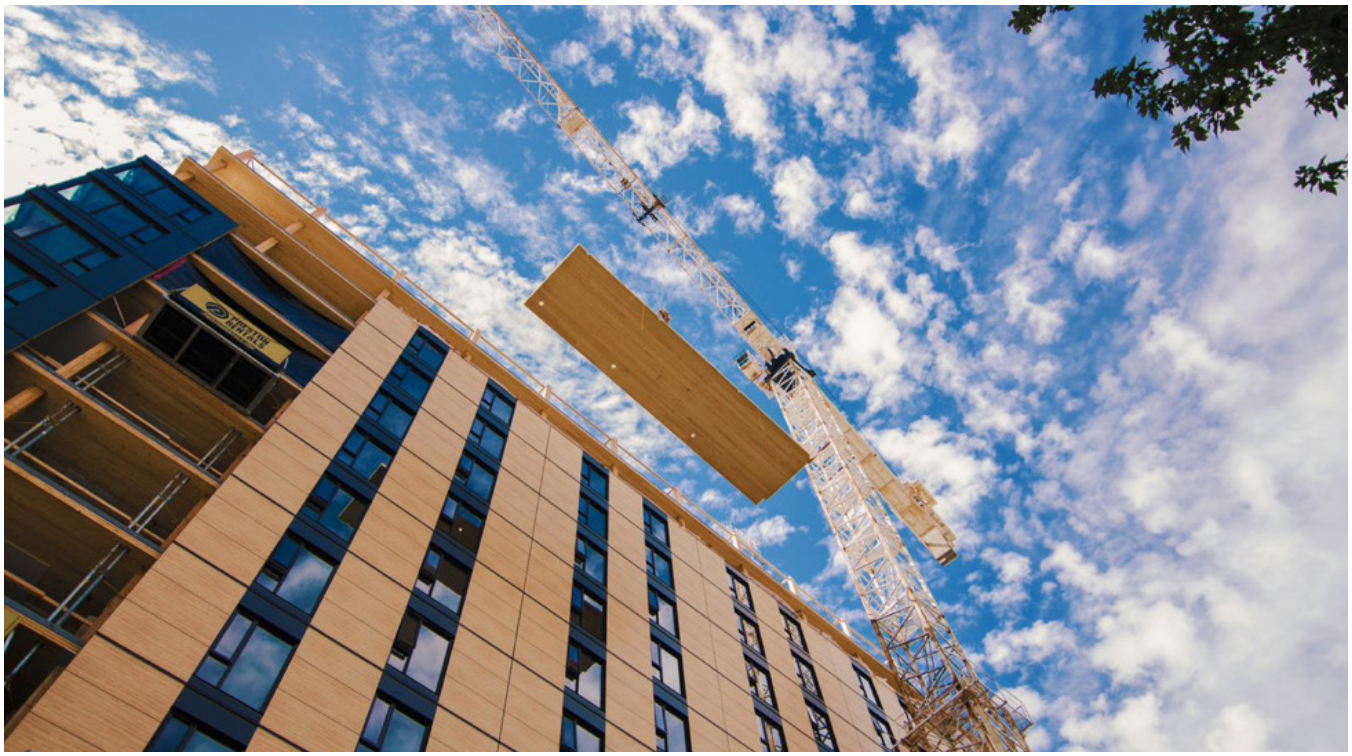
Layton also describes how CLT could be helpful in keeping our forests healthy and reducing the chance of wildfires—which are managed by thinning and setting prescribed fires.

"If we're going to thin, it costs millions of dollars if you do nothing with the wood, and where are you going to put it? One of the beauties of mass timber and increasing the number of wood products—including paper—is that we can take that wood, pay for it, and that then becomes either a paper or wood product that can be used," Layton said.

FSC www.fsc.org FSC® C156195 The mark of responsible forestry

PEFC™

SUSTAINABLE FORESTRY INITIATIVE SFI-03536



Brock Commons Tallwood House: Acton Ostry Architects, Vancouver, BC

Conclusion

Offering a host of superior performance benefits—innate fire-resistance, incredible seismic resilience, a sophisticated aesthetic, cost-competitiveness, embodied carbon reduction and a renewable, sustainably-sourced natural product—CLT is currently gaining acceptance across the United States. As of March 2020, 784 multifamily, commercial, or institutional projects were in design or constructed with mass timber in all 50 states according to a report of mass timber building trends from the Wood Products Council.

Katerra's experience with CLT has been no exception. After exhaustively testing Katerra CLT to ensure it meets all applicable construction codes and performance requirements, optimizing CLT's various performance benefits as compared with steel and concrete, Katerra's certified CLT panels entered the market in July 2019. Since then, Katerra has supplied a number of projects with their CLT and continue to explore new and innovative ways to put CLT to use in a variety of buildings.

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Thank you.

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