MASS TIMBER METHODS

An Investigation of Approaches to the Challenges, Opportunities, and Wellness Benefits of Mass Timber Architecture

Molly Taylor
Hart Howerton Travel Research Fellow
Summer 2017

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Hart Howerton

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PREFACE

Since 2006, the architecture and planning firm Hart Howerton has been committed to funding independent student research through an annual summer travel fellowship program. For summer 2017, the firm was interested in how to create conditions in the built environment that pro-actively improve health outcomes, while simultaneously arguing that these investments in health provided for an improved "return on investment" for owners when developing based on a wellness paradigm.

Since 2014 I had been at the University of Oregon (UO) working toward dual master's degrees in architecture and interior architecture. During my second term at the UO, I took the Building Construction course that, in addition to construction systems, covered the ecology of various building materials and their impact on the environment. I was alarmed to learn that according to the U.S. Energy Information Administration (EIA), about 47% of global greenhouse gas emissions are caused by buildings, both their construction and their operation[1]. According to a 2014 study published in the *Journal of Sustainable Forestry*, concrete and steel production contribute about 14% of total global fossil fuel emissions[1]. Most large buildings in the U.S. today are built primarily of concrete and steel. Since the development of steel-reinforced concrete in the 19th century these materials have come to dominate the building industry in many structure types, especially for larger and taller constructions.

For me, an aspiring architect, this was a bit of a let down—no matter what I would build, it would be contributing to this problem as long as it made use of these fossil fuel-intensive materials in conventional ways. This information also felt like a call to action: if I wanted the buildings I would help design to be positive additions to the planet, I needed to be conscious of not just their social, emotional, and aesthetic qualities, but also of 1) their operational energy needs from cradle to grave and 2) the use of carbon-intensive materials such as concrete and steel in their construction.

As my education at the UO progressed, I started to become familiar with a world of wood products and construction systems I now know to refer to as "mass timber." It became clear to me that while the conventional manner of construction makes heavy use of concrete and steel, many of these buildings could technically be built using less concrete and steel, and more engineered wood "mass timber" products. I also was drawn to wood simply for its natural beauty, and I liked the clarity of the process by which wood comes to be: starting with photosynthesis the sun's energy transforms into a tree, and then the tree becomes lumber, and the lumber becomes a usable, machinable building material. My interest in wood and mass timber grew with each passing class and studio project.

In late 2016 I learned of Hart Howerton's summer travel fellowship, and their interest in exploring win-win scenarios when it came to human wellness and improved return on investment. It occurred to me that nature has been closely linked with wellness, and that perhaps there existed research supporting a similar positive effect on wellness due to the presence of natural materials in built interior spaces. Wood is a natural material, and it is also a structural building material. I thought that it would be interesting to study links between wood and wellness, and the benefits and challenges of building with mass timber products, and see what synergies might be observed between these two points of view. Hart Howerton thought so too, and I was thrilled to be selected as the 2017 Hart Howerton summer fellow out of the San Francisco office. This report is the end product that has come out of that fellowship experience.

Molly Taylor, January 2018

THANK YOU

This report is a product of a research project made possible by the Hart Howerton Travel Research Fellowship program. Hart Howerton's commitment to independent student research every summer since 2006 is inspiring and I feel incredibly grateful to have been a part of it. Thank you to David Howerton, Robert Hart, and all of the Hart Howerton staff for making the Fellowship possible. Thank you in particular to my fellowship committee in the San Francisco office: Eron Ashley, Christopher Pizzi, Rachel Hsu, Karl Sveinsson, and Sarah Bice.

My deepest thanks to each person who took the time to communicate with me over the course of this project. Your anecdotes and insights were invaluable. In order of our meetings:

Iain MacDonald of the TallWood Design Institute in Oregon, who gave me case study and research advice; David Fell of FP Innovations, who referred me to fascinating research linking wood and human health; Joseph Mayo of Mahlum Architects, and author of the 2015 book Solid Wood: Case Studies in Mass Timber Architecture, Technology, and Design, who answered my questions by phone before my trip and met with me in Seattle; Dean Lewis of DCI Engineers in San Francisco, who gave great advice before and after the trip; Emily Dawson of SRG Architects, who answered my questions by phone before the trip and met with me in Seattle; Alex Zelaya of Hacker Architects and the excellent tumblr blog Resilient Wood, who also answered my questions by phone before the trip and met with me in Portland; Beatrix Boutonnet of B&O Group, who spent a day showing me around the Bad Aibling campus; Daniel Nieberle of Rubner Holzbau, the site manager for the Green Center Kaufbeuren project who showed me around the construction site; Christian Dörschung of Christian Dörschung Carpentry + Timber Construction, who took me to lunch near the Green Center Kaufbeuren to discuss mass timber construction; Christoph Gruler of Rubner Holzbau, who sent detailed email responses to my follow-up questions; Sebastian Pint of Schankula Architekten, who met with me and also provided diagrams included in this report; Thomas Auer, head of the Building Technology and Climate Responsive Design Chair at the Technical University of Munich (TUM); Laura Franke, a graduate student in the Auer chair who spent an afternoon showing me around TUM; Stephan Ott, a researcher in the Stefan Winter Chair at TUM who shared his research; Evelyn Brandt, my gracious AirBnB host in Feldkirch, Austria; Leonie Neff of CREE who showed me LCT One; Christoph Dünser of Hermann Kaufmann Architekten, who spent two hours meeting with me and provided drawings, images, and advice; Ivo Walser and Susanne Kremmel of Vorarlberger Mittelschule, who gave me a tour of the campus during a school holiday; Oskar Leo Kaufmann and Gordian Kley, who orchestrated a meeting for me at Merz Kley Partner; Bertram Käppeler and Martin Vogelmann of Merz Kley Partner, who answered all my questions about room-modular construction; Robert Abbrederis of Getzner, who helped turn a serendipitous meeting into a crash course in sound control in timber construction; Dr. Andrea Frangi of ETH Zurich's Institute of Structural Engineering, who spent an afternoon talking with me and showing me various research projects around campus; Craig Curtis, Hans-Erik Blomgren, and many more of Katerra, who talked with me about Katerra's exciting plans for mass timber in the U.S.; Deborah Sigler, who gave me a tour of the Bullitt Center in Seattle; Dawn Melody, Mingyuk Chen, and Amanda Reed at Michael Green Architecture, who met with me despite scheduling difficulties; Dr. Peter Marshall, who showed me around the mass timber buildings on the UBC campus; Thomas Robinson, Jonathan Heppner, and Geoff Sosebee of LEVER Architecture, who gave me a window into the cutting edge of mass timber construction in the U.S.; and finally, thank you to all of the users, passersby, and survey respondents who spoke with me about each project. If you ever encounter this report, thank you for speaking to a stranger about wood architecture.

Thank you also to my mother, Sally Ellis, for painstakingly proofreading this report. All remaining errors are my own.

Introduction:
MASS TIMBER

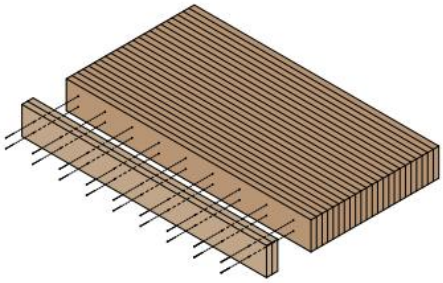
Human construction practices have varied by region, culture, and climate over time, but there is little doubt that wood has played a significant role as a building material throughout the history of building construction. The use of wood to support human structures predates the invention of masonry, and its relative ease of machinability and accessibility over millennia have ensured its continued relevance. However, since the innovation of steel-reinforced concrete of the 19th century, concrete and steel have come to dominate the construction of most large building types. An examination of our urban landscapes make it clear that buildings constructed using primarily concrete and steel have a monopoly in this area.

In past decades, however, new innovations in wood products have opened up new horizons in wood architecture and construction. These wood products are "engineered," which refers to the process of fixing together the strands, particles, fibers, veneers, or boards of wood using adhesives or other methods to form composite materials. The construction industry has long made use of engineered wood products such as plywood and OSB, but a range of products that can perform structurally in ways similar to concrete and steel are referred to as "mass timber" products. These product innovations have given rise to a new category of construction methods referred to as "mass timber" construction.

While different approaches exist within the mass timber construction category, all use wood, usually a mass timber product, as the primary structural material. All of the mass timber products mentioned in this document are defined on the following page. On all subsequent pages these products are referred to using their acronym or nickname.

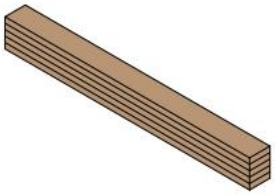
Mass Timber Products

NLT - Nail Laminated Timber



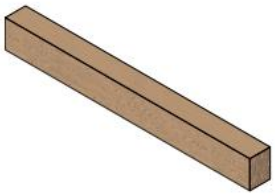
- The most traditional solid wood panel element; goes back at least 150 years
- Individual members can be bent and assembled to create custom curved structures
- Panels not airtight
- Plywood sheathing adds lateral strength

Glulam - Glue-laminated Timber



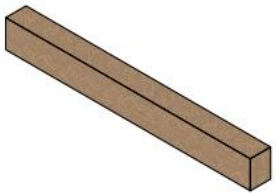
- First patented in 1901 in Switzerland
- 10% weight of steel, 20% weight of concrete
- Low strength-to-weight ratio enables efficiencies in transport and construction

PSL - Parallel Strand Lumber



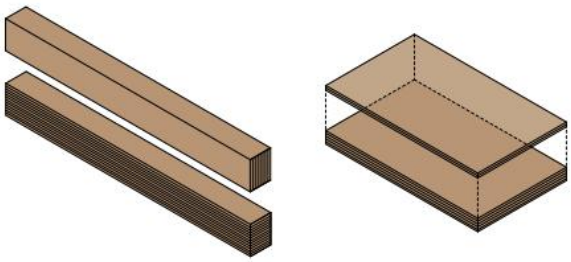
- Patented in the late 1960s
- Uses wood strands and strips oriented in the same direction. Strips are longer than those used in LSL
- Uses a higher percentage of the log than LVL or traditional lumber techniques

LSL - Laminated Strand Lumber



- Patented in the late 1960s
- Similar to LVL, but uses flakes instead of veneers
- Flakes can be taken from small-diameter tree branches
- Uses cheaper, faster-growing tree species typically used as pulp logs, unlike LVL and PSL
- Lower strength than LVL

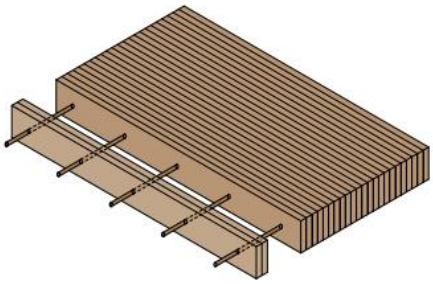
LVL - Laminated Veneer Lumber (AKA "Microlam")



beam configurations *panel*

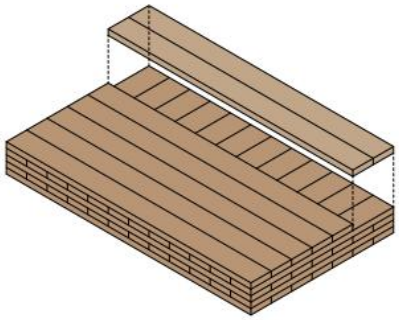
- Patented in the late 1960s
- Less expensive than glulam, though not quite as strong
- Considered not as attractive as glulam
- Uses small dimension, rapidly-renewable tree species

DLT - Dowel Laminated Timber



- Invented in Germany in the 1970s
- Softwood planks and hardwood dowels, differential moisture content ensures strong connection
- Sometimes glue is also added
- Can do cross-banded DLT, though it is not as strong as CLT
- Dowels can be arranged diagonally in an "X" rather than as shown

CLT - Cross Laminated Timber (AKA "Crosslam")



- First employed in German roof systems in the mid-1970s, patented in France during the mid-1980s, and developed for commercial production in Austria and Germany in 1990s
- Originally developed as a way to reduce waste in saw mills
- Utilizes low-grade wood of smaller dimensions to produce a large, structural-grade panel
- Two-way span
- Can be used as floors and shear walls
- Panels are monolithic and experience little shrinkage
- Performs well in fire—"A" rating with ASTM E84-15b

Mass Timber Products not referenced in this document:

OSL - Oriented Strand Lumber

- Similar to LSL and PSL, but lower strength and stiffness

MPP - Mass Plywood Panels

- Designed as an alternative to CLT with similar strength but using less wood

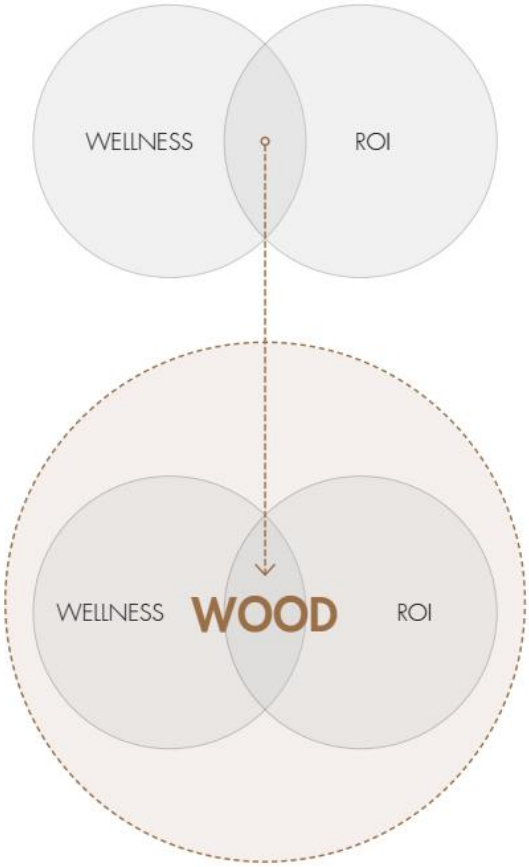
Part 1:

RESEARCH CONTEXT

Intuition tells us that viewing and experiencing nature are beneficial for human health and wellbeing. Since the 1980s, scientists have been investigating whether or not there is any substance to this intuitive connection between nature and wellness. Researchers have found that nature can offer human beings health benefits in a variety of ways. Walking in nature, viewing a natural scene out of a window, and bringing plants indoors are all ways that nature can be employed to benefit human health.

Most importantly for the purposes of this report, there is another way to bring the benefits of nature indoors: using natural materials, such as wood, in our buildings. This section introduces the context of the fellowship proposal and research by summarizing the health benefits of wood in our interior environments, and drawing connections between this research and mass timber construction.

Research Proposal



Hart Howerton has been working to identify and measure outcomes associated with wellness-focused design. In doing so, the firm hopes to find ways to attain an improved return on investment (ROI) for owners when developing based on a wellness paradigm. This interest in exploring win-win scenarios when it comes to human wellness and improved ROI ties in well with mass timber products and construction, given both 1) the connection between natural materials and human health, and 2) the non-health-related benefits possible with mass timber construction systems. This research aims to explore the connection between wellness and ROI when it comes to mass timber construction, with literature reviews, in-person interviews, and an electronic survey distributed at case study sites.

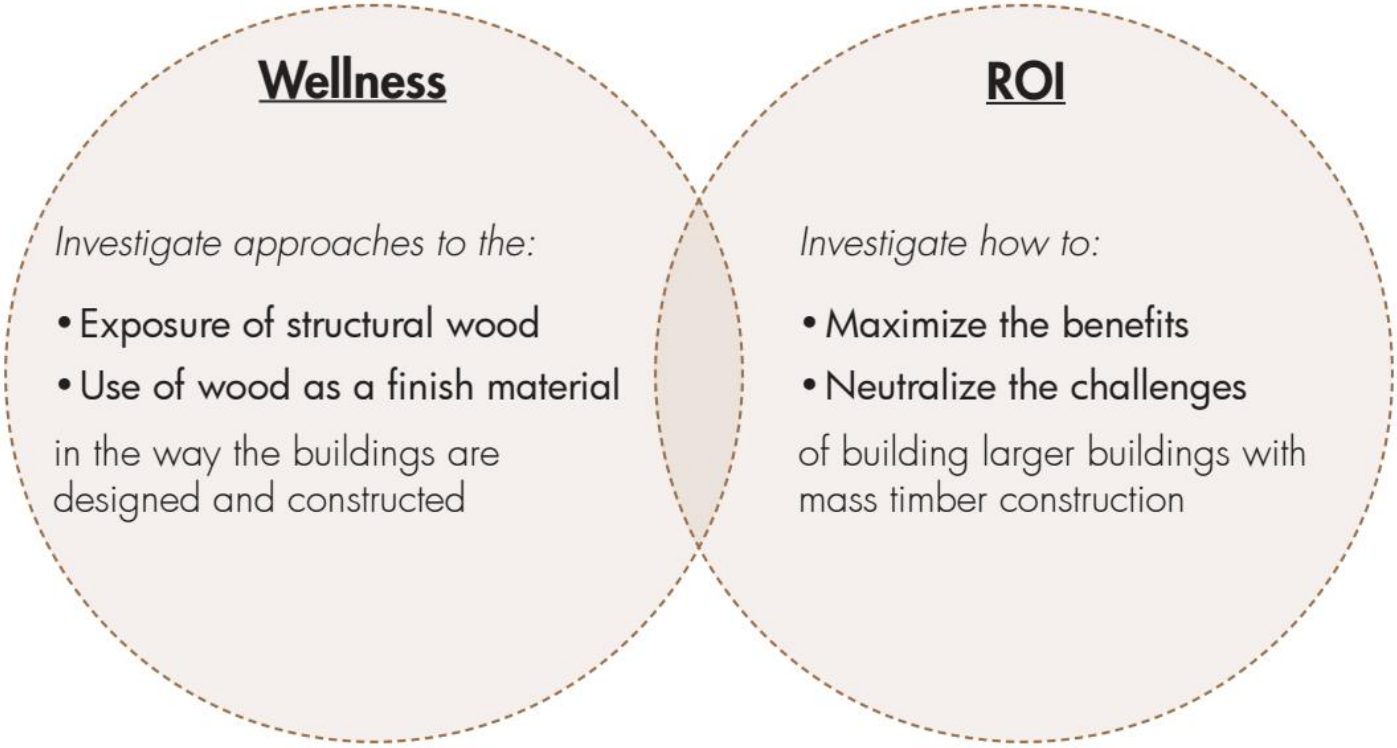
Evaluating the ROI potential of mass timber construction necessarily involves researching what sort of investment is involved in undertaking this construction type. Building with mass timber is different from building with concrete and steel, and it comes with both opportunities and challenges when applying mass timber construction to building types more commonly undertaken with other building materials. In order to evaluate the ROI potential, it is necessary to investigate what methods mass timber professionals use to maximize the benefits of building with mass timber products and neutralize the challenges associated with these new systems.

There are many ways that buildings can affect human health. Indoor air quality, light quality, ventilation, and more all impact the wellbeing of building occupants. While all ways that buildings impact health are important, this investigation of mass timber methods

focuses on the health benefits associated with visible wood in its capacity as a natural material. Of particular interest to me is whether or not there is a difference in the perception of wood based on whether it is used as a structural material or a non-structural finish material.

Research methods combined a literature review with in-person interviews and an electronic survey. In-person interviews included users encountered on case study sites as well as scheduled interviews with architects, engineers, carpenters, and other professionals involved in case study buildings. The survey link was distributed at case study sites, and focused on user perceptions of the buildings' structural materials, finish materials, and spatial design. Insights from interviews and the survey are discussed in individual case studies in Part 2: **CASE STUDIES**, and survey results are examined as a whole in Part 3: **INSIGHTS**.

The rest of this section will outline the main take-aways from the literature review in terms of the relationship between wood and wellness and the extent to which there is a difference between the effect of wood when used in a structural application versus in a finish application.



Plants + Health

The bullet points below summarize the established benefits, through published, controlled scientific studies, of plants on human health and behavior. Studies like these that investigate links between plants and wellness activated the curiosity of researchers who wondered whether the beneficial powers of plants extended to natural materials used in building design.

Bullet points summarizing the links between wellness and wood are listed on the following page, with important words and phrases **highlighted in bold** for emphasis.

The information on these pages is paraphrased from a June 2015 publication by Sally Augustin of Design With Science and David Fell of FP Innovations titled *Wood as a Restorative Material in Healthcare Environments*[1]. This publication is a review of published research on the human response to natural elements in the built environment, and was an invaluable resource in this mass timber methods investigation.

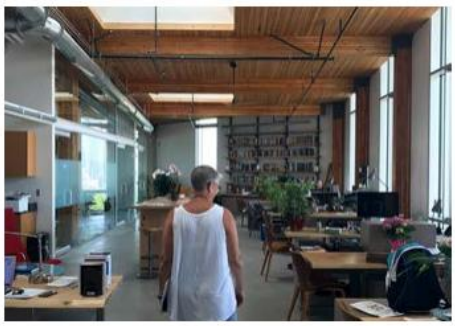
Plants in the interior of Ludesch Community Center (case study p. 97).

- Lower blood pressure, heart rate, and aggression
- Lower pain perception
- Increased ability to focus attention, perform concentration and creative tasks
- Shorter post-operative hospital stays, fewer analgesics
- Fewer sick days
- Better interpersonal relations

Wood + Health[2]

- **Reduced cortisol levels** in hospital isolation room with wood (compared with concrete)
- **Enhanced subjective wellbeing** in nursing homes (plants and natural materials for furniture compared to homes where those are absent)
- More **appealing** hospital rooms are more likely to contain wood furniture than less appealing ones, and hospitals with these rooms got higher ratings from patients of doctors and food
- Employees at a Norwegian hospital rated patient rooms with an **intermediate level of wood** to be **most preferable**
- Adding wood panels to a room did not have an effect on the amount of Volatile Organic Compounds (VOCs) in patient rooms
- **Increased parasympathetic nervous system activation** in wood-dominated versus non-wood classrooms
- Rooms with 0%, 45%, or 90% surfaces covered with wood: **blood pressure was lowest in the 90% wood room**, though the 45% room was most preferred by participants
- **Blood pressure** of people who like wood as a finishing material **dropped significantly** when facing a wooden wall versus a white steel wall, while those who dislike wood as a building material did not experience a blood pressure effect. Liking steel did not seem to influence the blood pressure of people looking at white steel walls, though it increased with steel dislikers
- Respondents in a study **expected that wooden surfaces contribute to human health and wellbeing**
- Spaces were seen as pleasantly relaxed places to be as the proportion of wood surfaces increased up to 43% wood
- Firms with wooden finishes in reception areas seen as more **prestigious, energetic, innovative, and comfortable**, and were felt to be **more desirable organizations to work for**
- Wood **promotes studying** by undergraduates
- During stressful tasks in a lab setting, **lower heart rate and blood pressure were observed when alpha-pinenes scent was present**
- **Alpha-pinene scent linked to lower adult heart rates**, compared with no scent or other wood extractives.
- Scent also linked to **lower infant heart rates**
- **Pulse rate lower** by 3 beats per minute (bpm) in a room with wood walls as opposed to white cloth walls
- Wood wall room also linked with activation of the parasympathetic nervous system
- **Wood seating surfaces selected more frequently** than plastic, metal, or stone/concrete surfaces in long-term camera observation study
- Wood booth associated with **higher relaxation, better focus and recall** compared with a non-wood booth
- **Solid wood** flooring area was played on most frequently in a long- term daycare study when compared with veneered wood, artificial wood, and solid color synthetic surface

Structural CLT exposed on hotel room interior at Alpenhotel Ammerwald (case study p. 107).



Structural glulam and NLT exposed on the interior at the Bullitt Center (case study p. 65).

Wood as structure (glulams at left) and finish in Vorarlberg Mittelschule (case study p. 93).

Wood + Health: Structure + Finish

In 2014 Terrapin Bright Green LLC, an environmental consulting and strategic planning firm, produced a document titled *14 Patterns of Biophilic Design: Improving Health + Well-being in the Built Environment*[3]. It aims to articulate the relationship between nature, human biology, and the design of the built environment in 14 applicable patterns. These patterns are meant to guide designers on how to leverage the benefits of the connection between human beings and nature in architectural applications.

While the patterns developed in the report are focused on design application, each pattern came to be through a review of scientific studies. The patterns are therefore not arbitrary, but rather supported by published scientific research. Two patterns in particular apply to the use of wood as an exposed structural material, and they are quoted below.

14 Patterns of Biophilic Design

[p. 9] Material Connection with Nature

» "In some cases, there may be several layers of information in materials that enhance the connection, such as learned knowledge about the material, familiar textures, or nested fractals that occur within a stone or wood grain pattern"

[p. 10] Complexity + Order

» "A coherent spatial hierarchy, [such as that provided by exposing building structure and mechanical systems,] helps create a visually nourishing environment that engenders a positive psychological or cognitive response"

Pattern nine [p. 9] articulates how information possessed by building users about materials in the building can enhance their appreciation for and enjoyment of a particular space. If a user knows, for example, that a wood element in a room is actually helping to hold up the building, as in a column or a beam, this understanding can enhance the user's appreciation of that element as one with an essential function. The natural beauty of wood grain can enhance this appreciation further – form and function together. This potential positive effect can be enhanced with more information: for example, if the user knows that the wood used helped reduce greenhouse gas emissions, or if the production of the wood product helped provide a high-quality job in their region, this information can contribute to the user's appreciation of the element and the space.

Pattern ten [p. 10] emphasizes the potential benefits of exposed structure, if the structural system shows a "coherent spatial hierarchy." The benefits of this coherent spatial hierarchy are enhanced if the visual properties of the structure itself are also beneficial, as they are with wood and wood grain.

Patterns nine and ten work together to show the potential benefits of exposed mass timber structure. For more information on biophilic design and the research that supports it, access the *14 Patterns* document for free on www.terrapinbrightgreen.com.

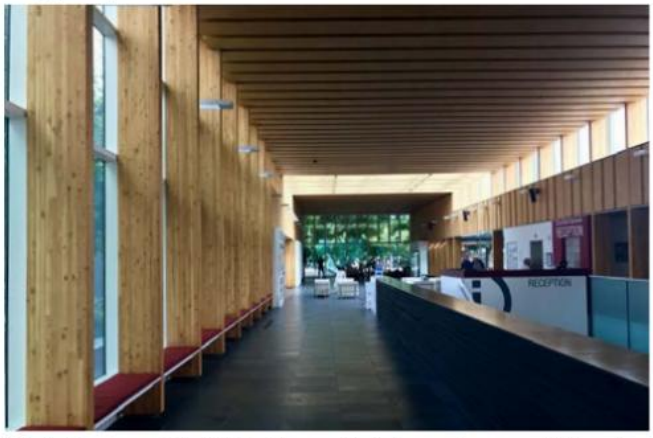
Structure

Finish

The images below show spaces from case studies with either exposed structural wood, or wood used as a finish material in a concrete portion of a mass timber building.

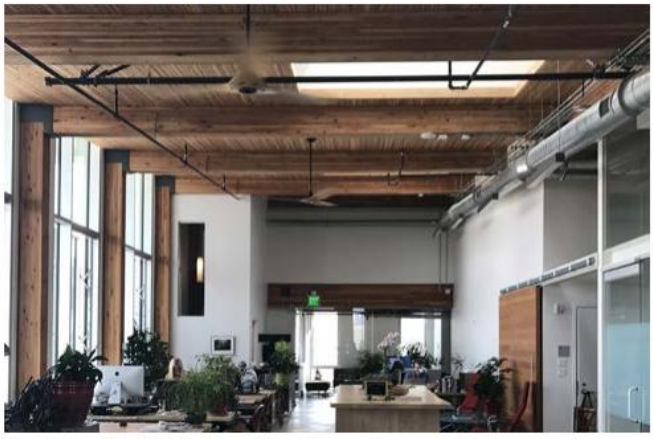
Ground floor of H8, with underside of CLT floor slab exposed (case study p. 89).

Ground floor of Brock Commons, which is concrete construction, with wood used as finish and furniture (case study p. 79).



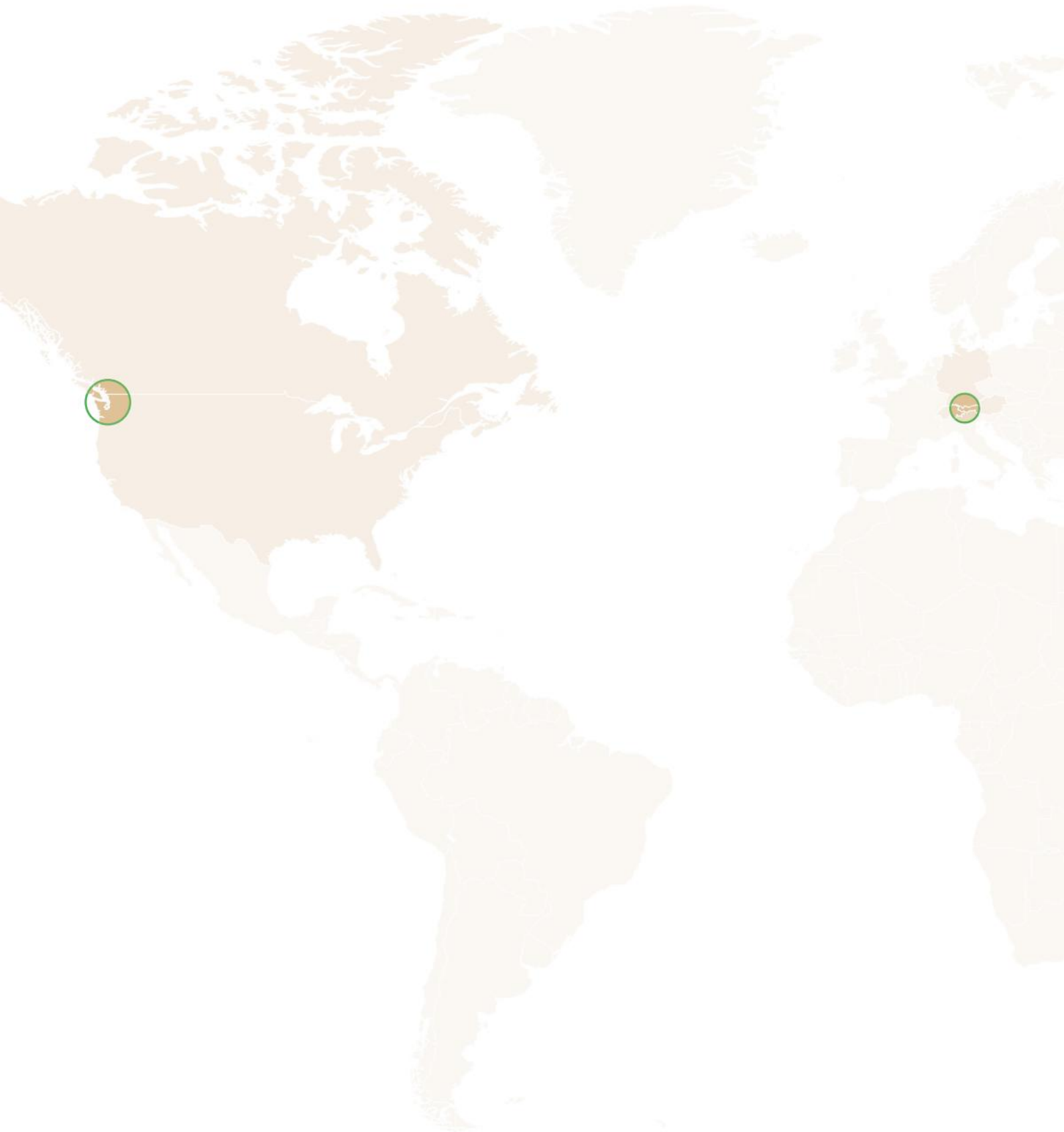
North Vancouver City Hall atrium, with glulam columns and LSL roof modules exposed (case study p. 75).

Ground floor of Alpenhotel Ammerwald, concrete construction with wood used as finish and furniture (case study p. 107).



Top floor of Bullitt Center, with glulam columns and beams and underside of NLT floor slab exposed (case study p. 65).

Ground floor of IZM, which is concrete construction, with wood used as finish material (case study p. 29).



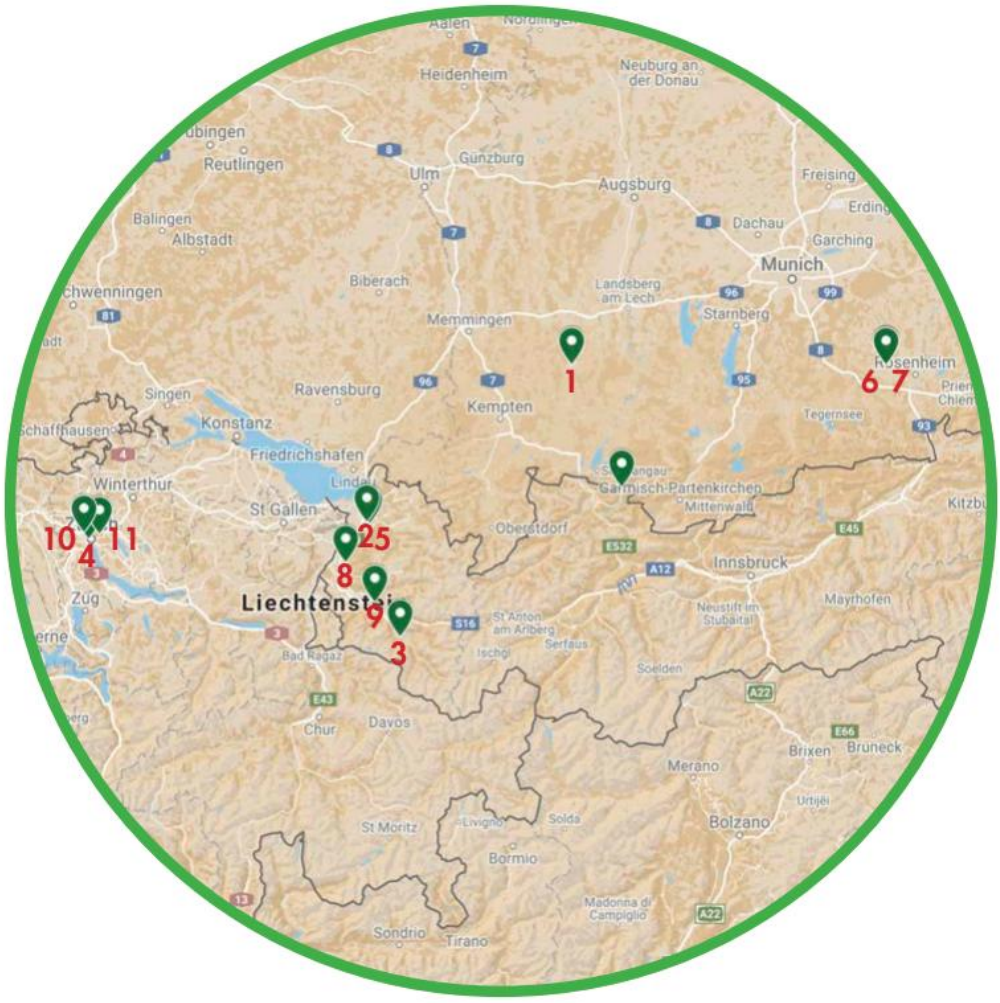
Part 2:

CASE STUDIES

The following 23 case studies were investigated using a combination of literature review and in-person interviews. At least one key detail drawing or diagram is cited for each case study.

While there are significant innovations in mass timber methods all over the world, the aim here was to visit the most mass timber buildings possible with the highest diversity of attributes within the context of the Hart Howerton fellowship. Given that different geographic contexts employ different methods when it comes to mass timber construction, two zones of study were selected: 1) Alpine Europe (Bavaria, Germany; Vorarlberg, Austria; and Zurich, Switzerland), and 2) the Pacific Northwest (PNW) region of North America (Seattle, WA, USA; Vancouver, BC, Canada; and Portland, OR, USA). By focusing on these two regions, it was possible to compare and contrast two areas with similar connections to forestry but different contexts for mass timber construction.

ALPINE EUROPE SITES



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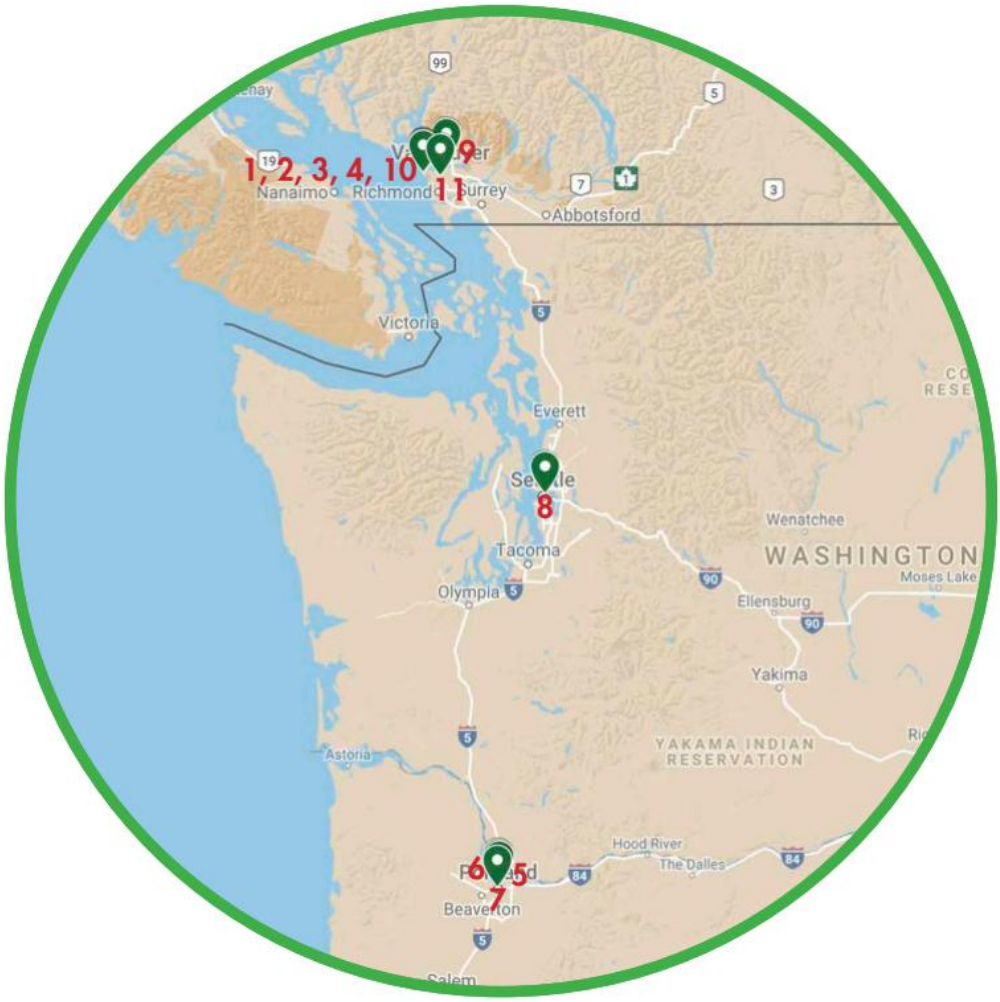
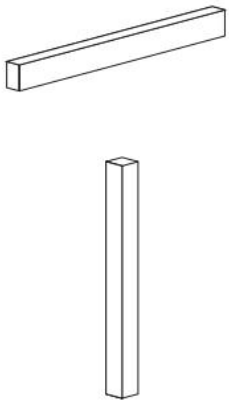
11. Kaeng Krachan Elephant Park *117*

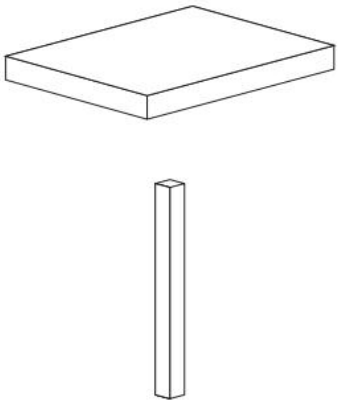
PACIFIC NORTHWEST SITES



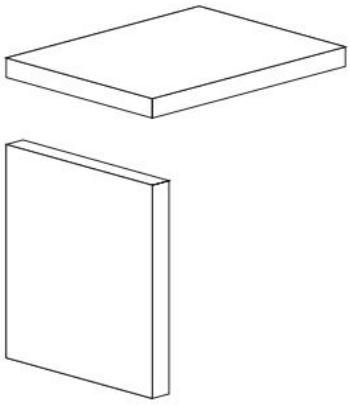
1. Earth Sciences Centre, UBC *37*
2. Forest Sciences Centre, UBC *41*
3. Centre for Interactive Research on Sustainability, UBC *45*
4. Bioenergy Research and Demonstration Facility, UBC *49*
5. Albina Yard *53*
6. Carbon12 *57*
7. Framework *61*
8. Bullitt Center *65*
9. North Vancouver City Hall *75*
10. Brock Commons, UBC *79*
11. Ronald McDonald House BC *101*



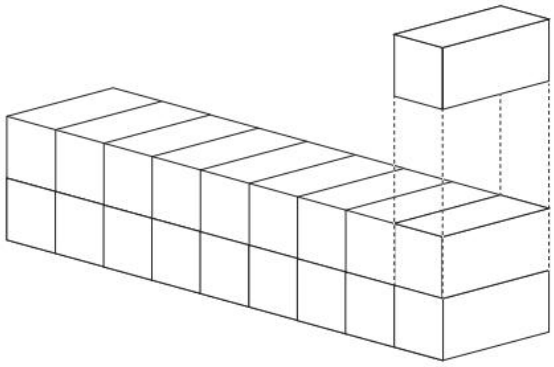
POST + BEAM



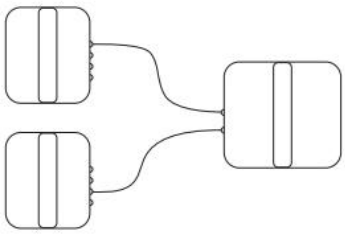
POST + PLANE



PANELIZED



ROOM-MODULAR



COMPUTER-ASSISTED DESIGN

CONSTRUCTION STRATEGIES

With the variety of mass timber products available and the near-infinite particular conditions that differ from site to site and project to project, designers employ a range of strategies when it comes to mass timber construction. The construction method that is appropriate and useful for a rural hospitality project likely differs from what makes sense for an urban office building, or an institutional project with mixed uses. Seismic and other high lateral loads, site access issues, and foundation conditions are just a few of the site and project particularities that must be taken into account.

Moreover, each mass timber product presents the designer with different opportunities and challenges. What mass timber products are available, what they cost, and how this fits in with the project budget must be taken into account. Whether or not the client or designer wants to expose the structural timber also plays a significant role in the decision-making process. All of these factors and more interact with one another to devise the overall mass timber strategy employed in any given project.

The categories at left—Post + Beam, Post + Plane, Panelized, Room-Modular, and Computer-Assisted Design—serve to organize the case studies investigated in this report. An introduction to each strategy's characteristics begins each section in the pages that follow.

Within each construction category section, case study buildings are grouped by geographic location, and geographic groups are listed by the order in which each site was visited. In total there are three sites in Germany, six in Austria, three in Switzerland, one in Seattle, three in Portland (one unbuilt), and seven in Vancouver.

Green Center
Kaufbeuren, Germany
Office, Primary Education

Illwerke Zentrum Montafon (IZM)
Vandans, Austria
Office

LifeCycle Tower One (LCT One)
Dornbirn, Austria
Office

Tamedia Headquarters
Zurich, Switzerland
Office

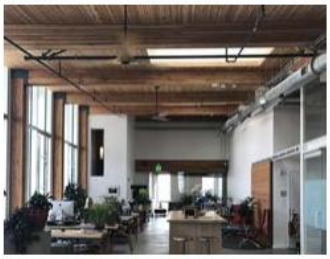
Earth Sciences Building
Vancouver, BC, Canada
Higher Education

Forest Sciences Centre, UBC
Vancouver, BC, Canada
Higher Education

Centre for Interactive Research on Sustainability
Vancouver, BC, Canada
Higher Education

Bioenergy Research + Demonstration Facility
Vancouver, BC, Canada
Higher Education

Bullitt Center
Seattle, WA, USA
Office

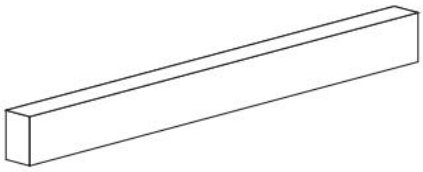


Carbon 12
Portland, OR, USA
Condominiums

Albina Yard
Portland, OR
Office

Framework *(unbuilt)*
Portland, OR
Mixed-occupancy

POST + BEAM



- An interconnected system of beams and columns.
- A good fit with building programs that require larger and more flexible interior spaces[1].
- Provides the opportunity for larger areas of glazing than panelized systems[2].
- Requires additional measures, such as cross bracing and shear walls, to address seismic forces and other lateral stability issues[3].

heinle
www.dtb-trockenbau.de

GREEN CENTER

Kaufbeuren, Germany | Florian Nagler Architekten

2018

38,750 sf

Office, Primary Education

Kaufbeuren, Germany is a Bavarian town about an hour's train to the west and south of Munich, with a population of less than 50,000 people. The Bavarian region and Ostallgäu district governments are building a "green center" on a publicly-owned site. The building consists of a three-story administrative office building and a two-story school, connected on the ground level. The project is essentially a service center for the rural area, and shows the high importance of agriculture in the region, as it will unite the Kaufbeuren Agricultural Office with related programs offering advice, education, and promotion in one place[1]. The building will be certified with a Passivhaus standard, and is being built by contracting company Rubner Holzbau, which specializes in all types of wood construction.

The project utilizes a timber-concrete hybrid construction, with prefabricated floor elements made up of glulam beams and a concrete slab. These hybrid panels rest on glulam columns, and the glulam columns and beams are to be exposed on the interior. While the use of wood adds to the project's ecological credentials, the concrete is necessary due to its qualities when it comes to fire protection. The code requirements for this project are stringent due to the presence of a school on the site, and the use of concrete floor slabs helped calm the nerves of code officials and get the construction approved. The hybrid system of timber columns and beams with a concrete floor slab is similar to the LifeCycle Tower (LCT) system; see case studies on pages 25 and 29.

Hybrid timber-concrete panels with temporary supports, inside the administrative building.

Project Manager Daniel Nieberle showing how timber-concrete hybrid panels are installed.

Inside the school building on the top floor.

Administrative building, corner detail.

Administrative building, corner detail from the interior.

The connection between the concrete panels pictured in the images at left is not water-tight. At the time these photos were taken there had been two days of heavy rain. Project manager Daniel Nieberle said that the moisture situation would need to be monitored while the work team continues to move forward in order to get the roof on the building and prevent further moisture. In general, Rubner Holzbau has concluded that the wood can typically handle about one week of exposure to rain.

The project manager and subcontractors on the site lauded the precision possible with prefabricated timber elements, and lamented that the prefabricated concrete slabs could not reach the same level of precision. It is also more difficult to modify the concrete elements if they arrive on site with inaccuracies than to do so with the timber elements, which can be easily machined on site.

While the Kaufbeuren project does not make use of a significant amount of CLT, many of the workers on this project are familiar with the mass timber product. Christian Dörschung, the master carpenter on site, has been working in the industry for 30 years and was around for the introduction of CLT to the marketplace. In fact, Christian says that the biggest change in the industry during this career in carpentry has been the appearance and growth of CLT, with the impact due to its structural capabilities. Christian enjoys working with CLT, and he thinks its development has been good for the timber industry in his experience.

LIFECYCLE TOWER ONE (LCT ONE)

Dornbirn, Austria | Hermann Kaufmann Architekten

2013

107,640 sf

Office building

LCT One, at 8 stories, is the tallest wood building in Austria. It is the first built result of an extensive three-year research effort initiated by Creative Resource and Energy Efficiency (CREE), the sustainability division of the Austrian company Rhomberg. CREE was drawn to the potential of building with renewable, carbon-sequestering timber rather than carbon-intensive concrete and steel. The LCT building system was conceived of as a prototype using wood construction capable of being built anywhere in the world as a variety of building types. By leveraging prefabrication in a systematized building approach, CREE also hopes to speed up construction and increase the level of finished quality. Over the course of the research effort, funded by Rhomberg and by the Austrian government, extensive fire and structural testing led to the system as it is today: glulam columns, hybrid floor panels with glulam beams and reinforced concrete floor slab (a key innovation), and a non-load-bearing prefabricated facade. The Austrian architect Hermann Kaufmann, who has been pushing the limits of timber construction for decades, was a key player in the research effort.

LCT One was a success in terms of its construction process. It took approximately five hours to complete each floor, completely sealed and grouted. The entire structural frame, including facade and floor elements, airtight and watertight, was installed in eight days. By contrast, the cast-in-place concrete core took two weeks per story, for a total about 3.5 months of construction time[1].

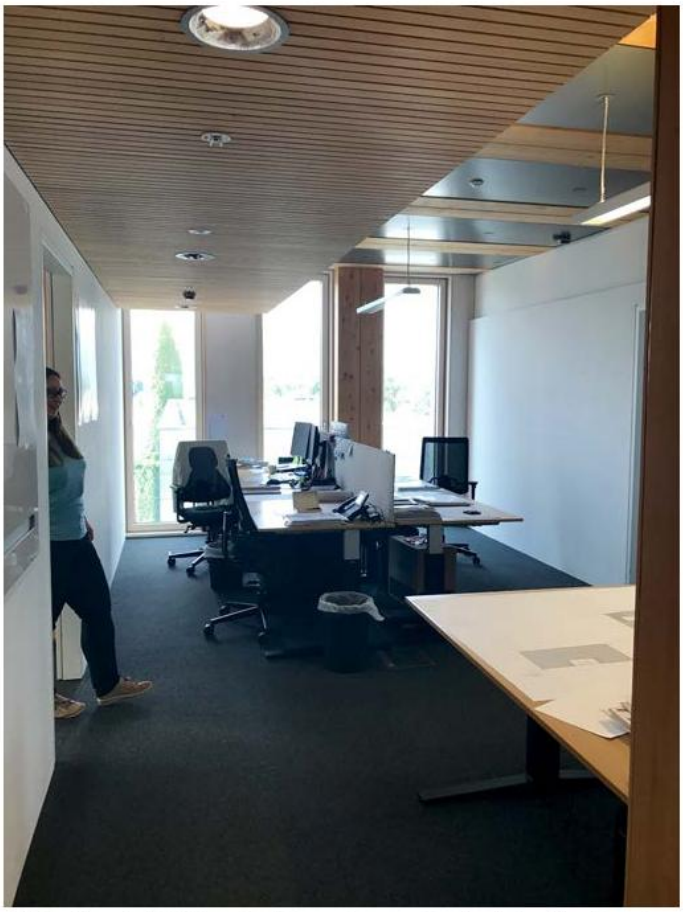
The research effort was also a success in terms of innovation in building with wood. Specialists involved in the project learned new things; the company that made the concrete slabs for the hybrid timber/concrete panels had no previous experience in hybrid construction or prefabrication. The concrete slab helps greatly with two technical challenges facing building large structures with wood: fire protection and acoustics.

Scale model of the LCT building system.

Exhibit of wood products used in LCT One.

Scale model of a LCT system hybrid timber-concrete slab, with a 1:1 section model under glass.

LCT One, looking at the front entrance.



CREE offices in LCT One. Each tenant can customize their office layout.

The LCT building system can reach 20-30 stories tall. It is optimized for resource efficiency, and its unique combination of materials saves 50% on resources while providing a smaller carbon footprint and Passivhaus energy performance. According to CREE, this system offers a 90% improvement in CO_2 emissions over traditional buildings while reducing construction times by as much as 50%[2].

The next step for CREE and the LCT system is more projects. The approach of those who developed the system is stepwise, with future buildings intended to grow incrementally taller and more ambitious. Other future innovations may include the use of wood cores instead of concrete, likely with CLT, and using the system on a multi-family housing building type[3]. Though there are no seismic concerns in Austria and Germany, where the system was developed, it can be modified to accommodate high seismic loads.

The LCT system was used with some modifications on the Illwerke Zentrum Montafon project, completed in 2013 and also in this report (p. 29), located in Austria a little over an hour's drive from LCT One. Projects are underway abroad as well, including two large scale office buildings in Berlin, Germany and a 323,000 sf college in Singapore. According to CREE, they have also been approached by Chinese companies.

The interior of the building benefits from the construction. The smell of wood is palpable and pleasant, and the level of precision enabled by the prefabricated building process results is evident in the high quality of finished craftsmanship.

The first floor of LCT One has a show room with materials including information on the research effort, the building system, the wood products used, and the interior finishes and systems. There is space on an interior wall to project videos showing time lapse images of the construction and other details about the project. These videos are available on the CREE YouTube channel.

ILLWERKE ZENTRUM MONTAFON (IZM)

Vandans, Austria | Hermann Kaufmann Architekten

2013

107,640 sf

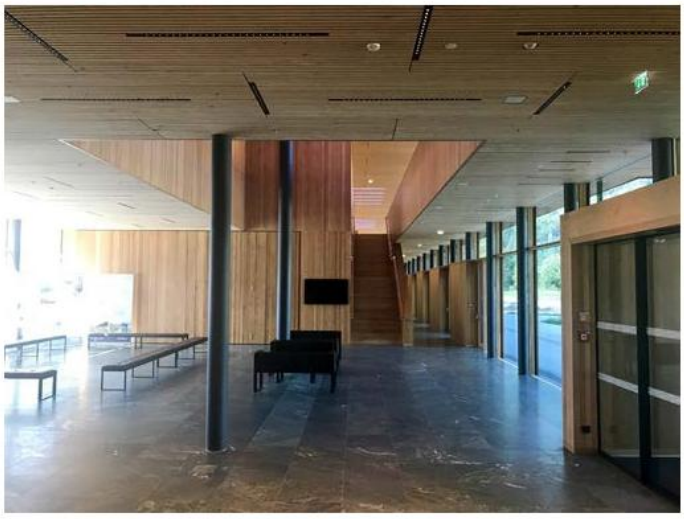
Office

In 2010, the Vorarlberg utility company Illwerke held a competition for a building to house their administrative offices. The firm Hermann Kaufmann Architekten, whose namesake had been a key player in the research effort developing the construction system for LCT One, won first prize for a scheme making use of the system they had helped develop. The building is alternatively known as LCT Two, though it is almost never called by this name, and is the first application of the LCT system on the open market. When construction completed in 2012, it became the largest wood office building in central Europe.

IZM uses the same components as LCT One, but adopts a central spine of steel columns that eliminate the necessity of the floor slabs to be supported by a vertical core[1]. Like LCT One, construction speed was impressive thanks to the building system. The first two levels are concrete, and the three levels of wood structure above the concrete base were put together in just six weeks[2]. The building is five stories tall, which enables it to have a wooden facade; Hermann Kaufmann claims this facade can last up to 30 years untreated[3]. Wood is an important part of the design concept of the building; Hermann Kaufmann Architekten describes with pleasure how the structural wood remains a visible part of the interior construction, as opposed to being covered up by gypsum as is often the case in larger wood buildings[4]. Wood is also used extensively as an interior finish material, and because local wood was used in both the glue-laminated elements and the finish elements there is a consistent aesthetic on the interior.

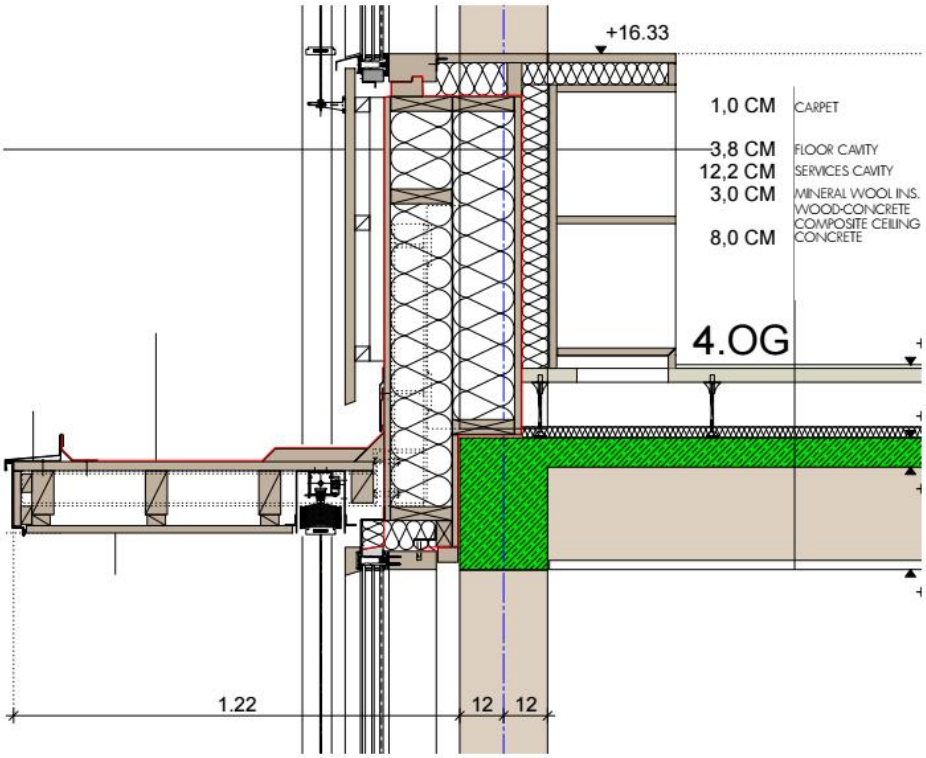
Panel installation. Source: Architekten Hermann Kaufmann

Upstairs office interior. Source: Architekten Hermann Kaufmann



Public reception area.

View from across a reservoir, which is regularly drained and refilled to generate electricity.



Exterior wall detail; the green is concrete, brown is wood. Source: Architekten Hermann Kaufmann

East facade.

While the architects' approach was characterized by thoughtfulness, preparation, and attention to detail, not everyone who uses the building liked the spatial design at first. It is a very modern aesthetic that was jarring to some employees that preferred old, traditional buildings. Over time however, after getting accustomed to the style, employees came to appreciate it more. Even with initial misgivings, users consistently appreciate the wood, on both the interior and exterior. Users appreciate how the interior materials harmonize with one another, and that the wood used is local (see **INSIGHT #4** on p. 155 for more from IZM users).

Despite the systematized building approach of this project, Hermann Kaufmann Architekten is determined to avoid "over-industrialization" in their work. The use of CLT, for example, excludes local carpenters, since most small carpentry businesses in Vorarlberg do not have the large, expensive machines necessary to fabricate CLT panels. The architects are native to the region, and in this part of the world the wood industry is incredibly local and often personal. Nevertheless, through their work with wood over the years on both smaller and larger projects, the firm has come to appreciate the benefits of doing things fast. Speed of construction protects the wood from too much exposure to the elements, and it also saves money. Hermann Kaufmann Architekten continues to manage the benefits of prefabrication and the industrial nature of that process while maintaining the strong, interconnected building culture that has enabled the Vorarlberg region to become a global leader in wood construction.

TAMEDIA HEADQUARTERS

Zurich, Switzerland | Shigeru Ban Architects

2013

109,000 sf

Office building

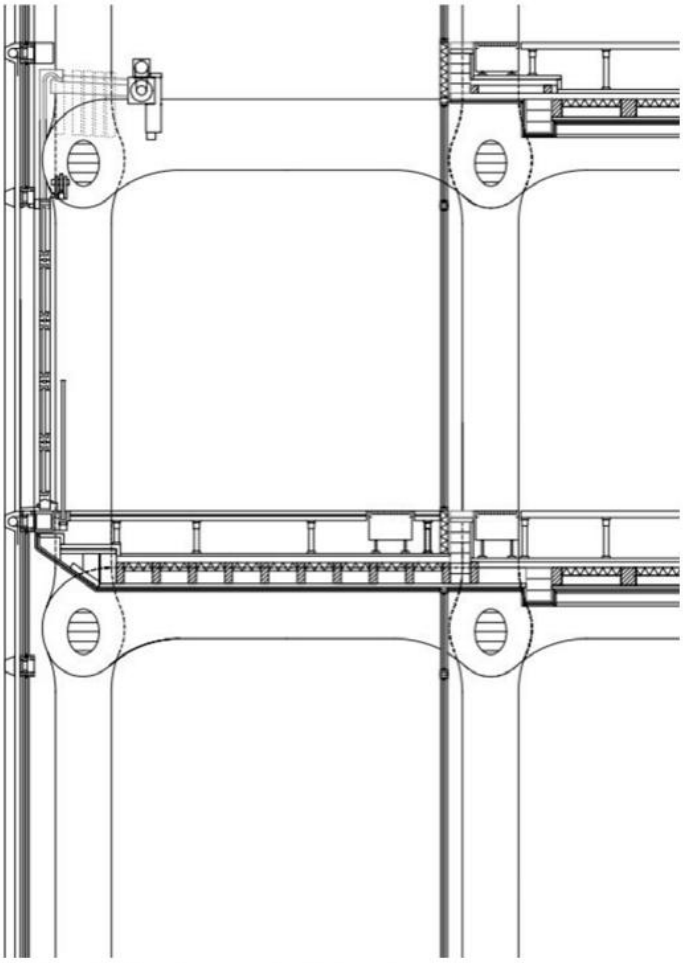
Tamedia is a private Swiss media company that was founded in 1893 as a newspaper under a different name, and today it publishes daily and weekly newspapers, digital platforms, and magazines[1]. The company wanted to consolidate the majority of its Zurich employees in one centralized location, and they enlisted Shigeru Ban for the design[2]. The new building opened in 2013: a seven-story timber post-and-beam structure.

Ban chose to use wood for its sustainable and aesthetic properties[3], and he collaborated with Swiss engineer Hermann Blumer and the Blumer-Lehman corporation on the post-and-beam system design. The system was inspired by traditional Japanese joinery in that it has no metal connections[4]. It consists of Austrian spruce glue-laminated timber columns and beams, which are connected by joints featuring dowel connectors made of beech plywood. The dowel connectors are concealed in the final assembly, so all the viewer sees is glue-laminated spruce.

The column-beam connections are oval in shape, an important detail that goes beyond aesthetics. The oval cross-section prevents the beams from rotating, thus enabling them to absorb lateral forces without causing deflection in the structural frame. These lateral forces are absorbed by the contact between the beech plywood dowel and the spruce glulam beams and columns, so it was key that the fit be precise[5]. This system would not have been possible without the precision of CNC routing in a prefabricated setting.

The stability of the column-beam joints is also made possible by the differing wood species used for each element[6]. Beech is a hardwood and spruce is a softwood, and hardwoods typically have a lower moisture content than softwoods. The hardwood beech dowels take in moisture to reach equilibrium with the spruce that surrounds it, thereby locking the joint in place in a way that mimics the construction of DLT.

Column-beam connection exploded axon diagram. Note that this diagram does not show the beech plywood dowels.
Source: www.archdaily.com

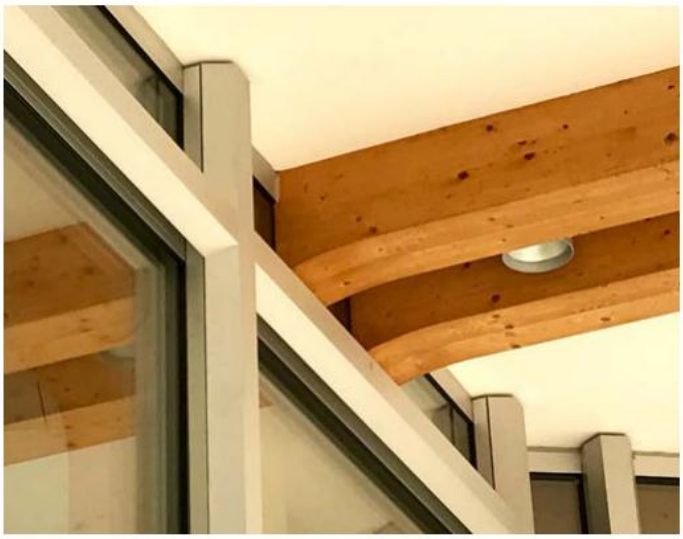


Section of high-performance double facade.
Source: Detail Magazine, 02/2014

Column-beam connection detail.

Column-beam joint partially assembled, showing beech plywood dowel.
Source: Detail Magazine, 02/2014

Exterior view of the front entrance, with blinds drawn.



Detail, glulam beam passing through glazing with fire stop.

The timber structural system was designed as a kit of parts that could be delivered to the site and assembled like a three-dimensional puzzle[7]. While most buildings are built from the bottom up, Tamedia headquarters was built bay-by-bay, with the southernmost bay being built ground to top, as a template, and subsequent bays filling in until all were completed[8].

The design team was resourceful in addressing two of the major challenges associated with timber buildings: fire code and acoustics. For acoustics, sand was used in the floor assembly to isolate vibrations. According to the Swiss fire code at the time there was a six-story limit on wood buildings, so the design team had to secure an exemption (the code has since been changed)[9]. The timber members were oversized by three centimeters in cross section as a char layer, and a fire stop had to be integrated within a glulam beam between the atrium and the office spaces where the atrium glazing meets the wood member[10] (see photo above right).

In addition to the ambitious wood structure, it was important to Tamedia that the building perform well in terms of energy. A combination of ground-source heat pump and high-performance building envelope enable a carbon-neutral operation[11].

Thanks to the high-performance glazed facade the unique structural system is visible from the exterior, and the open-plan layout of the interior space ensures that the wood structure is visible throughout. The ground floor material is terrazzo made with river stones, a choice that complements the natural feel of the wood. The staff loves working in the building, though its architecture has become such an attraction that they received too many tour requests, which eventually became distraction to the workers and are now rejected. Tamedia employees love the building so much they have taken to calling it "the chalet," reflecting on the timber construction's similarity to the feel of an alpine lodger[12].

EARTH SCIENCES BUILDING, UBC

Vancouver, BC, Canada | Perkins + Will

2012

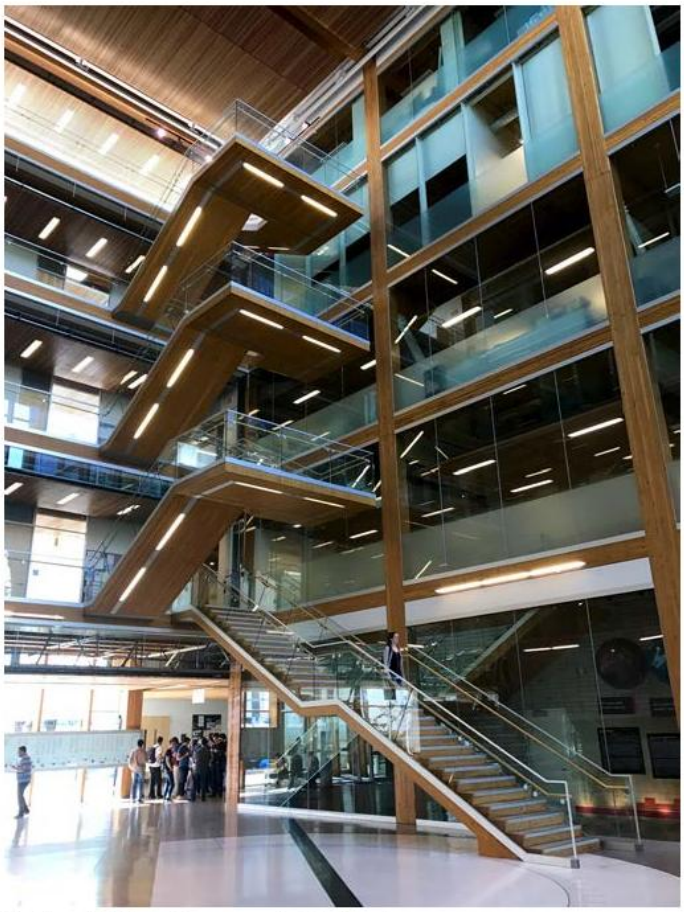
85,000 sf (wood wing only)

Higher Education

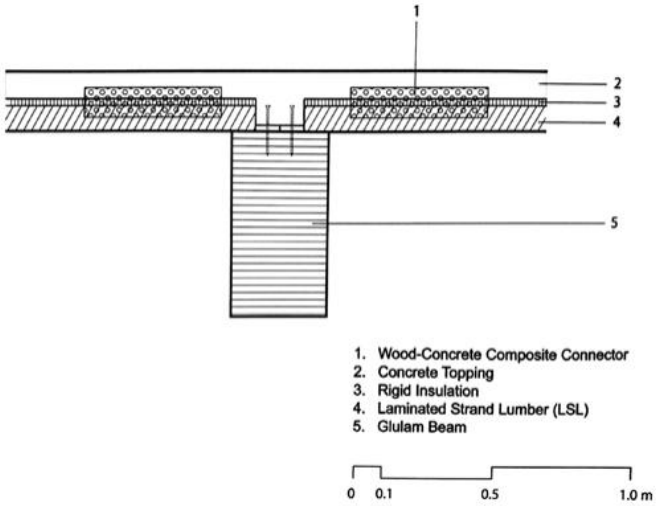
The University of British Columbia (UBC) in Vancouver, Canada is practically a breeding ground for mass timber buildings. The provincial government of British Columbia encourages the use of wood products in public buildings through the 2009 Wood First Act. The Earth Sciences building on the UBC main campus was one of the first applications of CLT in North America. The project consolidates teaching, laboratory, and administrative spaces for several related departments that had previously been dispersed[1]. Mass timber is not used for the entire project; a concrete wing houses the labs and offices, which are areas with higher-hazard occupancies and complex systems requirements[2]. Wood is used for the five-story office and lecture theatre wing. A five-story atrium, pictured at left, links the two wings, and its centerpiece is a cantilevered stair made of CLT with high-tech steel connections.

The construction system of the wood wing consists of glue-laminated columns and beams, with the columns extending the full height of the structure. Beams are connected to the columns with proprietary connector by the Austrian company SHERPA, which functions as a dovetail joint but using aluminum pieces that fit together, one affixed to the column and the other to the end of the beam. When assembled, the connectors are concealed from fire by the wood. The lateral system of the structure is provided by the concrete stair core, roof diaphragms, and a unique chevron bracing system consisting of glulam braces and custom ductile steel knife plate connectors[3].

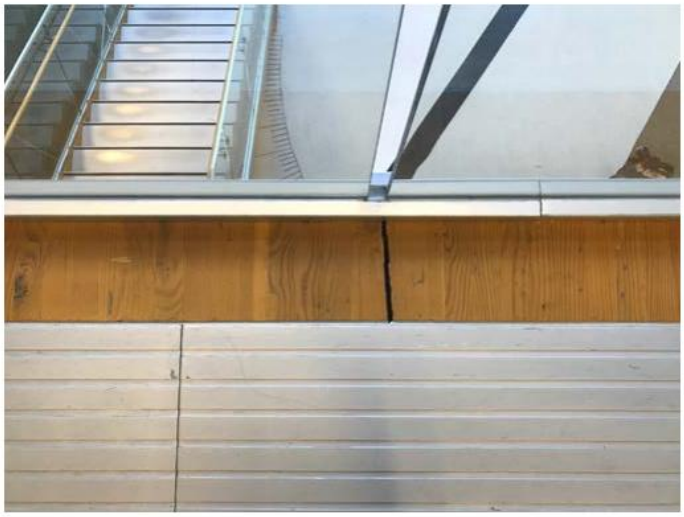
While the building was being designed CLT was not yet easily available on Canada's west coast, and was only specified for areas that came toward the end of the construction process[4]. While it would have been ideal to use CLT for the floor, the replacement system is a hybrid of LSL panels, perforated steel shear connectors, and site-poured concrete (see detail on following pages), a proprietary blend by German company TiComTec.



Section of high-performance double facade.
Source: Detail Magazine, 02/2014



Composite LSL/concrete floor detail. Source: Solid Wood book by Joseph Mayo



The landing crack through from the bottom (pictured left) to the top (pictured above) was in approximately the same place on each level.

The landing crack through from the bottom (pictured above) to the top (pictured right) was in approximately the same place on each level.

Earth Sciences Building from the outside, showing the CLT canopy.

CLT canopy supported by glulam columns.

The visibility of the wood in this project is a welcome change from the status quo of institutional buildings, which are typically concrete structures whose finish materials need to do most of the work to add warmth to the interior. The warming effect of the wood is first apparent in the approach to the building, where it is difficult to miss the five-ply CLT canopy supported by glulam beams surrounding the building on three sides (pictured above). Upon entry to the five-story atrium the effect of the wood on the feel of the interior space continues to be pronounced, as the glulam post-and-beam structure is visible in all sides.

The centerpiece of the atrium is a so-called "masterpiece" of wood engineering: the cantilevered stair. While the engineers, Eric Karsh and Bernhard Gafner from Equilibrium Consulting in Vancouver, first considered using CLT for the stair runs and landings due to its two-way bending capability, they ended up developing a solution using glulam panels[5]. This choice was due to the glulam's better finished appearance over CLT and its greater strength and stiffness along the stair runs. To resolve bending forces the engineers used a steel bar to strengthen the landings across the grain and distribute local stresses[6]. Pictures at left show a crack in the glulam panels that is present on each landing of the stair, though it does not seem to have caused alarm or affected performance.

It is difficult to understate the significance of this project to the progression of mass timber architecture in North America. It was one of the first projects to take a traditional heavy timber post-and-beam construction and modernize it by incorporating advanced prefabrication methods, wood/concrete composite components, and proprietary connection systems[7]. On top of this, the construction would not have been possible without the tireless approach of the design team in undergoing alternative solution development for code, structural research and testing, and thoughtful planning around materials and construction schedule.

Forest and Conservation Sciences
Faculty of Forestry

FOREST SCIENCES CENTRE, UBC

Vancouver, BC, Canada | DGBK

1998

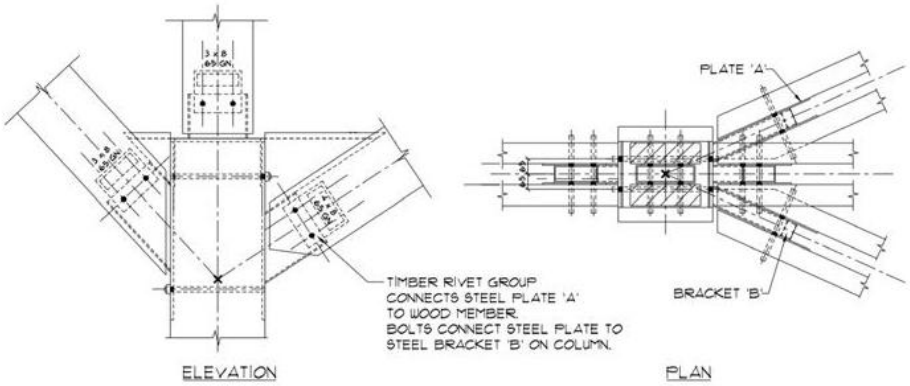
188,400 sf

Higher Education, Research

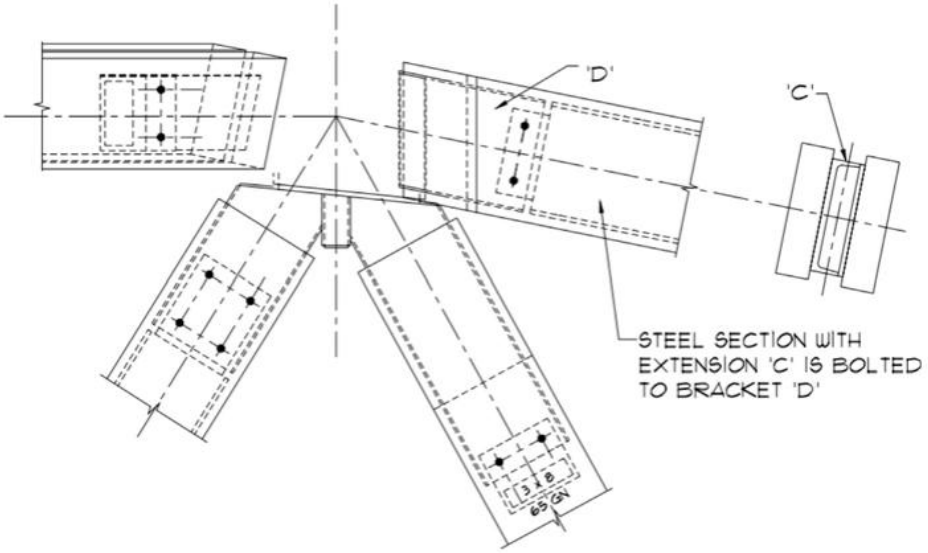
The Forest Sciences Centre (FSC) is another timber project on the University of British Columbia's campus, though it predates the Earth Sciences Building by 14 years. It was the first building on the UBC campus that used a lot of wood in its construction. The main goals of its design were 1) to demonstrate the use of wood in non-residential construction, and 2) to expand the market for BC wood products[1]. Meeting these goals involved innovative processes to get the project built long before the building code and provincial government had many accommodations for unconventional timber construction methods, and before many timber companies had the resources to provide the materials and workmanship necessary for such a complex undertaking.

To meet building code at the time of construction the building was separated into three blocks: a four-story laboratory block, a four-story office block, and a two-story wood processing center block. The three blocks surround a large sky-lit atrium, and are separated by seismic joints and fire barriers. Because of its specialty equipment needs and code limitations, the laboratory block is a conventional concrete structure[2]. The office block is a wood post-and-beam structure, with columns and beams made of PSL. They support a floor assembly of engineered wood joists and plywood sheathing topped with concrete[3]. The processing center structure is Douglas fir glulam beams and columns supporting exposed wood trusses and I-beams for the roof[4].

All told, the project involved the following wood products in different aspects of the construction: glue-laminated Douglas fir, PSL, LVL, dimension lumber of Douglas fir and spruce, wood I-joists, light metal plate connected trusses, Oriented Strand Board (OSB), and Douglas fir plywood[5].



Column cluster to branching members connection detail. Source: Sebastian Butler, John H. Peddle, Gary C. Williams



Exploded axon column cluster to branching members connection detail. Source: Sebastian Butler, John H. Peddle, Gary C. Williams

Column clusters.

Closer view of the branching structure that supports the skylight glazing.

Classroom in the processing center block, showing an exposed truss.

Forest Sciences Centre entry. Source: DGBK

The central atrium is the space where the project's commitment to using wood in its construction is most celebrated. The skylight roof is supported by column "clusters:" four PSL columns connected together with custom steel plates[6]. Each cluster is then connected to the branching "trusses" above that support the skylight glazing with steel plates and rods. The steel elements are affixed to the PSL elements with timber rivets. The branching trusses are anchored against the office block and cantilevered toward the lab block, and the skylight above is framed by long wood purlins spanning between the PSL roof frames[7]. The branching trusses were described by a professor who works in the building as "over-designed," as not that much wood is needed to hold up the load of the skylight. The branches also tend to attract dust, which is visible since upper level balconies that look over the atrium are right in line with the branching structure. Nevertheless, the wood has held up well, and instructors, students, and other users like the building.

As mentioned previously, one of the goals of this project was to demonstrate the use of wood. With this goal in mind, wood was also used extensively as a finish material, with wood veneer cladding visible throughout the atrium space and in the lecture theatre. It is interesting to note the contrast between this approach and that of the Vorarlberger Mittelschule (VMS) case study (p. 93). The interior finish approach in Vorarlberg was distinct from that of the FSC, aiming for material honesty rather than focusing solely on wood. The VMS designers chose to use wood as a finish element only on the parts of the building where wood was also the structural element. This project differs from the FSC in that its wood structure was primarily within prefabricated box elements, so, unlike the FSC project, no columns or beams themselves were exposed. What both projects have in common is the desire to use wood as much as possible, and to celebrate the use of this renewable building material.

Building Positive Space
Research

CENTRE FOR INTERACTIVE RESEARCH ON SUSTAINABILITY, UBC

Vancouver, BC, Canada | Perkins + Will

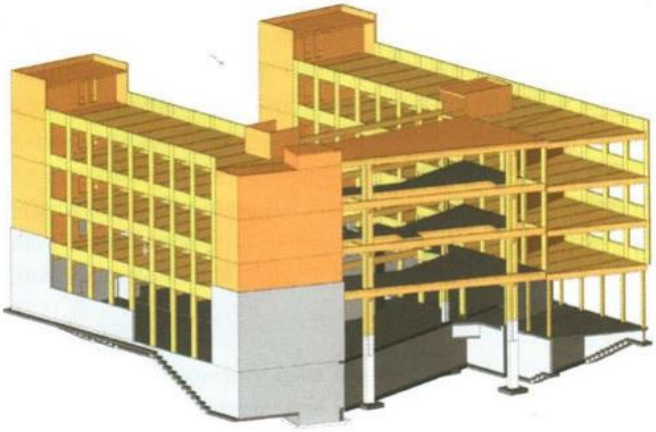
2011

61,000 sf

Higher Education

Yet another innovative mass timber project on the University of British Columbia's campus, the Centre for Interactive Research on Sustainability (CIRS) was completed in 2011. The Centre was first conceived of in 1999 as an opportunity to create a sustainability demonstration project in BC with a building that would push the envelope of sustainable design by integrating passive design strategies with the most advanced sustainable technologies available[1]. Today, CIRS houses UBC sustainability researchers, planners, and policymakers in two building wings: the office block and the laboratory block. The program includes office space, laboratories, classrooms, and a 450-seat auditorium, with public-access exhibition spaces, meeting rooms, and a café. The atrium is the "heart, lungs, and soul of CIRS"[2], as it links the two four-story wings while also serving as a building lobby, entry to a day-lit 450-seat auditorium, a stack ventilation space, and social space.

The use of wood for the structure of the building was not always a given, though it was decided upon early in the design process for its sustainability benefits[3]. The decision to use wood constrained some of the more elaborate building forms and design features. For example, an early design sketch had the building cantilevered over the pedestrian path on the site. In deciding to use wood, the design team chose to prioritize repeatability and reasonable construction costs, and therefore the building's form is simple and rectilinear[4]. The use of wood in this scenario was cost-competitive with more conventional construction methods using steel and concrete, and the wood used sequestered 904 tons of carbon, reducing the building's carbon footprint over the average UBC building by 90%[5]. CIRS is also the first commercial project to use primarily Forest Sustainability Council (FSC)-certified and beetle-kill wood[6].



Wood and concrete portions of CIRS. Source: Fast+Epp via Solid Wood by Joseph Mayo

Under construction; lateral supporting box beams visible along facade on the right. Source: Fast + Epp. Photo credit: Stephan Pasche

CIRS 450-seat auditorium. Source: Perkins + Will

Custom steel column-beam connection detail.

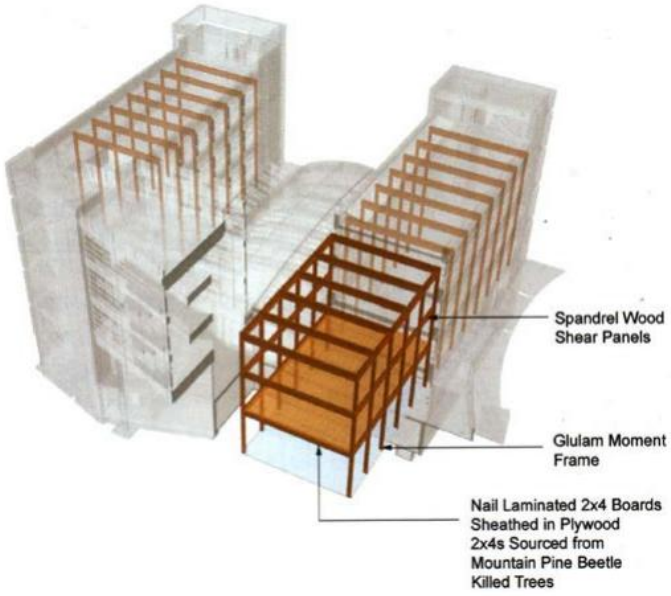


Diagram of CIRS structural system. Source: Solid Wood by Joseph Mayo

The engineers at Fast + Epp designed the wood structural system and strategized ways to keep costs down. They aimed for a system that could utilize prefabrication while avoiding the need for expensive CNC machinery, and could be assembled by construction crews without special skilled labor[6]. The structural system that met these requirements is glulam post-and-beam. The floor system is prefabricated NLT panels with plywood sheathing, topped with a raised floor employing resilient pads. The resilient pads enable spatial flexibility and improved acoustics. The NLT panels are made from dimensional spruce, fir, and pine lumber, with the pine coming from beetle-kill* wood.

There are two ways that the building is stabilized laterally: one in the short direction and the other in the long direction. Along the length of the building the post-and-beam system becomes a wood moment frame with the addition of prefabricated hollow box spandrel panels acting as box beams between the structural columns[7]. The short side of the building is stabilized laterally by conventional plywood-sheathed light wood frame shear walls.

CIRS was one of the first buildings to be designed after British Columbia's Wood First Act of 2009, which required that the potential to use wood be investigated for all publicly-funded projects[8]. The use of wood is celebrated throughout the building, as wood aligns with the project's focus on sustainability. The ability to expose the structural wood as an aesthetic material on the interior enabled the design team to "do more with less"[9]. Non-structural wood products are also used as an interior finish material, most visibly as ceiling slats in the atrium and wall paneling in the auditorium. In this way, the interior finish approach is in line with the UBC Forest Sciences Centre (FSC) (p. 41) with its celebration of wood products of all kinds.

*Beetle-kill wood comes from trees dying as a result of a climate change-driven epidemic decimating forests in British Columbia

3
THE BOILER
Hot flue gas enters the boiler and heats water to convert it to steam
This steam will eventually be converted to hot water and distributed through UBC's Academic District Energy System
The Academic District Energy System is a network of underground piping stretching around the campus that heats our buildings and domestic hot water

BIOENERGY RESEARCH + DEMONSTRATION FACILITY

Vancouver, BC, Canada | Macfarland Mrceau Architects Ltd.

2012

21,000 sf

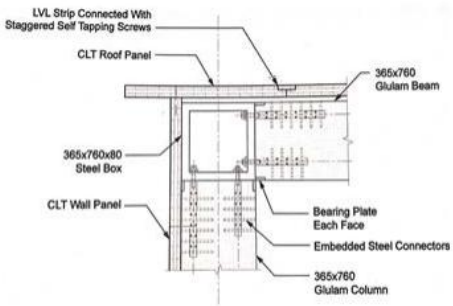
Higher Education

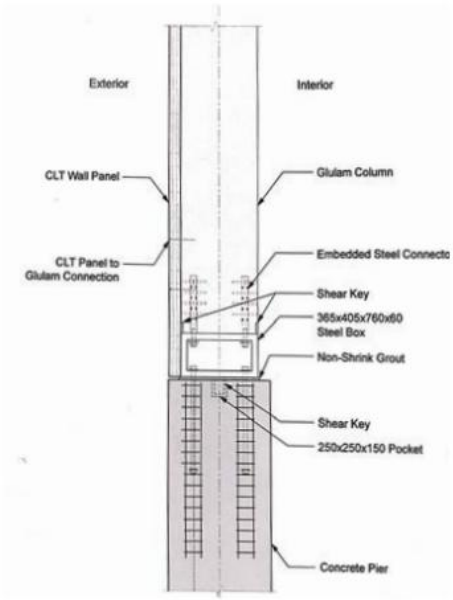
The trend of innovative mass timber buildings on the University of British Columbia campus continues with the Bioenergy Research and Demonstration Facility (BRDF). The project houses machinery that produces energy through biomass gasification; in the case of this facility, the biomass used is wood chips and other wood debris. Programmatically, the main space housing the biomass gasification systems is supplemented by the biomass material receiving and handling area, a building operations control office on an upper level, a multi-purpose lab, and public viewing spaces. This project shows that mass timber construction can be used successfully to build industrial facilities. This facility is a "medium hazard" industrial occupancy[1]. The project also further demonstrates that mass timber construction can work on institutional buildings.

The form of the building is designed to accommodate varying sizes of process equipment, and thus takes the shape of a wedge whose profile rises from east to west[2]. This wedge shape is also climate-responsive[3]. The structural system that supports this form is a series of moment frames that span the full width of the building, 80' total, and leave the plant floor unobstructed by columns. They are made up of glulam columns and glulam beams, connected by steel box connectors. The system is supported laterally by CLT walls, floors, and roof diaphragms[4]. CLT is also used outside the perimeter of the moment frames as supporting elements for the exterior glazing. The glazing is important for the demonstration nature of the project, and provides views into the floor plant and the equipment it houses. The wood sourced for the CLTs is 90% beetle-kill*[5].

*Beetle-kill wood comes from trees dying as a result of a climate change-driven epidemic decimating forests in British Columbia

BRDF Interior, showing equipment and glulam moment frames. Source: UBC

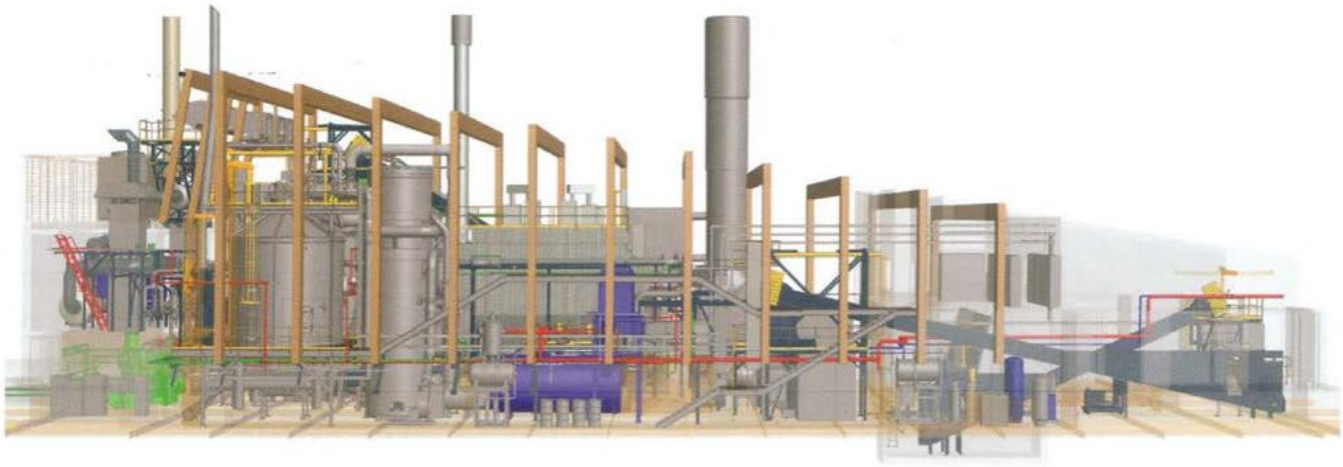




Glulam moment frame steel box details. Source: Solid Wood by Joseph Mayo

Glazing supported by CLT "fins."

CLT structure-to-glazing connection detail.



Glulam moment frames diagram. The frames were installed after the equiptment installation.
Source: Solid Wood by Joseph Mayo. Diagram credit McFarland Marceau Architects

The particularities of the site resulted in a number of challenges for the construction team, and also presented an opportunity to illustrate some of the benefits of using mass timber construction. The site was tight, narrow, surrounded by trees, and heavily trafficked by campus operations personnel. These conditions made it helpful that the timber frame eliminated the need for scaffolding[6]. The elimination of scaffolding was particularly beneficial because there were two contractors working on the project at once; one focused on the energy equipment and the other on the building frame and enclosure. The lack of scaffolding allowed both contractors to complete their work simultaneously, at times using three cranes at once. The site conditions and the nature of the equipment installation process would have made the project impossible to construct with tilt-up concrete construction, and steel or stick frame construction would have been far more labor-intensive[7].

This project was one of the first large-scale CLT projects in North America, and the building was instrumental as a research project that helped generate CLT guidelines and the publication of the CLT Handbook in 2013[8]. Special measures had to be taken to ensure the CLT roof panels were protected from excessive moisture exposure during construction. To accomplish this the panels were covered with a peel-and-stick weather protective barrier[9].

Once the building was protected from the elements, the wood structure could be exposed. The CLT and glulam elements can then serve as both structure and interior finish. The warmth of the wood improves the feel of an otherwise mechanical and industrial space, at no extra charge in terms of interior finishes.

4719

ALBINA YARD

Portland, OR, USA | LEVER Architecture

2016

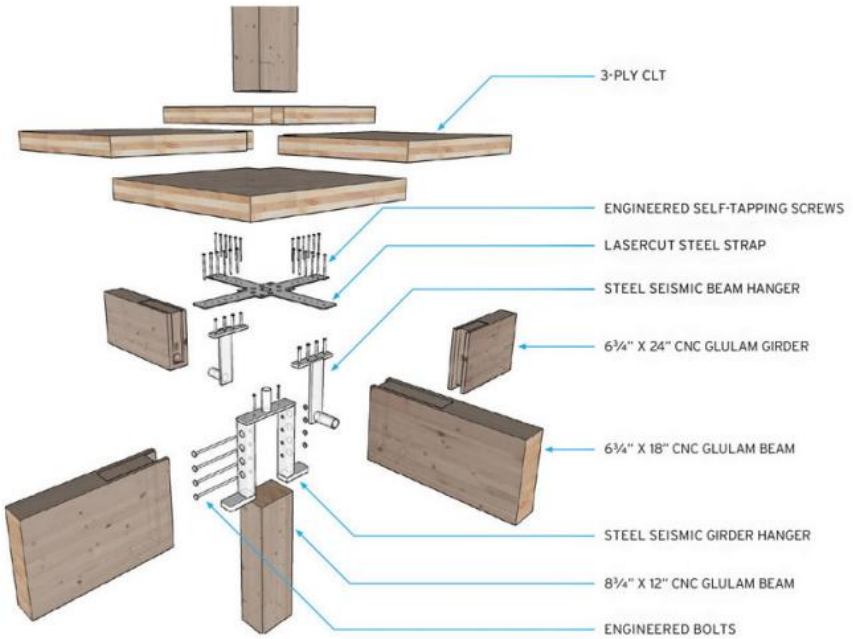
16,000 sf

Office

Albina Yard is a four-story office building with ground floor retail in Portland, Oregon. It was the first building in the United States to utilize mass timber construction and domestically-fabricated CLT[1]. This achievement inspired the concept "Forest to Frame;" a play on the "farm to table" movement, but with domestic timber and buildings rather than locally-grown food. Mass timber architecture in Oregon is part of a cultural and economic story that is energizing stakeholders. Governor Kate Brown spoke at the 2017 Mass Timber Conference held in Portland, OR, emphasizing that mass timber presents an opportunity for Oregon that many in the state hope will revive the lumber industry and in turn rural jobs, while providing a sustainable and renewable building material for buildings both urban and rural[2].

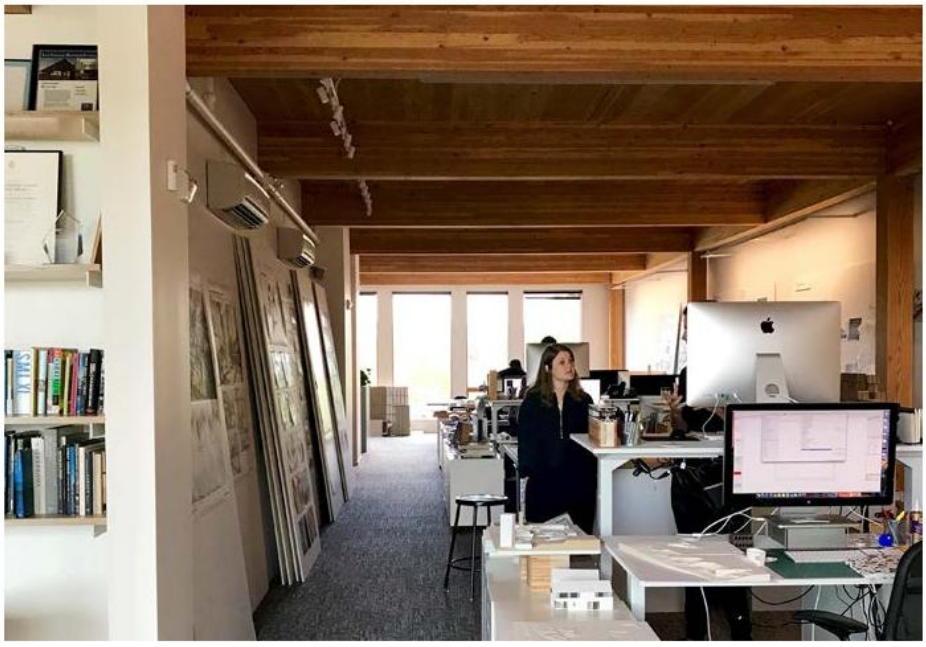
The primary goal of the Albina Yard project was to utilize domestic CLT in a market-rate office building that would pave the way for broader market adoption of mass timber construction technologies in Portland and beyond[3]. The structure of Albina Yard is a post-and-beam system, using domestic Douglas fir glulam. The floor system is three-ply CLT topped with gypcrete, to add mass for acoustic dampening. The lateral system consists of light frame shear walls and CLT as the structural diaphragm[4].

The Albina Yard process provides a window into some of the ways that building with mass timber is different from conventional practices, even with a modest building size. It went up in only four weeks; the structure of the first floor was installed in just four hours, and by the time the five-person construction crew reached the fourth level they were down to two hours[5]. Fast construction times and reduced on-site labor are two advantages that help save costs with mass timber construction. These advantages are made possible by more investment in pre-construction coordination and planning between the architects, engineers, and contractors.



Column-to-beam connection exploded axon. Source: Continuing Education Center

Column-to-beam connection detail image.



Inside the LEVER office on the fourth floor of Albina Yard.

CLT stair.

LEVER office conference room.

Exterior view.

The LEVER team noted that with mass timber buildings, there is increased pressure on the design team to figure things out in advance. The contractor's job is simplified by this pre-planning. Contractors and subcontractors do, however, have distinct challenges when working with mass timber, especially as they build experience with new construction systems. The construction of Albina Yard took place largely during the winter in Portland, which is a rainy season. Water was coming through the CLT joints, and workers had to tape the joints over with flashing to avoid too much water penetration into lower floors. At the end of each day, they would push water over the side of the structure with a squeegee. Another risk with moisture on site was with the steel connectors. A member of the LEVER design team said that one of the best decisions they made was to powder-coat all steel connectors; in this way they avoided rust streaking from the rain.

Since Albina Yard is at the forefront of mass timber building in the United States, the design team faced other atypical challenges. These included regulatory hurdles with CLT, especially when it came to seismic requirements, since it is a relatively new material to this market. It was also necessary to navigate the limited CLT supply chain and fabrication capabilities, since at the time of construction there was only one domestic producer of CLT. This had implications for cost; it actually would have saved money to order the CLT needed all the way from Austria, since companies overseas have so much more experience producing the product and their economy of scale enables far lower prices than the one Oregon CLT plant could charge. Another significant challenge when it comes to price is working with subcontractors; it was necessary to convince risk-averse subcontractors to price the job reasonably. The LEVER design team describe the process as "re-educating an entire system."

CARBON 12

Portland, OR, USA | PATH Architecture

2017

38,000 sf

Condominiums

When it topped out in summer 2017, Carbon12 became the tallest timber building in the United States. It is 85' tall at eight stories. Though it will soon be supplanted by Framework (p. 61) in the height competition, Carbon12 is an example of how cost-effective engineered wood products and construction systems can be[1]. In joining the wave of recent mass timber projects in Portland, OR, the project is helping make the case for the potential of new construction practices with wood to help regenerate Oregon's timber industry and the jobs that come with it, both rural and urban. The Oregon Built Environment & Sustainable Technologies Center, Inc (Oregon BEST), an independent nonprofit funded by the Oregon Innovation Council and Business Oregon, granted Carbon12 a $45,000 reward for being a runner up in their CLT Design Contest Award. The money would go towards acoustic and moisture testing[2].

The structure of the building is a post-and-beam system using glulam columns and beams. Lateral bracing is provided by a steel elevator and stair core[3]. Since Portland is in a seismic zone, the team behind Carbon12 lauds is seismic stability, including 41 steel pilings under the foundation[4].

Carbon12 under construction in August 2017.

Diagram showing the structural system of Carbon12, including seismic pilings. Source: www.carbon12pdx.com

Craning a CLT panel into place. Source: Structurlam and Munzing Structural Engineering via ArchDaily

Marketing poster for Carbon12. Source: PATH Architecture, Inc.

While Carbon12 is unique from conventional eight-story buildings with its mass timber structure and construction, other parts of the building such as the enclosure system are basically the same as a conventional building. Subcontractors working on the facade installation did not need any special training, and once the timber structure was installed, their experience of the job site was not unique.

Despite these similarities and the extra effort designers took to make sure the building performed well seismically, the experience of permitting for Carbon12 illustrates the regulatory challenges that mass timber construction systems face. No U.S. building code exists for a timber structure taller than 85 feet, and the City of Portland had more stringent permitting requirements than Oregon State, including wanting a costly outside review of the computer simulations and modeling of the building developed to demonstrate its safety[5]. Since Oregon State has been trying to incentivize further development of mass timber construction, it did not require this extra step, and the developer of the project had it permitted through the state offices in Salem rather than through Portland city officials. A compromise was struck with Portland City officials, as the City of Portland Development Services is performing the building inspections[6].

Source: Courtesy of LEVER Architecture

FRAMEWORK

Portland, OR, USA | LEVER Architecture

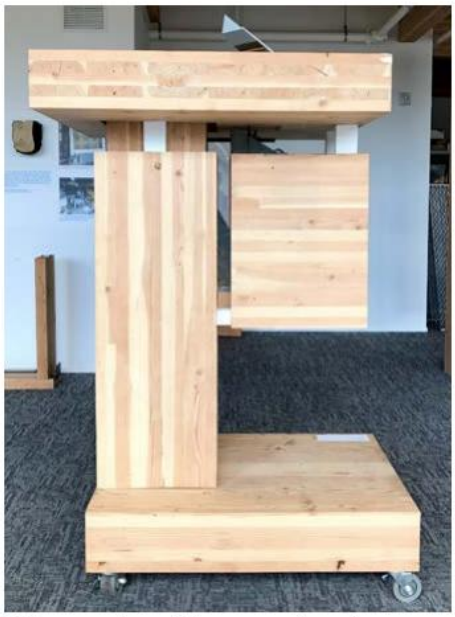
2018-9

90,000 sf

Mixed-use

Yet another mass timber project set to make an impact on Portland's skyline is Framework, a 12-story mixed-use project in the Pearl District. Framework is designed by LEVER Architecture, the firm behind Albina Yard (p. 53). Once completed it will feature retail and public exhibition on the ground level, five levels of office space, and affordable housing[1]. The project had not yet broken ground in August of 2017, but the Albina Yard building has a show room displaying Albina Yard materials and information alongside Framework developments. There have been a lot of developments to display; in 2015 Framework was awarded a $1.5 million grant from the U.S. Tall Wood Building Prize Competition, sponsored by the USDA and Softwood Lumber Board[2]. The prize money has gone on to fund the research and development necessary to utilize mass timber in high-rise construction in the U.S. The building won design review approval in 2016, and has carried out concept testing in the areas of fire protection, acoustic protection, and seismic performance[3].

Framework's structure is glulam post-and-beam with CLT floor panels. The CLT floor panels are topped with two inches of gypcrete to enhance acoustic performance by adding mass. All of the glulam on the interior will be exposed, as will the CLT from the underside. The regional Douglas fir that will be used for the mass timber elements is attractive, and demand is already high to rent space in the building once it is completed. The cultural and economic factors that underlie the Forest to Frame concept and tie Portland mass timber buildings to a larger context that many in the region embrace make Portland an ideal place for what will be the first permitted high rise mass timber building in the U.S.[4] It is worth noting that the other half of the Tall Building Prize money went to a New York City project that is now defunct, killed by the NYC fire department[5] in a region long-dominated by concrete and steel interests.



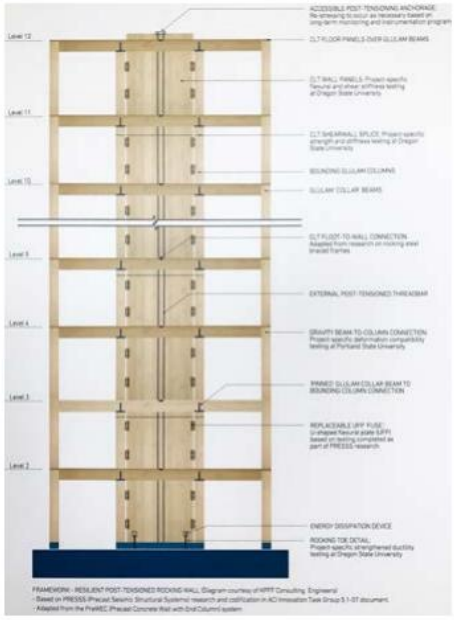
Full-size mock-up of the seismically-performing timber column-to-beam joint, displayed in the Albina Yard showroom.

Detail image showing the steel connection in the seismically-performing timber column-to-beam joint, displayed in the Albina Yard showroom.

Full-size mock-up of facade displayed in the Albina Yard show room.

Interior rendering of the Framework ground level exhibition space. Source: Courtesy of LEVER Architecture

Exploded axon detail, two-hour rated column/beam assembly. Source: LEVER Architecture



Resilient post-tensioned rocking wall. Source: Albina Yard show room. Diagram credit KPFF.

Each element of the structure has undergone extensive testing funded by the Tall Wood Building Prize. The custom glulam beam-to-column connection developed received the first two-hour fire rating in the world[6]. The same beam-to-column connection also underwent full-scale seismic tests at Portland State University, to validate that the connection could undergo the maximum anticipated seismic drift from an earthquake and remain undamaged[7]. The lateral system is an elevator/stair core made from CLT. When completed, Framework will be the first structure in the world to use a post-tensioned CLT rocking wall as the lateral stability seismic system[8]. Several different versions of the CLT wall panels underwent structural testing to ensure that they meet seismic performance goals; the connection between adjacent nine-ply CLT panels was one variable and ultimately tested successfully[9].

One factor in mass timber construction is the intensive amount of pre-planning required of the design team to ensure a successful installation. The Framework design team consists of the architects (LEVER Architecture), the structural and civil engineers (KPFF Consulting Engineers), the timber design-assist and construction specialists (StructureCraft Builders), the M/E/P engineers (PAE Consulting Engineers), and the fire and acoustic engineers (ARUP), who are also consulting on sustainability. The general contractor (Walsh Construction Co.) must also work closely with the design team to ensure all are on the same page. Though the building's construction starts in January 2018, design team members have figured out everything from the dimensions of the prefabricated CLT panels to the erection sequence of all structural components. To make matters more complicated, the only domestic manufacturing facility capable of providing the CLT is DR Johnson. With other mass timber projects in the region on similar schedules also hoping to use domestic CLT, it will be a challenge for all to ensure that DR Johnson can meet the high demand.

EXIT

BULLITT CENTER

Seattle, WA, USA | Miller Hull Partnership

2013

52,000 sf

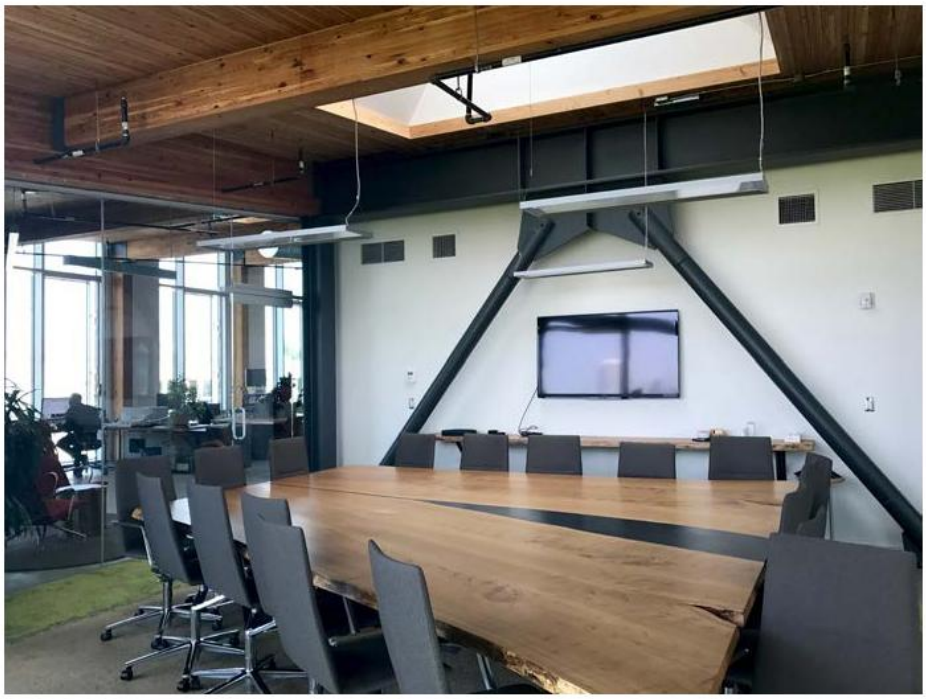
Office

Seattle's Bullitt Center builds on a forgotten legacy of heavy timber construction in the Pacific Northwest city. While "Heavy Timber" construction under the Type IV category has been in the national building code for over a century, this construction type was largely abandoned during the 20th century in favor of steel, iron, and reinforced concrete[1]. This is in part because the code limits the allowable height of buildings made with wood products.

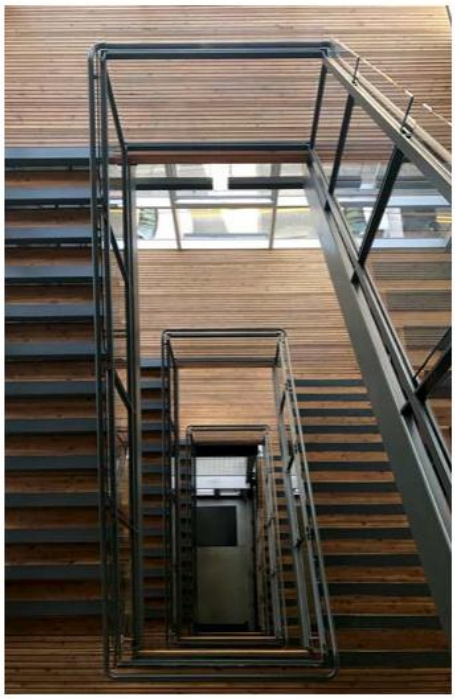
The Bullitt Center is a "podium" structure, with two stories of concrete supporting four stories of heavy timber construction. At six stories, the Bullitt Center has reminded Seattle of the potential of this construction type, and when it was completed in 2013 it was the first Heavy Timber building built in Seattle in 80 years[2]. The City of Seattle has since funded a CLT feasibility study and there is interest in how mass timber construction can be employed to improve city development.

The Bullitt Foundation did not set out to design a timber building; rather, sustainability was at the forefront of all of their decisions as they related to the project. After running life cycle assessments of concrete, steel, and timber options, wood came out as the clear winner[3]. It was important that the specifics of the wood used aligned with the high environmental standards of Miller Hull: 100% Forest Stewardship Council (FSC) Certified wood from mills within 600 miles of Seattle[4].

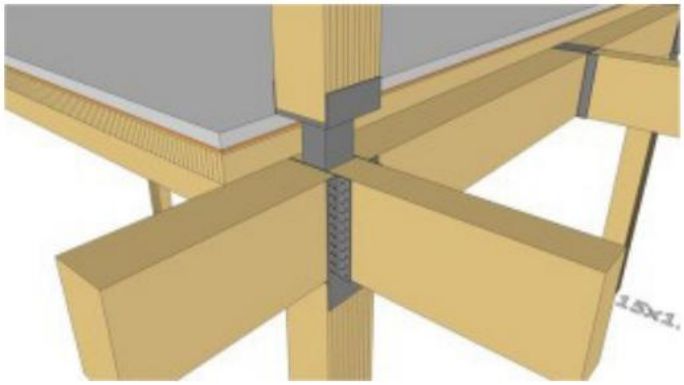
The total project cost was about 23% more than the cost of a comparable building, with the premium mostly due to the integrated design process, negotiating with regulatory agencies, and other hurdles typically faced by projects that break the mold[5]. With the building's advanced systems making it net-zero energy and water, owners and designers argue that the premium costs will be more than made up for over the lifetime of the building[6].



Custom steel chevron bracing, exposed in an upper floor conference room.



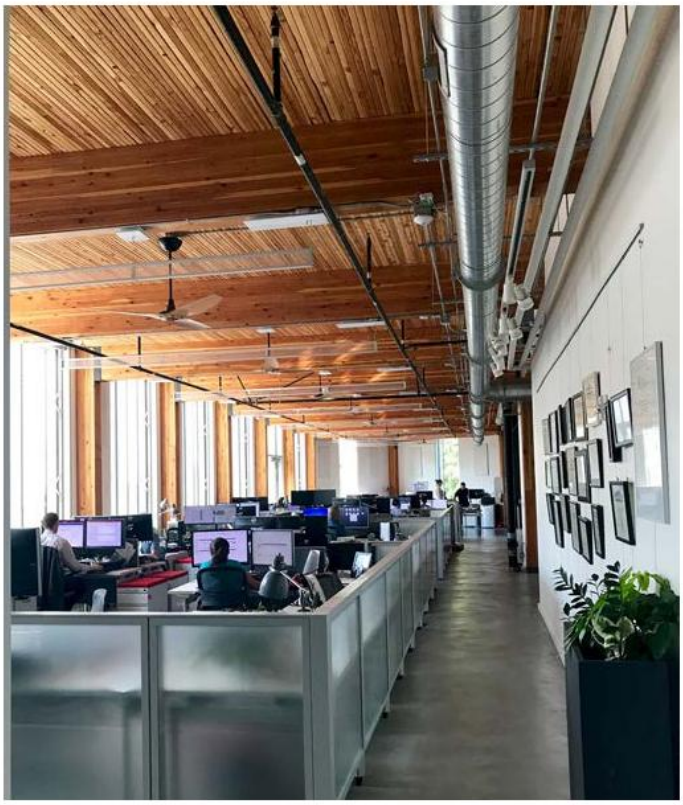
The wood and steel "irresistible stair."



Timber framing at column-beam connection diagram. Source: Bullitt Center

Custom steel connectors. Source: Bullitt Center

Exterior view, showing large overhang with PV panels above.



Level 3 offices.

The four stories of timber structure are largely reminiscent of typical heavy timber construction, and utilize glulam for the columns and beams. One departure from tradition was with the steel connectors, which needed to be custom-designed because at the time there were no off-the-shelf options for glulam post-and-beam connections[7]. To reduce vertical shrinkage of the building, which can happen when timber is loaded perpendicular to the grain, the columns are connected to one another in a vertical line with a steel tube[8]. In this way, the columns do not bear on the timber floor system, and vertical shrinkage is minimized. The steel connectors also had to satisfy fire concerns, since steel does not perform well in high temperatures. The bucket connector system designed is installed so that each of the main girders and beams has at least three inches of material bearing directly on the timber columns[9].

The floor and roof structure is NLT panels, nailed together on site, topped with ½ inch plywood panels that help to create a structural diaphragm. The plywood was topped with an insulation mat as a noise barrier, followed by three inches of concrete. The concrete helps with acoustics, serves as thermal mass for the Center's natural ventilation strategy, and is fitted with radiant heating. In addition to the NLT diaphragm, lateral stability in the four wood stories of the building comes from a custom chevron steel brace frame[10].

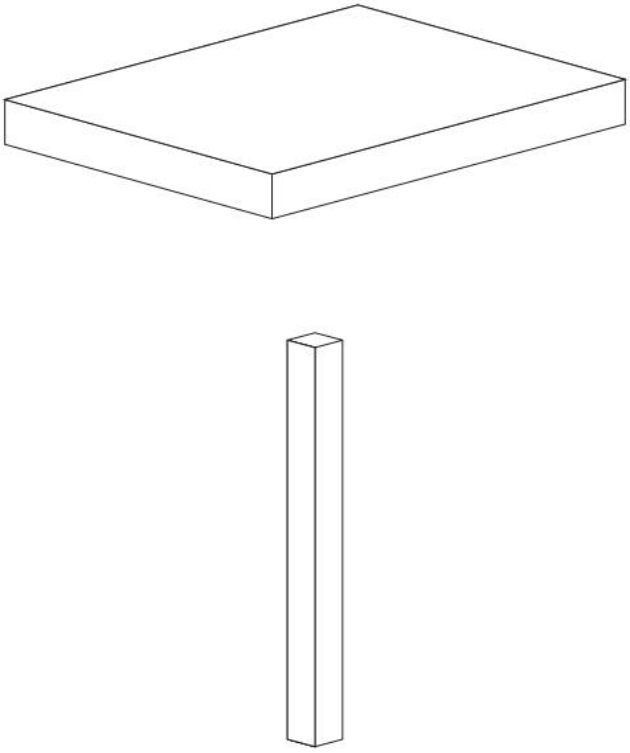
The interior finish strategy in the Center aligns more closely with the idea of material honesty (see VMS, p. 93) than the uninhibited celebration of wood in all forms (see FSC p. 41 and the CIRS p. 45). The concrete is left exposed in the two lower levels. For the upper four levels, the exposed structural timber defines the interior aesthetic. One of the most ambitious aspects of the Bullitt Center undertaking is the Living Building Challenge (LBC) certification. As part of the LBC certification a Post-Occupancy Evaluation was conducted, which revealed that building occupants' single favorite thing about the building is the exposed timber structure[11].

Ölzbündt Housing Development
Dornbirn, Austria
Multi-family Housing

North Vancouver City Hall
North Vancouver, BC, Canada
Civic

Brock Commons
Vancouver, BC, Canada
Student Housing

POST + PLANE



- Similar to Post + Beam, except beams have been replaced by panels that can span on their own and do not need to rest on a beam.
- Panels are either solid or prefabricated elements made up of multiple parts.
- Panels typically rest on columns on each corner.

ÖLZBÜNDT HOUSING DEVELOPMENT

Dornbirn, Austria | Hermann Kaufmann Architekten

1997

20,450 sf

Multi-family Housing

The Ölzbündt Housing Development was an important milestone in the development of architect Hermann Kaufmann's interest in prefabrication with wood. Hermann Kaufmann is part of the second generation of Austria's "Vorarlberg School of Architecture," which has built on the region's long vernacular history of building with wood, and values strong collaboration between designers and builders[1].

Kaufmann started out designing mostly residences, but his firm has always been interested in timber innovation. This innovation includes the use of prefabrication for timber construction, especially in larger structures. Professionals in Austria today describe prefabrication as an essential advantage of timber construction. They say that prefabrication ensures that timber construction can meet desired performance standards in building types conventionally done in steel and concrete. Prefabrication also saves time on site and thus saves money, which can help keep timber cost-competitive with more standard building practices.

The majority of Ölzbündt's components were prefabricated in a local carpentry workshop, including fully prefabricated bathroom units and prefabricated exterior walls with windows and cladding preinstalled[2]. The structural components of Ölzbündt include glulam columns with custom steel tube connectors at the bottom and top[3]. The floors and roof are prefabricated hollow box elements made from glulam beams and very narrow CLT panels, and filled with insulation and gravel for acoustic protection. The entire project was completed in 4.5 months and meets Passivhaus standards; Kaufmann said that a conventional construction would have taken 15 months[4]. This fast construction speed was made possible by rigorous pre-planning in design and detailing[5].

Completed construction, 1997. Source: Architekten Hermann Kaufmann

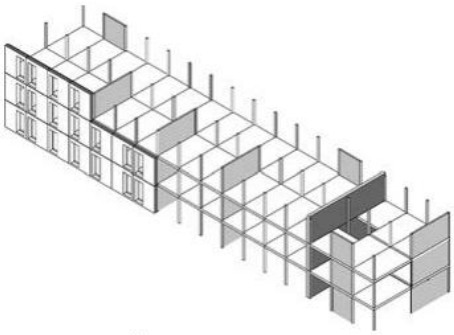
Photo, August 2017.

Full-size column connection mock-up display

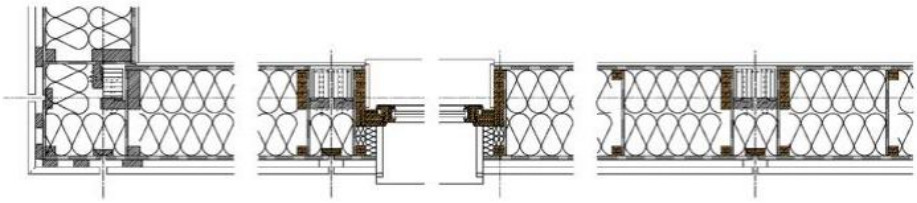
Full-size box element mock-up display.

Image of unit interior, showing one exposed glulam column.

Allmeinteilweg Housing Development.



Axonometric Ölzbündt layout diagram, showing exposed glulam columns on interior. Source: AHK



Exterior wall horizontal section. Source: AHK

Despite a few timber columns being exposed on the interior of the apartments, a former resident at the development said that the apartments feel the same as any other apartment building constructed of masonry or another material. Most of the interior surfaces are clad in gypsum wallboard, and no structural wood is exposed. Over the past 20 years residents have some complaints about the building, though not with the materials; rather, they claim that some of the Passivhaus technology was in its infancy in 1997, and as a result there is not always enough hot water.

In August of 2017, the multi-family housing project threw a 20-year anniversary celebration. Hermann Kaufmann has a brother, Anton Kaufmann, who is the president of the contracting company Kaufmann Bausysteme and collaborated with Hermann Kaufmann Architecten on the project. Anton Kaufmann was host of the anniversary party, and architect Hermann Kaufmann attended.

Hermann Kaufmann had hoped that the success of the Ölzbündt project would have led to subsequent projects using the same system, but this did not immediately come to pass. Kaufmann decided to redesign the Ölzbündt details in a way that made the construction accessible to any carpentry company[6]. After this development multiple projects based on the Ölzbündt model were completed in 2001, 2004, and 2007[7]; the 2007 project, Allmeinteilweg Housing Development, is pictured at left. The Ölzbündt system also planted the seed for the LCT system, used in LCT One (p. 25) and IZM (p. 29), with more projects to come.

RECEPTION

NORTH VANCOUVER CITY HALL

North Vancouver, BC, Canada | McFarlane Green Biggar Architecture + Design
Michael Green Architecture

2012

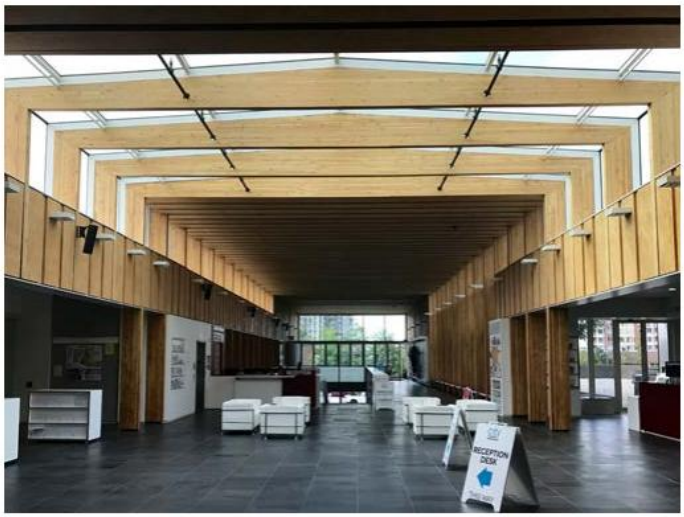
38,000 sf

Civic

The "Green" in "McFarlane Green Biggar" (MGB) is Michael Green, who went on to found his own firm Michael Green Architecture (MGA) in March 2012. Green was the project architect while working at MGB, and the North Vancouver City Hall (NVCH) started at MGB and finished at MGA.

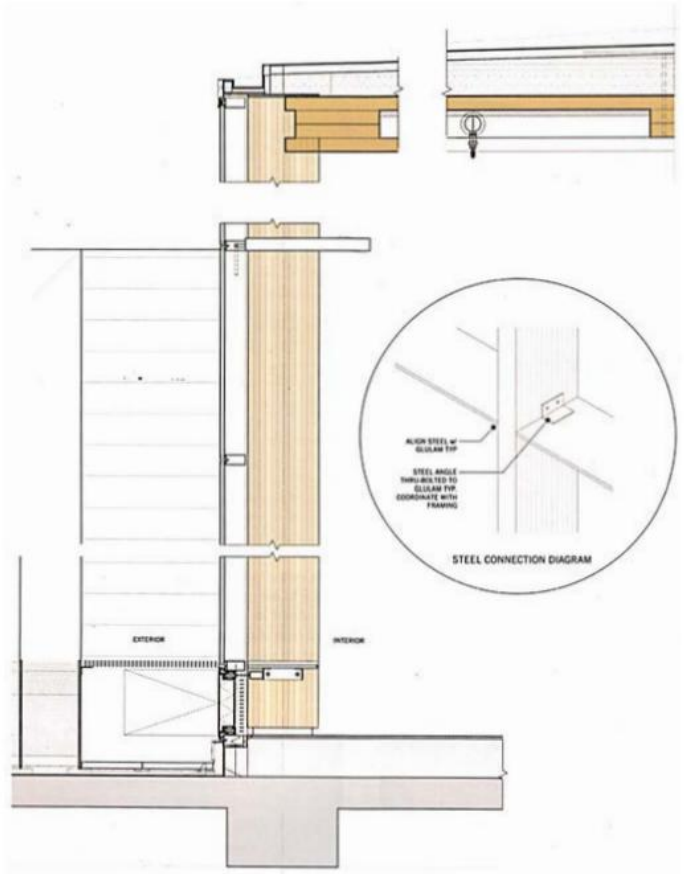
MGA, located in Vancouver, British Columbia, Canada, is at the forefront of the development of mass timber architecture in North America. Green gave a widely viewed TED talk in 2013 titled "Why we should build wooden skyscrapers"[1]. The talk detailed the high environmental cost of the building industry, the potential of using wood to build taller and larger buildings than is conventionally done, and how using a carbon-sequestering, renewable building material like wood can serve the dual purposes of helping combat climate change while building affordable housing for which demand will only increase in years to come. Similar to Oregon's "Forest to Frame" concept, Michael Green argues in his TED talk that "while earth grows our food, it can also grow our buildings."

Since its founding MGA has been well known for its research and work in tall wood buildings and for its innovative use of wood products. NVCH is a fine example of the latter, with the timber structure of its new central atrium. The atrium is the main spatial organizational tool[2], and connects two pre-existing concrete structures while enhancing wayfinding and circulation, and improving the public engagement of the building. The feel of the atrium is defined by the prominent use of exposed timber structure: glulam columns supporting prefabricated roof modules made primarily of LSL. LSL is usually seen in industrial applications and is not typically celebrated for its aesthetic appeal[3]. The design team at MGA turned this notion on its head and exposed it, taking advantage both of the budget benefits of this inexpensive material as well as the inherent warmth of the wood product.

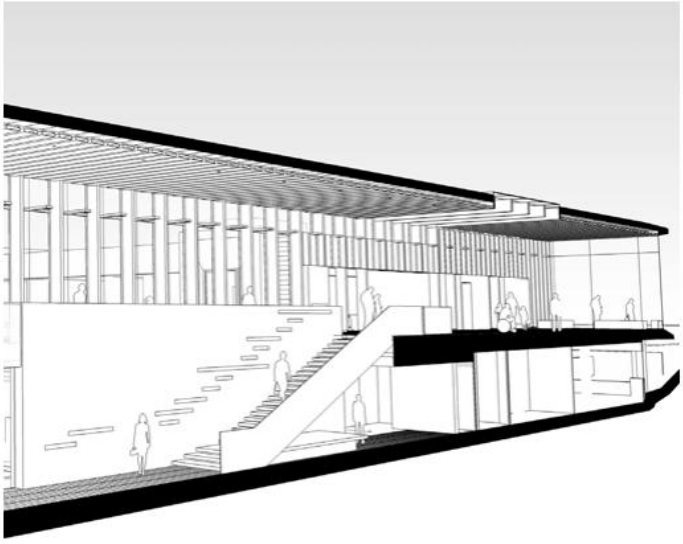


Atrium looking south, showing the skylights supported by glulam frames, and the LSL used as interior cladding on the transom level.

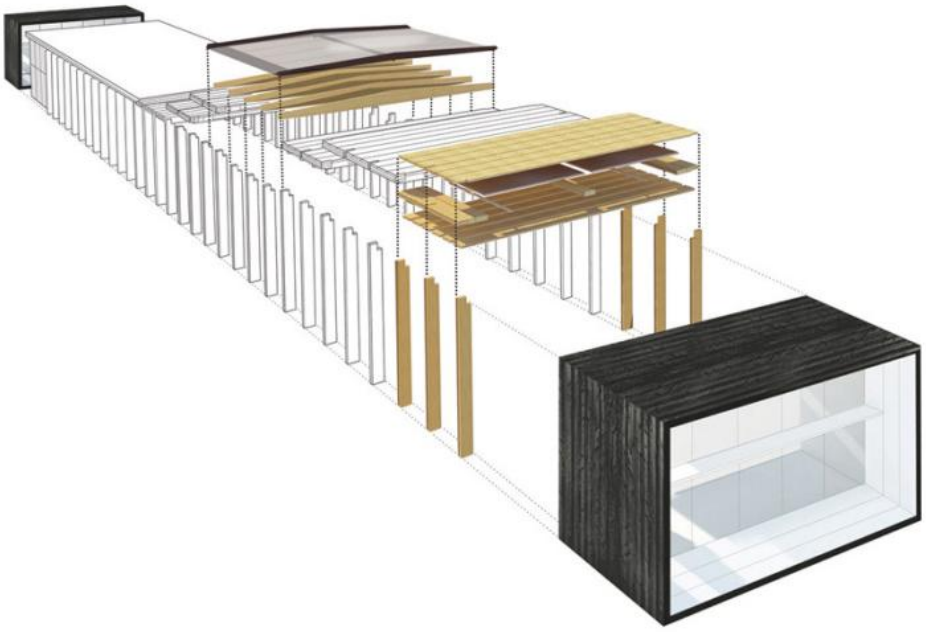
Atrium looking north, detail view of glulam columns with LSL panels above.



Glulam column and roof module detail section. Source: MGA via Solid Wood by Joseph Mayo



Atrium Section. Source: WoodSolutions



Atrium construction exploded axon diagram. Source: Michael Green Architecture

Atrium structure unit exploded axon diagram. Source: WoodSolutions

Using the LSL in this unconventional way was both a structural innovation and a material use innovation in this project. As shown in the above diagrams, each roof module consists of four layers of LSL that create a custom cross-laminated construction[4], using the same concept as that behind CLT. LSL is typically not used in full-size billets as it is here; rather the billets are cut down into smaller pieces. Using the full-size billets was a first for the manufacturer, and required negotiation on the part of the MGA design team to get the manufacturer to work outside of their normal practices. The LSL use in this project transformed the manufacturer's perceptions of their product, and in so doing opened them up to new opportunities[5].

The roof modules were prefabricated, shortening the construction time[6]. All of the wood products had to be protected from weather during construction, so the glulam columns were wrapped until the building was fully sealed, and a vapor barrier was pre-installed on top of the roof modules to protect them before the addition of insulation and the final roof membrane[7].

The roof modules are not the only innovative use of wood in the NVCH. Exterior overhangs are prefabricated hollow box elements made of PSL beams and plywood panels[8]. Wood is also used in parts of the floor system, as glulam beams topped with plywood and about four inches of concrete. The glulam beams and concrete slab are connected by perforated steel plate HBV shear connectors cast into the concrete topping and epoxied onto the timber beams[9]. Lateral support for the building does not use timber; rather it is provided by concrete shear walls in two directions. These shear walls, along with light frame walls, also supplement the glulam columns in their support of the roof module[10].

Acoustics can be the most difficult techincal challenge with mass timber construction. This is especially true when the structural wood will be exposed. Acoustic protection in the atrium is provided by an insulation layer affixed to the top of the LSL panels in the void space between layers, which also houses a code-required sprinkler system[11].

BROCK COMMONS, UBC

Vancouver, BC, Canada | Acton Ostry Architects

2017

162,700 sf

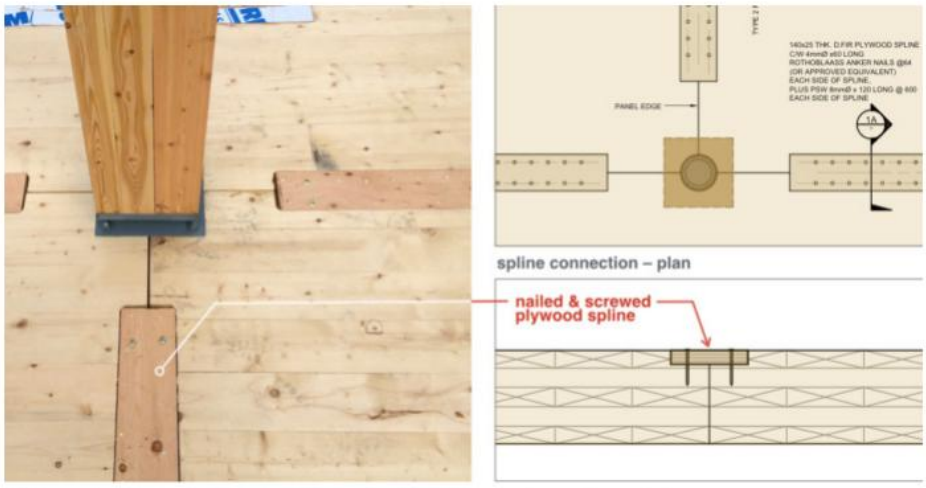
Student Housing

The University of British Columbia (UBC) is in a push to provide students with more on-campus housing[1]. While Brock Commons, or Tall Wood House, is not the only dormitory building recently completed on the UBC campus, it is certainly the most special: at 18 stories (174 feet) tall, when completed it became the tallest wood building in the world[2]. Designed by the local firm Acton Ostry Architects (AOA) with tall wood advising by Hermann Kaufmann Architeken (AHK), engineering firm Fast + Epp and timber manufacturer Structurlam were also collaborators.

The building is one story of concrete with 17 stories of mass timber construction above. The mass timber structure consists of glulam columns supporting CLT panels. The ability of CLT to span in two directions was instrumental to the viability of mass timber for this project, because it enabled the designers to bypass the use of beams[3]. Beams can be problematic for two reasons: 1) you must devise a way to integrate services into the beam system and 2) they require more vertical space, increasing the required floor-to-floor heights, and therefore decreasing the total number of floors possible within a certain height limit. With the beams eliminated, the construction is more similar to concrete[4]. Lateral support for the building is two concrete stair cores[5].

This was AOA's first mass timber project, and they won the proposal by staying focused on UBC's stated goal: to build a low-cost mass timber structure for a student residence building with 400 beds[6]. UBC already had an ongoing program for building student residences, typically using concrete construction, and they had applied to a Natural Resources Canada program that would provide the funding gap for construction of tall wood buildings (over 12 stories). The attitude of the architects was that they would use the provided exploratory funding, and if it turned out that mass timber construction was not viable for the project, it would be done conventionally using concrete[7].

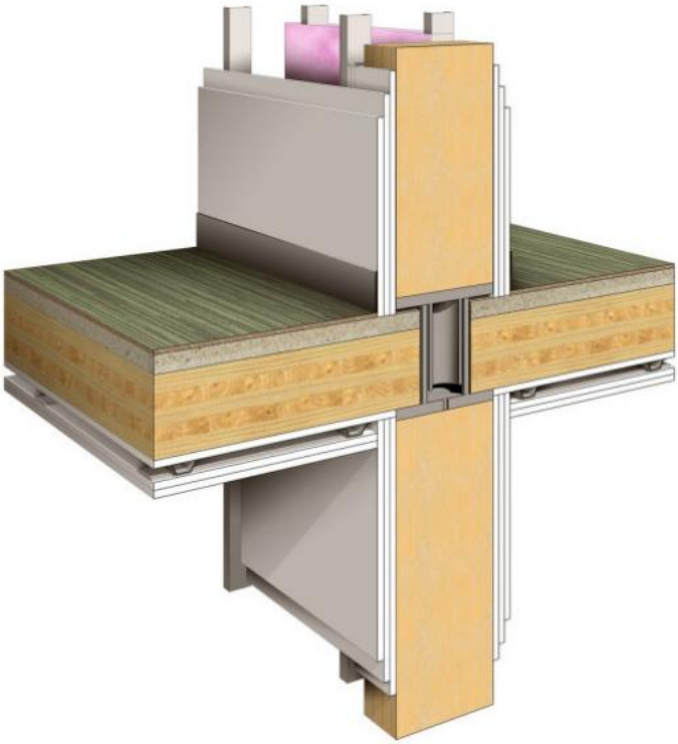
Brock Commons during construction. Source: Acton Ostry Architects



CLT panel connections using a plywood spline. Source: Acton Ostry Architects

View of the building from afar.

Images of the interior on the ground floor, which is concrete construction, showing emphasis on wood interior finishes.



Completed Construction Assembly. Source: Acton Ostry Architects

Mass timber construction before and after encapsulation. Source: Acton Ostry Architects

Mass timber did prove viable, and ended up having significant construction benefits. Prefabrication and ease of installation with precisely-milled timber components enabled the structure to be completed in less than 70 days once the prefabricated elements were delivered to the site[8]. The superintendent on the project, who had previously only worked in concrete construction, was amazed at the precision of the prefabricated parts, as well as how clean, dry, and quiet the construction site was. The installation crew was completing two floors per week, a speed that had been predicted by the integrated design team but no one on site believed was possible. Construction delays were not due to the timber construction, but rather to the fact that sub contractors on the interior team had not believed they could get to certain stages as fast as promised, and they were not ready as soon as the building was.

The designers of Brock Commons approached regulatory challenges, a common problem with mass timber construction, by being conservative. They knew that the regulatory authorities would be skeptical of the capability of mass timber to perform well in fire despite successful testing. So, the designers decided to entirely encapsulate the wood structure in gypsum wallboard, in the way typically done with steel construction[9].

Brock Commons is, in a sense, a microcosm of the differences between the state of the industry in Europe, with a couple of decades of development under their belt, and the younger state of the industry in North America. An architect at AHK advising on the Brock project described how a Canadian architect told them the desired tolerances of the prefabricated CLT panels were not possible. After inquiring further AHK found that the manufacturer had a German-made machine that AHK knew was capable of the desired precision. It turned out that the manufacturer had never calibrated their machinery to achieve such precision, having never been asked for such precision before. In the end, the CLT boards were fabricated with the desired tolerances.

H4
Bad Aibling, Germany
Multi-family Housing

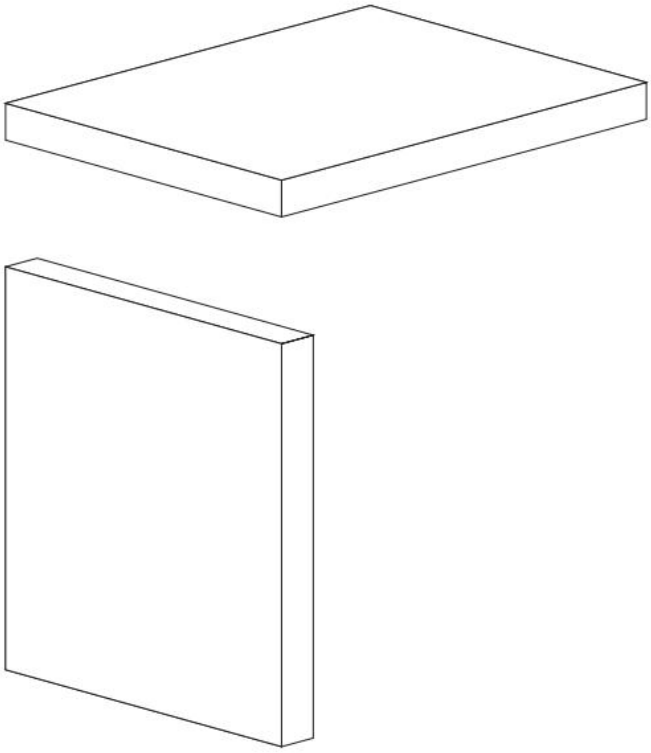
H8
Bad Aibling, Germany
Multi-family Housing

Vorarlberg Mittelschule
Klaus, Austria
Primary Education

Ludesch Community Center
Ludesch, Austria
Civic

Ronald McDonald House BC
Vancouver, BC, Canada
Healthcare, Multi-family Housing

PANELIZED



- Vertical and horizontal loads are carried by solid wood or prefabricated panel elements arranged in two directions in plan.
- Tend to result in spaces with limited flexibility for reconfiguration over the life of the building and therefore are better-suited to programs where occupant needs are fixed, such as multi-family residential.

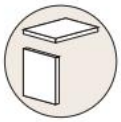
H4

Bad Aibling, Germany | Schankula Architekten

2010

6,000 sf

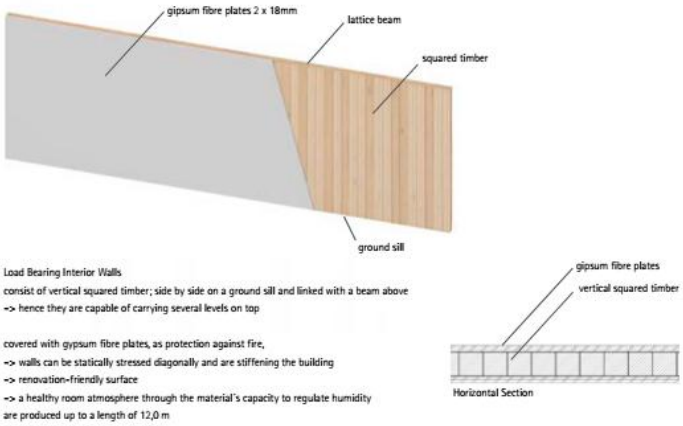
Multi-family Housing



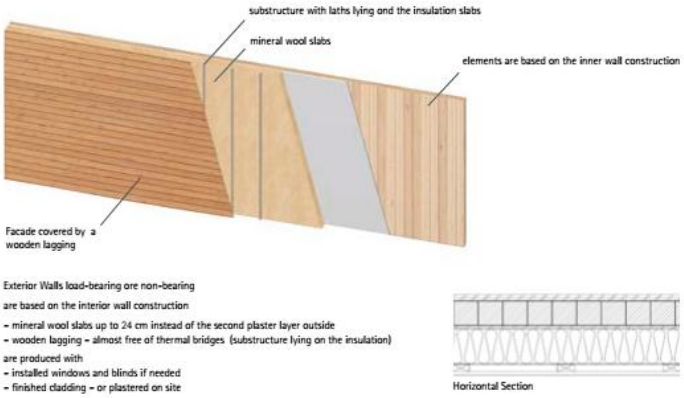
A large property in the small Bavarian city of Bad Aibling, Germany was owned by the U.S. Army from May 1945 until 2004. The German company B&O Group bought the land in 2005, and today it is a company campus with housing, offices, schools, a hotel, and eventually retail. B&O started out specializing in roof shingles. They expanded to become a housing maintenance and renovation company, and have been very successful. The company uses the Bad Aibling campus to experiment with new building materials and processes, which is how H4 (and H8, p. 89) came to be. Both H4 (short for "Holz4;" "holz" means "wood" in German) and H8 are pilot projects, developed with the goal of demonstrating that highly efficient wood buildings can play a major role in supporting net-zero cities.

Schankula Architekten is based in Munich, Germany, and did not set out to become experts in timber construction. Rather, they started off interested in prefabrication, which they employed successfully in a 2008 facade refurbishment project on the B&O campus. In the years after 2008, the firm worked on many Munich high schools. While developing this work they realized that wood construction worked out better than steel and concrete for the span most commonly associated with these projects (nine meters, or about 30 feet). Prefabrication and wood have been key for these projects, since often schools are on a tight construction schedule due to limited vacation time.

H4 is a four-story structure of mass timber construction built on an existing basement. It was funded in part by the German Environmental Foundation (DBU)[1], and was the first building of a movement seeking to develop an economic construction system for up to eight-story timber buildings. Schankula worked closely with the fabricator Huber & Sohn from the beginning. Researchers at the Technical University of Munich and the University of Rosenheim also contributed to the building design.



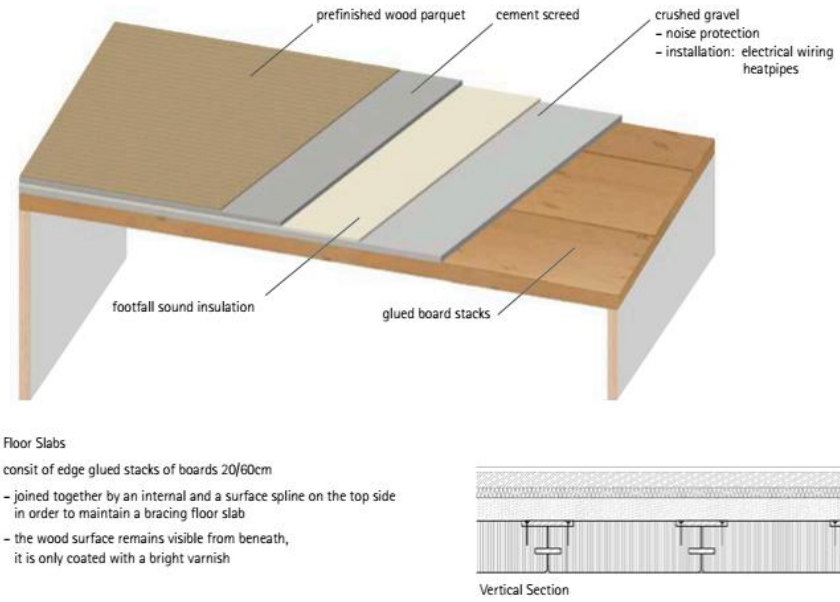
Load-bearing interior wall detail. Source: Schankula Architekten. Reprinted with permission.



Load-bearing interior wall detail. Source: Schankula Architekten. Reprinted with permission

H4 construction site, day 2. Source: Huber & Sohn

H4 exterior stair, also showing metal fire breaks at each level on the facade



Floor slab detail. Source: Schankula Architekten. Reprinted with permission.

Apartment interior, showing exposed ceiling. Source: Schankula Architekten

H4 houses six apartments, and the entire building is constructed of wood, including the elevator core. The only exception to this is the exterior staircase, made of steel, as code required an egress route made from non-combustible material[2]. The gravity structure of H4 is load-bearing interior and exterior walls; detail shown at left. The panels are made of solid wood posts stacked and bound together by gypsum wallboard and horizontal posts at the top and bottom of the stack[3]. The floor structure, shown above, consists of edge-glued stacks of boards joined together by two splines, one internal and one on the top side. Floor/ceiling modules, like the wall panels, were prefabricated by Huber & Sohn. Lateral stability is provided by a stair core made of CLT, completely prefabricated and crane-lifted into place[4].

Speedy construction times were a hallmark of the H4 project. The entire building was erected in just four days[5]. While speedy construction does save money, H4 was still more expensive to build than anticipated[6]. The lightness of wood structure relative to concrete and steel is usually a benefit, but in this case it was too light. The installation of steel tie rods was required to prevent the building from overturning in strong winds[7].

For the floor/ceiling panels the wood is exposed on the underside, providing wood ceilings to the apartment below. The design team had to get special permission to expose the wood due to fire concerns, but it was possible to do so since most of the wood in the project is encapsulated with gypsum wallboard[8]. Gypsum wallboard is easier to patch and repair over time than the structural wood panels would be, so it made sense that the walls would not leave the timber exposed. Residents like the wood on the ceiling and the white walls, expressing that the wood conveys warmth while the white walls enhance brightness.

According to the building manager, H4 (and H8) have had no major problems, with the wood structure or otherwise. They also both have high occupancy rates.

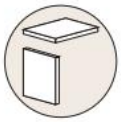
H8

Bad Aibling, Germany | Schankula Architekten

2011

14,400 sf

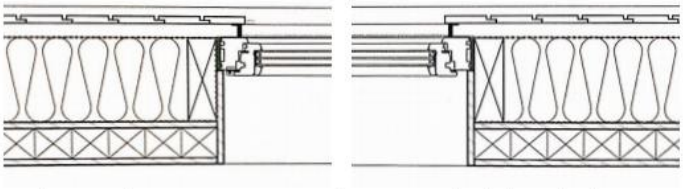
Multi-family Housing



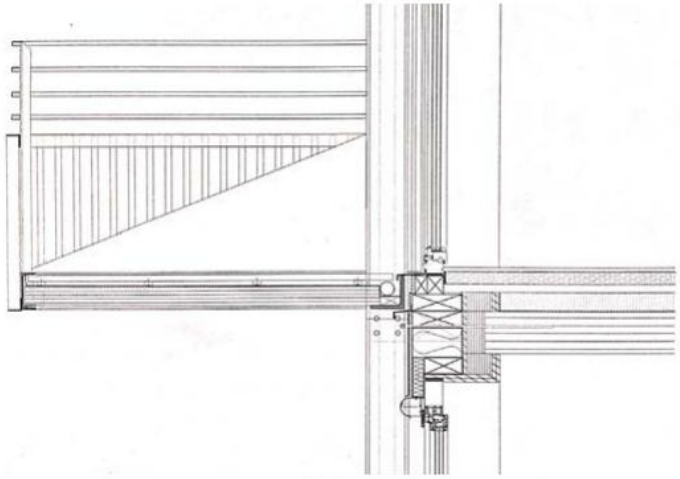
The H4 project (p. 85) led to the H8 project that was completed the following year. H8 built on the progress of H4, but set a loftier height goal of eight stories. When it was completed, H8 became the tallest wood building in Germany[1]. The height of H8 was carefully planned to make it as high as possible without it being classified as a technical "high-rise." This is because high-rise structures in Germany have other requirements that would have made the project more difficult; for example, they require two means of egress[2]. In order to get approval for the structure, the regulatory authorities required that the vertical circulation cores be made of a non-combustible material[3]. This meant that H8 could not use CLT for the core as H4 had, and instead the core is constructed in concrete.

The gravity structure of H8 is very similar to that of H4, with the same type of load-bearing prefabricated wall panels. The floor structure is different, as H8 uses 5-ply CLT, though the rest of the floor system is similar. As with H4, there are layers above the floor structure: a service cavity, impact sound insulation, screed, and a wood finish.

Exterior view of H8, with the building manager in the foreground

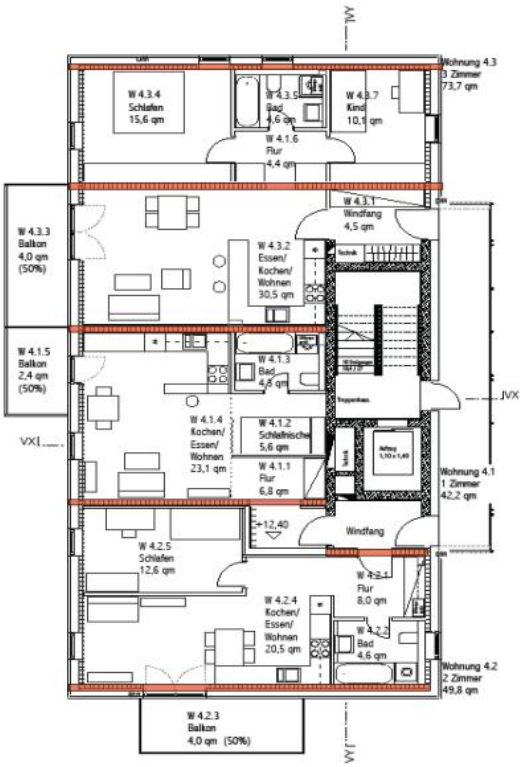


H8 horizontal section at exterior wall. Source: Schankula Architekten via Solid Wood by Joseph Mayo

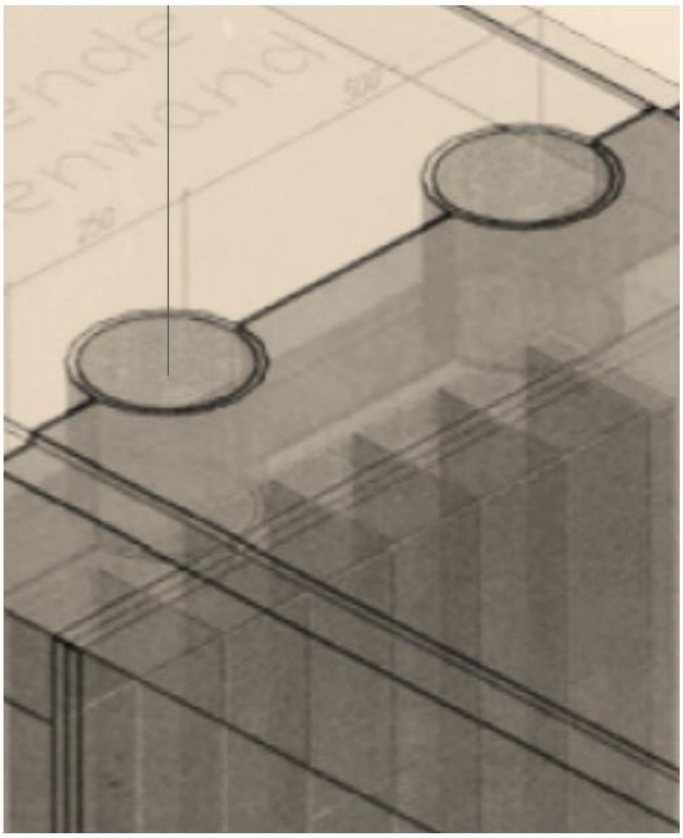


H8 vertical section at exterior wall, showing balcony attachment. Source: Schankula Architekten via Solid Wood by Joseph Mayo

Offices on the ground floor of H8, showing exposed CLT ceilings



H8 floor plan, showing load-bearing walls in red. Source: Schankula Architekten



3D model showing concrete compression dies. Source: Schankula Architekten

Because the concrete stair core and the rest of the building were constructed of different materials, the design team had to come up with ways to harmonize the construction systems with one another and to accommodate differential movement. This was done by drilling holes into the CLT floor slab and filling them with non-shrinking concrete. In this way the load-bearing walls would rest on the concrete rather than the CLT, and wood shrinkage perpendicular to the grain would not be a problem[4]. The CLT slabs are exposed on the bottom as is done in H4, though the top floor of H8 has all structural wood exposed. This was possible because fire spread is much less risky on the top floor.

Spatially H8 has one key difference that is an improvement upon its predecessor. In H8, the load-bearing walls are almost exclusively between units, not also within units as is the case with H4. This was an improvement, as at least one H4 tenant thinks the room layout is impractical, and there is not enough light in the spaces (see **INSIGHT #4**: Survey Results for more information). With load-bearing walls defining rooms, there is no ability to alter the spatial arrangement.

The prefabricated exterior wall elements go a long way to helping both H4 and H8 meet the high energy goals set forth by B&O Group. With insulation and cladding pre-installed the construction has few thermal bridges. While both projects perform well energy-wise, H8 performs better because it is larger and thus has a better surface area-to-volume ratio[5].

VORARLBERGER MITTELSCHULE

Klaus, Austria | Dietrich Untertrifaller Architekten

2003 School building, 2015 Gym addition

48,700 sf

Primary Education

In 2001 the city of Klaus in the Vorarlberg region of Austria held a competition for a new middle school. The project was awarded to the Bregenz, Austria architecture studio Dietrich | Untertrifaller Architekten. Two goals for the project from the outset were to meet 1) the highest possible energy efficiency and 2) the lowest possible budget[1]. Tasked with an 18-month time line on top of that, the architects chose a prefabricated wood construction system, which would not only enable a rapid assembly but also helped comply with the high ecological standards[2]. The school was finished in 2003, and meets Vorarlberg's Passivhaus guidelines. The new two-story building consumes 70% less energy than the building that it replaced[3], and accommodates 12 classrooms, special education rooms, and administrative offices. A 2015 addition includes the gymnasium, reception area, and specialized study rooms.

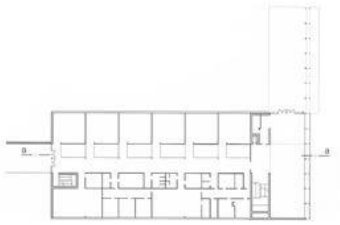
The architects chose a materially honest approach in the interior finishing strategy. Everything that is constructed of wood is also clad in wood, and concrete and plasterboard are left exposed[4]. Since most of the building is constructed in wood, this approach means that the interior makes use of a lot of wood paneling, specifically birch. Employees at the school described the effect as "cozy" and "comfortable." The wood aesthetic was complemented by a "friendly and warm" color palette, as characterized by the users (see **INSIGHT #4**: Survey Results for more information). In terms of structural material, the construction system consists of prefabricated hollow "box" elements[5] consisting of glulam beams, OSB, and plywood[6]. CLT is absent from the project, and lateral stability is provide by concrete stairwell cores[7]. The lightness of the structure helped avoid the use of elaborate pile foundations, thereby contributing substantially to cost savings of the project. In the end it cost just about 3% more to build than conventional means[8].

View from the school yard, looking south.

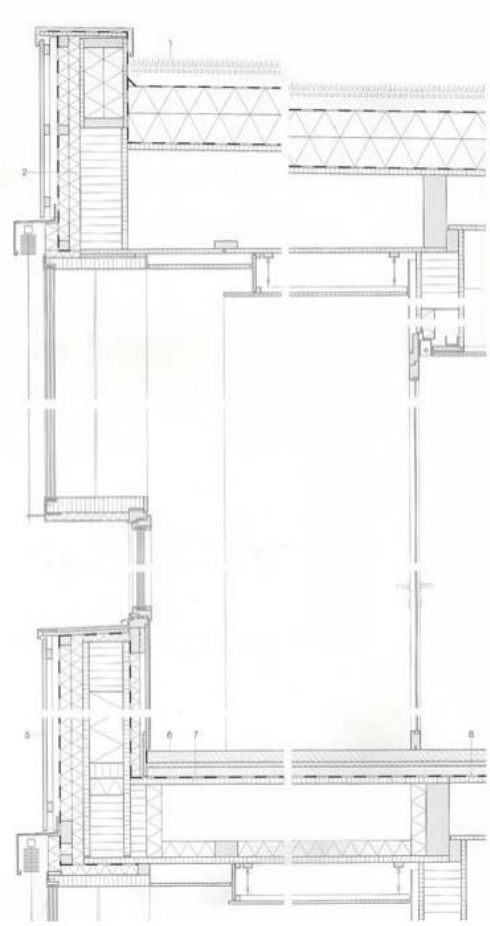
Library.

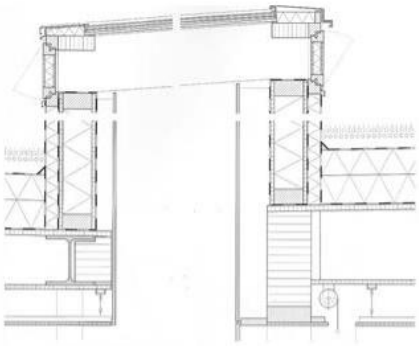
2015 Gym addition, under construction. Each skylight has a unique geometry and is optimized to provide daylight without glare.
Source: Dietrich | Untertrifaller

Gym addition, completed in 2015.



20 mm natural silver-fir boarding on
30 mm battens and 40mm counter-battens
windproof layer; 2x 40/60mm halved bearers
with rock wool insulation
33 mm laminated construction board
180 mm laminated timber beams
33 mm laminated construction board; vapor barrier
50 mm rock wool between 84mm battens
35 mm cavity; 12mm birch plywood





20 mm natural silver-fir boarding on
30 mm battens and 40mm counter-battens
windproof layer; 2x 40/60mm halved bearers
with rock-wool insulation
33 mm laminated construction board
180 mm laminated timber beams
33 mm laminated construction board; vapor barrier
50 mm rock wool between 84mm battens
35 mm cavity; 12mm birch plywood

Source: Detail Magazine, 1+2/2004

While much is successful about this project, a couple of issues stand out based on the post-occupancy experiences of users. The acoustics were described as "difficult" by a teacher at the school—both within the classrooms and between the classrooms. Despite the addition of small perforations in the plywood finish to dull acoustic reflectivity within rooms, and added insulation in the hollow box elements to prevent sound transmission through walls, the school building does not perform as desired acoustically. Acoustics is one of the biggest technical challenges when it comes to building with wood. The second complaint expressed by building users is its thermal performance. According to interviewees, the thermal conditions on the interior of the 2003 school building are unpleasant, indeed teachers "almost go crazy" in June due to heat (see **INSIGHT #4**: Survey Results for more information). This overheating is described as the biggest problem of the building, even more so than the acoustic issue. The 2015 gym addition incorporated radiant cooling in the floor of a new classroom, which dramatically improves the thermal situation in comparison with the 2003 classrooms.

Interior atrium

LUDESCH COMMUNITY CENTER

Ludesch, Austria | Hermann Kaufmann Architekten

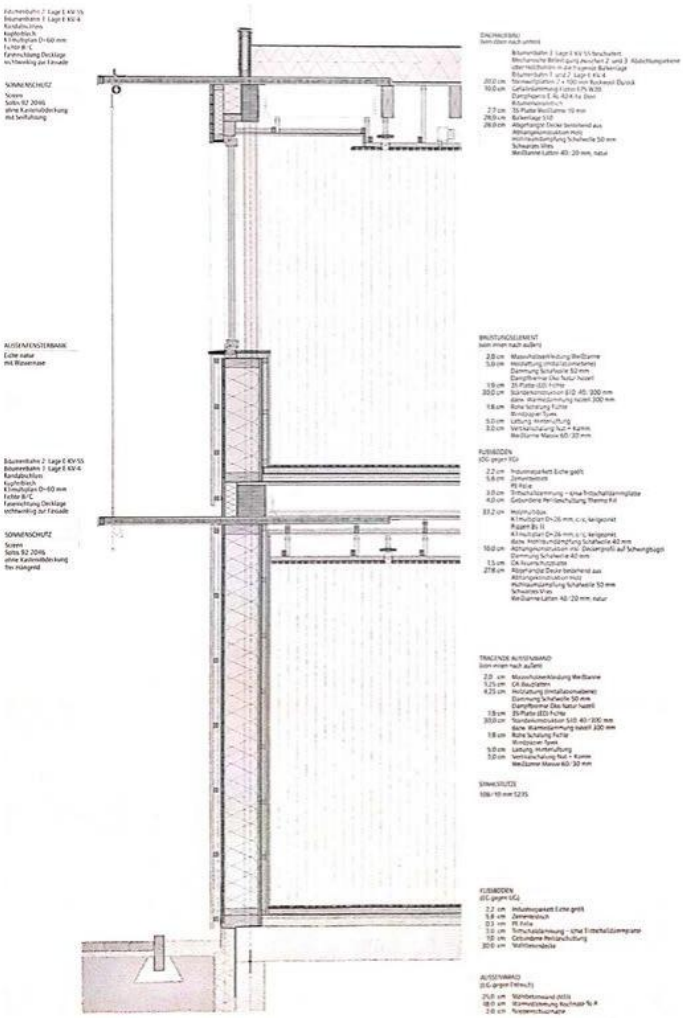
2005

156,000 sf

Civic

Ludesch is a small town in the Vorarlberg region of Austria with only about 3,000 residents. One third of the total area of Vorarlberg is covered in forest[1] and the timber industry employs many of the region's workforce in some way or another. As such, wood has a centuries-long history as a building material in the region, and traveling around the region at times feels like viewing a survey of both contemporary and traditional wood architecture. Today the region is saturated with award-winning architecture firms who work extensively with wood, including Hermann Kaufmann Architekten (HKA), the firm behind the Ludesch Community Center.

The process and outcomes of the Ludesch project are indicative of the direction of Vorarlberg wood architecture in the 21st century. Wood was selected rather than conventional concrete and steel construction due to its stronger performance in both the Passivhaus ecological and biological guidelines and its life cycle performance[2]. There is also a Vorarlberg eco-guide that the planning team consulted[3]. This construction system analysis is similar to the process done for the Bullitt Center in Seattle (p. 65). Specific building materials were selected according to regional value added, the use of local wood, environmental impact, and chemical safety[4]. One result of the effort to reduce toxic chemicals was the development of a PVC-free joint tape by a local manufacturer, which the company has since begun offering in its range of products[5].



Exterior wall detail (from a photo of a poster displayed at site)

Exterior wall detail (photo taken at site)

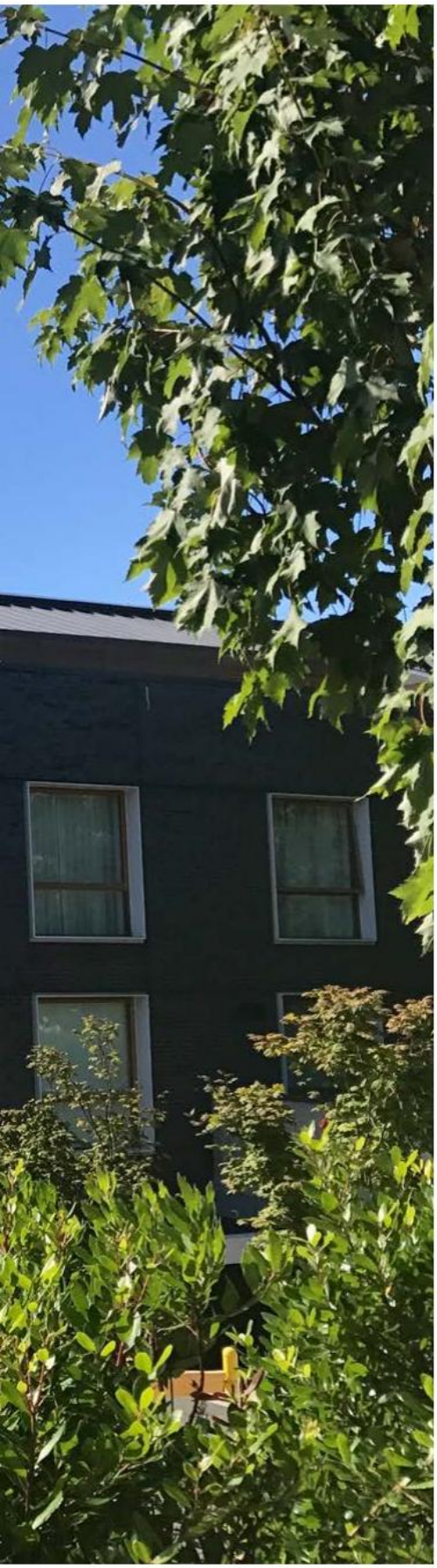
Exterior wall assembly full-scale model, located at site

Ground floor interior of main building

Courtyard with restaurant seating and PV panels above

The wood construction of the Ludesch project consists of prefabricated wall and ceiling hollow box elements. The boxes are made up of "ribs" enclosed by panels. The ribs are beam-like components made of wood or wood-based materials. The panels are called "K1 multiplan"[6], a product name, and consist of three-ply solid timber panels that are cross-laminated. The panels are approved for structural loads, and are shear-resistant. Glue is used to attach the ribs to the panels[7]. The panels were prefabricated by a local company before being installed on site[8]. Lateral stability is provided by select walls that are solid[9]. Slender steel columns also supplement the wood structural system, where they bring spatial advantages in the interior[10].

Silver fir was used for both the exterior facades and as an interior finish. Depending on the application of the panel, the architects specified that the fir be sawn, brushed, or planed[11]. The use of differing treatments in this way is one example of the attention to detail that Vorarlberg architects, and especially HKA, bring to the use of wood. While discussing a separate HKA project, an architect at the firm spoke at length about how the interior finish boards were installed right off the band saw, with the texture of the band saw still intact on the surface of the wood, rather than being sanded down. This excitement about wood and all it has to offer for architecture, whether as a structure or finish or a piece of furniture, is what drives the design and craftsmanship in the Vorarlberg region.



RONALD MCDONALD HOUSE BC

North Vancouver, BC, Canada | McFarlane Green Biggar Architecture + Design
Michael Green Architecture

2014

74,000 sf

Healthcare, Multi-family Housing

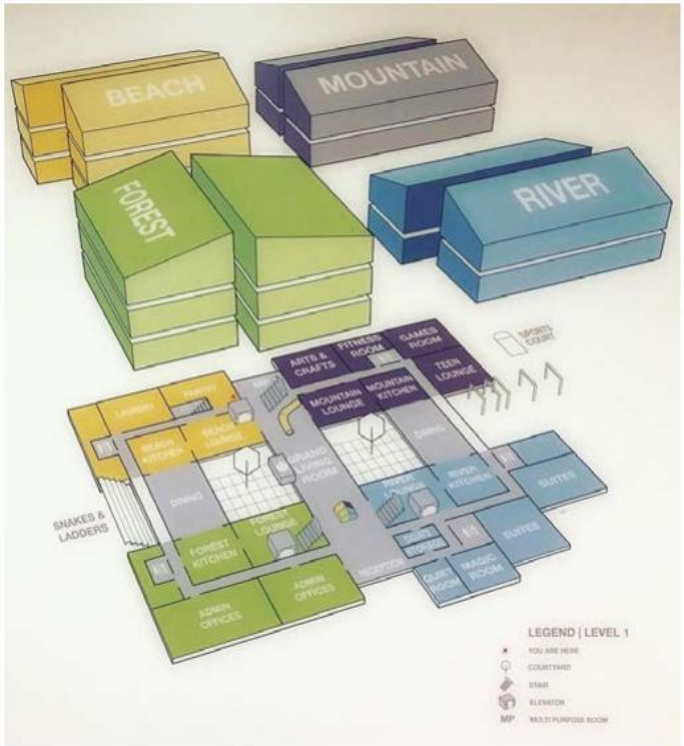
Ronald McDonald House Charities (RMHC) is an organization that provides a home environment with support and resources for seriously ill children and their families, keeping families together and close to the care and resources they need[1]. In Vancouver, the RMH is adjacent to the British Columbia Women's and Children's Hospital. The RMH British Columbia (RMHBC) previously only accommodated 12 families at a time and it was not meeting demand[2]. Michael Green Architecture (MGA) was enlisted to design the new facility that would house 73 families.

MGA wanted the project to look and feel more residential than institutional, in order to make families feel at home, and to harmonize with its surrounding neighborhood of single-family houses[3]. They organized the program into four "houses," each with its own identity and BC geography-inspired name. Each house accommodates six families and has a shared kitchen and living room, with shared dining rooms linking neighboring houses. The four houses are organized around a common courtyard that is split in two by an enclosed "Grand Living Room" shared by all four houses (see program diagram on following page).

MGA brought the same level of forethought and planning to the building design as they did to the construction, which is an innovative tilt-up CLT system. The structure of the exterior walls is CLT, fabricated into panels with pre-installed LSL ledgers to support the floor structure. Connections between CLT panels were also prefabricated, as were boxed dormers that were placed on site by crane[4]. The CLT is both the gravity structure and the lateral stability system. The floor structure (see diagram on following page) consists of wood I-joists supporting plywood decking that is topped with two inches of concrete incorporating radiant heating and covered by wood flooring. The concrete likely also helps with acoustic performance. The floor I-joists are covered on the underside with gypsum wallboard.

Photos during construction of the RMHBC, showing the tilted-up CLT during installation and wrapping. Source: Equilibrium Consulting Inc.

Interior shot, showing custom-designed wood play houses. Source: MGA. Photo Credit: Ema Peter



Program diagram displayed on interior of facility.

One of two locations where CLT structure is exposed. Source: Canadian Architect. Photo credit: Ema Peter

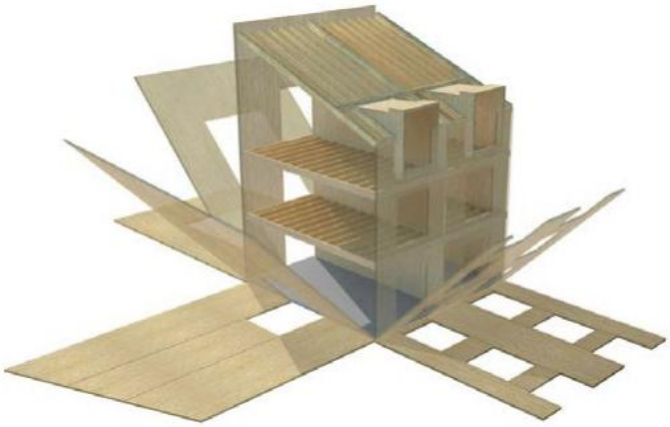
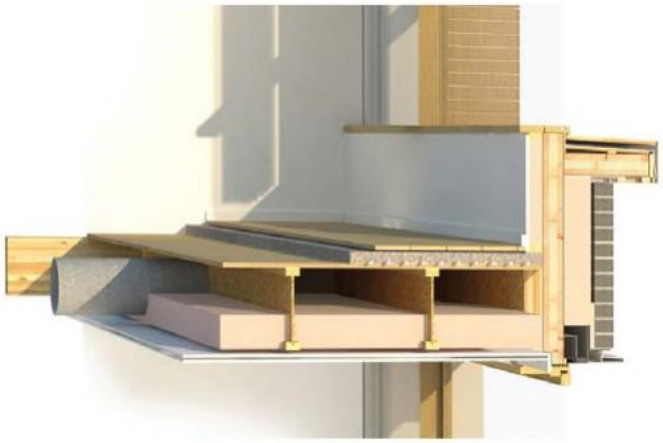


Diagram of CLT tilt-up construction. Source: MGA



Section perspective of construction at window. Source: MGA

The CLT tilt-up process is very similar to tilt-up concrete. Panels are assembled horizontally then levered into place. Despite the similarity, subcontractors bidding for the project had to be convinced that it would not be overly complicated[5]. The choice of construction system, though unfamiliar, paid off—the project opened two months early[6].

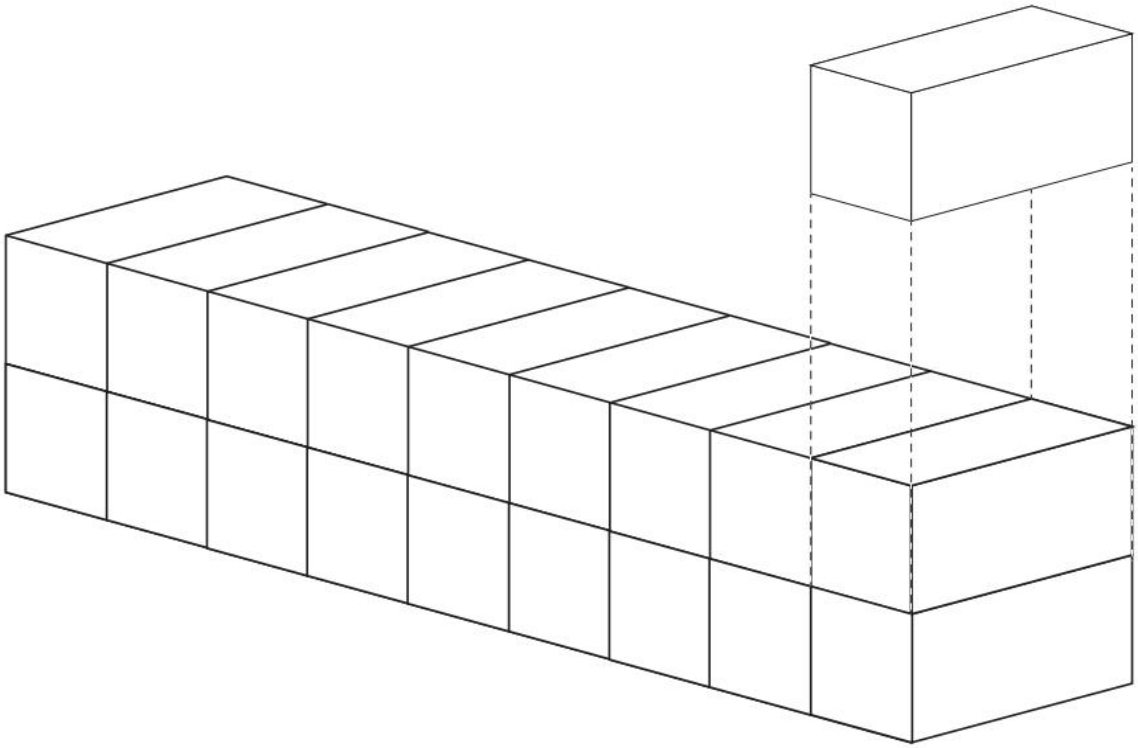
To quote Trevor Boddy, the author of a 2015 Canadian Architect profile of Michael Green, RMHBC uses wood construction as a "means" rather than an "end"[7]. The structural CLT is only exposed in two places in the entire project. While wood is used in furniture and sparingly as an interior finish material, the building does not feel like one with an innovative wood construction system. This is especially true when compared to many of MGA's other projects that celebrate the beauty of exposed wood structure (see North Vancouver City Hall, p. 75). The decision not to expose the CLT was made more for regulatory and budget reasons than aesthetic—exposing structural wood necessitates incorporating a "char layer" of wood to ensure structural performance in case of fire. This char layer would be provided by specifying thicker CLT panels for the walls, which would eat into the usable floor area of the buildings[8]. Structural wood as a finish is also less resilient than gypsum wallboard, which can be more easily patched and repaired over time.

Communal dining and living spaces that link the four house structures have a different roof structure: CLT roof panels topped with concrete[9]. The CLT is able to be exposed on the underside, enabling the structural wood to contribute warmth to the interior. This exposure strategy is similar to other "panelized" projects in this report (H4 p. 85 and H8 p. 89).

Brick was chosen as the exterior material because RMH wanted a system needing as little maintenance as possible[10]. The dimensional stability of the CLT wall panels makes them a suitable backup for the brick, providing for minimal differential movement between structure and façade[11].

Alpenhotel Ammerwald
Reutte, Austria
Hospitality

ROOM-MODULAR



- Vertical and horizontal loads are carried by solid wood prefabricated units stacked one on top of the other.
- Modules are often installed with furnishings included, all done beforehand at the factory.
- Best-suited to programs involving repeated cellular units, such as hotels, student dorms, or temporary housing.
- A module is a recurring basic unit. Prefabricated ceiling or wall elements are often referred to as "modules" in timber construction. This category is therefore called "room-modular" as opposed to simply "modular"[1].

ALPENHOTEL AMMERWALD

Reutte, Austria | Oskar Leo Kaufmann

2011

88,000 sf

Hospitality

The German company Bavarian Motor Works ("Bayerische Motoren Werke" in German), more commonly known as BMW, is headquartered in Munich, Bavaria, Germany. BMW wanted to build a recreational resort and seminar center for its employees with the hope that the design would be new, modular, modern, and made of wood[1]. In 2008 BMW held an invited competition for the design of the project, and the winning selection was by Austrian architects Oskar Leo Kaufmann and Albert Rüf.

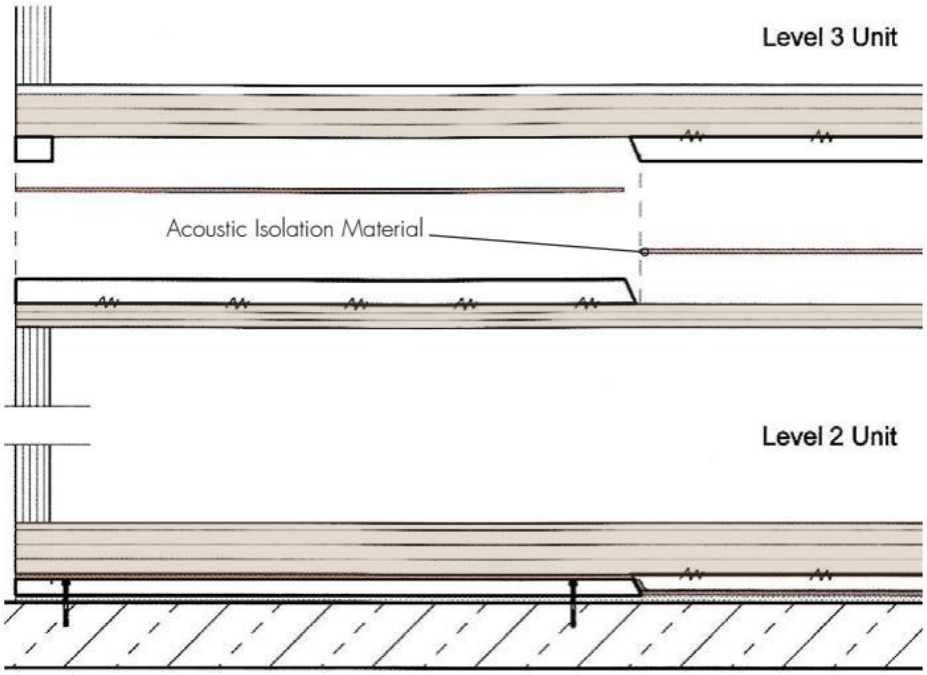
Prior to being awarded the Alpenhotel project, Kaufmann and Rüf had developed a concept for prefabricated, modular, wood housing units called System3[2]. Previous versions of the system, System1 and System2, were designed in 1997 and 2002 respectively[3]. System3 was finished in 2008, the same year as the BMW competition, and it won a separate competition held by New York City's Museum of Modern Art (MoMA) called Home Delivery: Fabricating the Modern Dwelling[4]. System3 was a key inspiration for the design of the BMW Alpenhotel project.

The hotel building is two levels of concrete supporting three levels of modular wood construction. In theory, the units can be stacked as high as seven or eight stories, according to the architects, and the hotel was originally envisioned as five stories of wood construction[5]. In the end, the design team felt that regulators would not approve a wood structure at such a height, since at the time it was unusual in Austria for a wood building to be taller than three stories. The proposed design of three stories of wood construction was approved with the incorporation of a fire-safety study, gypsum wallboard where required, and short escape routes[6].

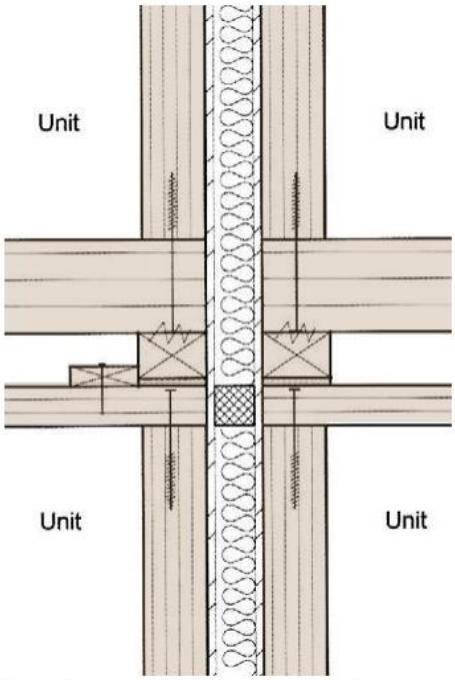
Installation of CLT box units. Source: Oskar Leo Kaufmann, Albert Rüf via Detail Magazine 06/2012[12]

Interior of hotel room unit.

Ground floor, concrete construction, showing use of wood finish and furniture.



Vertical section: floor connection detail at concrete slab and between units above. Source: Merz Kley Partner via Solid Wood by Joseph Mayo, color added



Vertical section detail: between units. Source: Merz Kley Partner via Solid Wood by Joseph Mayo, color added

The structure of the modular units is entirely CLT panels—floors, walls, and ceilings. The connections between the units are metal screw joints. The boxes are stabilized in relation to one another by interlocking wood blocks on the top and bottom of each unit that act in shear, and the stacks of boxes are stabilized by concrete staircases[7]. In order to separate the structures acoustically, an "acoustic isolation material" is inserted in contact points between boxes. This material is a resilient, petroleum-based product, and was specified to prevent the transmission of structural noise. There was no acoustic strategy to prevent impact sounds the boxes do not perform well acoustically in this area (in this author's experience). Some members of the design team recognize this problem and note that this project was the first attempt at the room-modular construction type for many of the participants on the project. In subsequent projects, acoustics are much improved. The design team has received no complaints from the client with regard to acoustics or any other issue[8].

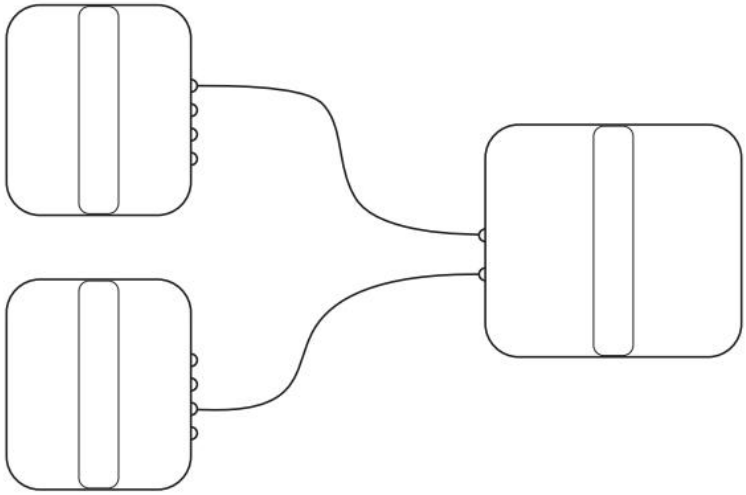
Many of the benefits of room-modular construction come from the high level of prefabrication inherent in this construction strategy. In the Alpenhotel, different trades (carpentry, plumbing, electrical) worked side-by-side in the factory[9]. Units were outfitted with all finishes and furniture. All of this off-site preparation can provide for a very speedy construction process. For example, the two levels of concrete construction took two months to form. By contrast, the three levels of CLT modules were installed on site, using a crane, in just 10 days[10]. The project was also completed within about 1% of the budget[11].

The engineer of the project is the Dornbirn-based firm Merz Kley Partner (MKP). Alpenhotel Ammerwald was their first prefabricated box project. Since its completion they have done over 2,000 boxes, and they say the market is growing.

Arch_Tec_Lab
Zurich, Switzerland
Higher Eduction

Kaeng Krachan Elephant Park
Zurich, Switzerland
Zoo Animal Enclosure

COMPUTER-ASSISTED DESIGN



- The structural system is developed using digital and parametric design and fabrication tools.
- The high machinability, precise prefabrication abilities, and favorable strength-to-weight ratio of wood make it a suitable material for these special structures.
- These projects tend to involve extensive research and development periods.
- Many of these structures are one-of-a-kind and expensive, and are demonstrations of feats in design, structure, and construction rather than replicable projects.

ARCH_TEC_LAB

Zurich, Switzerland | Gramazio Kohler Research

2015

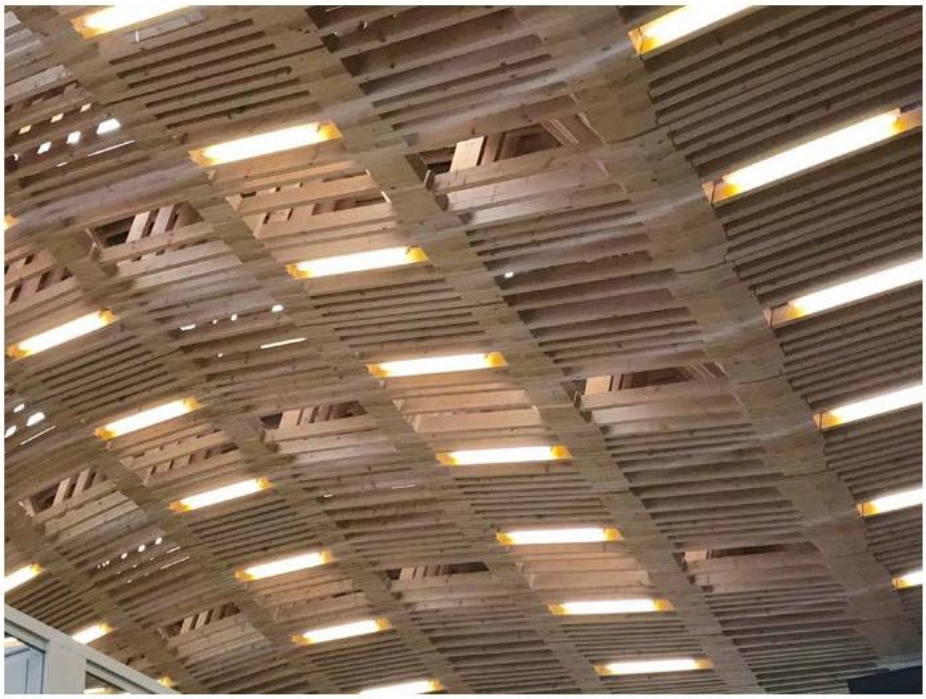
50,000 sf

Higher Education

If Vorarlberg, Austria is known for a long tradition of wood craftsmanship that has translated into contemporary innovation in wood architecture, ETH Zurich in Switzerland is pushing the boundaries of craftsmanship in architecture with digital technology and robotics. ETH Zurich is called, in English, the "Swiss Federal Institute of Technology in Zurich," and its campus just outside the city of Zurich is home to a well-regarded architecture school. On the campus is a new building that houses "a real-world laboratory for integrated building planning, zero-emission technology, and robotic building construction"[1].

Called "Arch_Tec_Lab," the building is the product of a six-year collaborative effort involving architects, civil engineers, building service engineers, and construction physicists from six Chairs at ETH Zurich's Institute of Technology in Architecture[2]. Another collaborator was ERNE AG Holzbau, the wood-focused subset of the Swiss construction and property management company ERNE Group. The entire process was led by Swiss architects and ETH Zurich professors Fabio Gramazio and Matthias Kohler. The building houses the largest, most advanced architecture and construction digital fabrication space in the world[3].

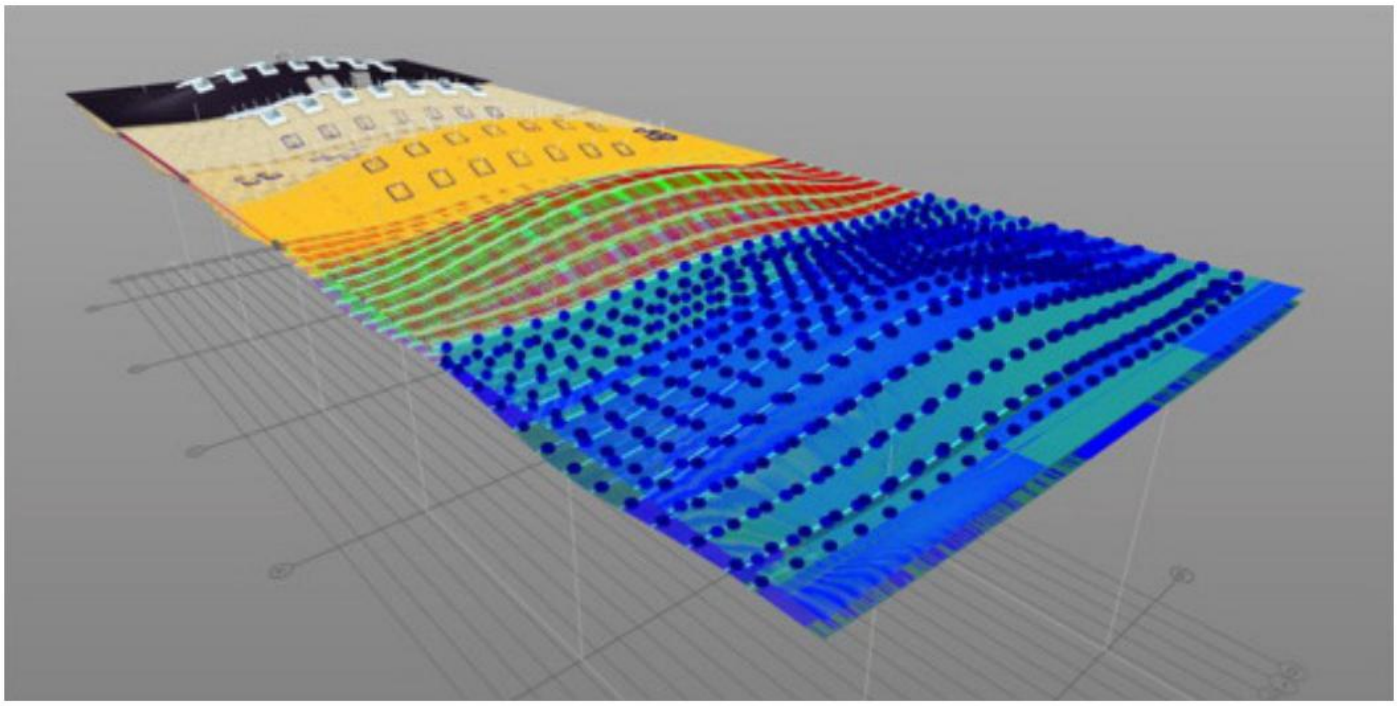
Gramazio and Kohler head the Chair of Architecture and Digital Fabrication, which is also titled "Gramazio Kohler Research." The duo also have their own architecture practice, called Gramazio Kohler, and as a firm they say that their designs "combine the physis of built architecture with digital logics"[4]. As such, researchers at the Arch_Tec_Lab are focused on construction and building methods of the future, and the project itself is a thought-provoking case study in this area.



Close-up image of robotic trusses.

Robotic fabrication of one "robotic truss." Source: ETH Zurich

Site installation of one "robotic truss." Source: ETH Zurich



Computational model of the Sequential Roof. Source: Arch_Tec_Lab AG via Schwinn and Krieg[14]

The building is constructed on top of an underground parking lot, making the weight of the new structure an important consideration[5]. The structure is steel, with one very notable exception: the roof is made from about 48,000 individual wood members[6]. The members, each up to 10' long, are arranged into 168 trusses[7]. According to the designers, steel and wood were chosen for their ideal strength-to-weight ratios. While its strength-to-weight ratio is a commonly lauded benefit of wood, the wood trusses in the Arch_Tec_Lab are anything but common.

Dubbed "robotic trusses," each has been assembled not by human hands, but rather by a large, custom, industrial robot[8]. Each spans about 50 feet[9]. The trusses were joined to one another during installation, and they integrate all building services including sprinklers and lighting[10]. Roof loads are distributed via the trusses to 12 steel columns[11]. The completed undulating roof structure covers an area of almost 25,000 square feet, and it has been dubbed "The Sequential Roof"[12]. The steel framework of the building is designed around the idea of flexibility and changing needs over time, and the large area of the roof structure contributes to the goal of interior adaptability[13].

While the Sequential Roof is one-of-a-kind, certain tenets of contemporary mass timber construction are still at play. Prefabrication and precise milling with CNC technology make the execution of the design possible. Close collaboration between the many contributors to the design and construction was also essential. Appropriate solutions for regulatory considerations, especially fire safety, must be integrated. The Sequential Roof takes these tenets to a new extreme with digital design and robotic fabrication.

KAENG KRACHAN ELEPHANT PARK

Zurich, Switzerland | Markus Schietsch Architekten

2014

90,800 sf

Zoo Animal Enclosure

Since the 1990s, European zoos have been upgrading their elephant enclosures to meet demand for more space, higher standards of enclosure quality, and visitors' desires to have a more interactive experience with the animals[1]. The Zurich Zoo decided it wanted to build the best new Elephant enclosure, and held a design competition in 2008 to meet this goal[2]. In 2014 the new enclosure opened to the public, offering six times as much space as the previous enclosure and able to accommodate as many as 10 elephants at a time[3]. It is named for a national park in Thailand where the Zoo supports an elephant-protection project[4].

The design concept behind the indoor enclosure was to mimic the natural Thai habitat of the elephants. With this in mind, the architects devised a dome-like shell structure with apertures providing light and casting shadows reminiscent of a tree canopy[5]. The architects did not want the perimeter facade of the grid shell to be oversized and inelegant due to the need to resolve heavy loads all the way around, so they undulated the edge to concentrate the heaviest loads in five places. The differing edge heights are based on what functions lie underneath, with height variations defined by three parameters: the impact and attack heights of the elephants, sight-lines for the visitors, and required door clearances[6].

On-site cutting of apertures. Source: Markus Schietsch Architekten

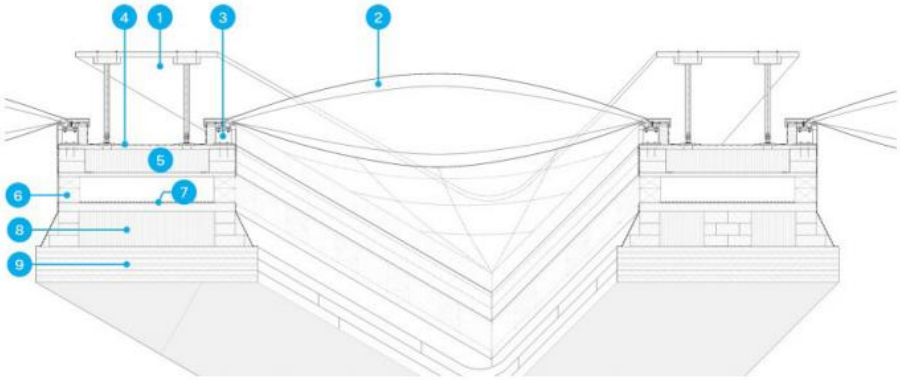
Timber blocking atop CLT shell.
Source: www.WoodSolutions.com.au

CLT shell after bending. Source: Markus Schietsch Architekten

LVL cladding panels. Source: Markus Schietsch Architekten

Close-up image of apertures, showing CLT with apertures

LVL cladding on exterior, showing patina



1. 33mm Kerto Q LVL protective panel
2. ETFE cushion, three-ply with hail-proof layer
3. Integrated aluminum gutter
4. Sarnafil TG 76-18 Felt roof membrane
5. 160mm mineral fiber insulation
6. Wood blocking
7. Roof underlayment
8. Box girder wood and insulation
9. Cross-laminated spruce panels, three layers

Section perspective of the roof system. Source: www.ArchitectMagazine.com

The structure of the shell is three layers of three-ply CLT panels. Typically CLT is cross-laminated at 90 degrees, but these panels were done at 60 degrees to better distribute shell forces in relation to the wood grain[7]. The panels were assembled flat on site, bent up into shape, and then attached together[8]. About 500,000 nails and custom screws ranging in length from 8.25 inches to 33.5 inches were used to connect the assembly[9]. The top layer of CLT panels are pre-cut with the apertures, and this layer was used as a template to guide the on-site cutting of the bottom two layers after the shell was erected[10]. In total there are 550 uniquely-shaped panels, and the completed shell spans 260 feet and covers 73,000 square feet[11].

A shell structure needs a perimeter edge beam to help it keep its form. Here the edge is bound by a concrete ring beam with pre-stressed steel cables, supported at five perimeter points[12]. Once the edge form is defined, the apertures in the shell structure can be positioned based on the structural forces. Support points around the perimeter rest on a concrete slab foundation supported by steel-reinforced pre-stressed concrete piers[13]. The roof cladding is 1.3-inch LVL panels, left unfinished to allow the wood to patina[14].

While the LVL cladding was chosen for aesthetic reasons, the CLT structure was not—rather it was chosen because the soil conditions of the site were not optimal and thus required a lightweight structure[15]. While timber's aesthetic qualities are not the primary reason behind its choice, they certainly contribute to the tree-canopy effect of the roof. It is difficult to imagine a similar structure in steel or concrete being as effective at this expression.

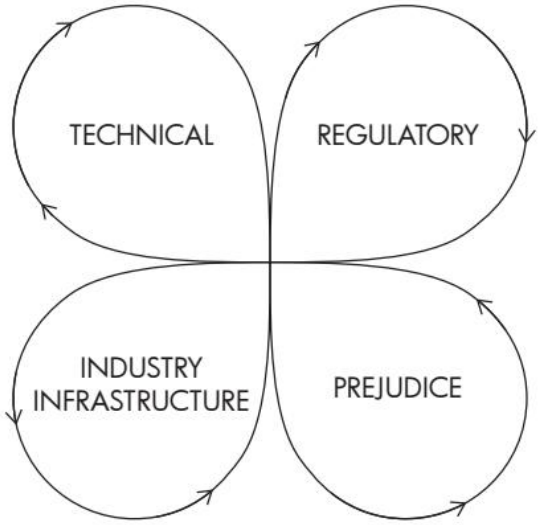
Part 3:

INSIGHTS

During this investigation of mass timber products and methods, certain lessons came up repeatedly. This section outlines those lessons, categorizing them into four insights. **INSIGHT #1** explores the main challenges industry professionals encounter when building with mass timber, and the main approaches used to solve these challenges. **INSIGHT #2** provides a window into the variety of assembly options possible with mass timber construction. **INSIGHT #3** outlines differences observed in this investigation between the mass timber industry in Alpine Europe and that in the Pacific Northwest of North America. **INSIGHT #4** shares results from the electronic survey distributed at case study sights. All together, this section serves as a bookend to Part 1: **RESEARCH CONTEXT**, where lessons gleaned from the travel research complement lessons learned from the pre-trip literature review.

INSIGHT #1:

The Main Challenges + Approaches



The challenges and solution approaches of mass timber construction fall under the categories of **Technical** challenges, **Regulatory** challenges, challenges with **Industry Infrastructure** and worker experience, and challenges with **Prejudice** against mass timber construction. These categories and the specific ways in which different challenges manifest themselves are deeply interrelated.

Technical Challenges

» Fire
» Moisture
» Acoustics
» Seismic

Fire

Fire gets the most attention in the media when it comes to mass timber, but according to most interviewees, it is the most straightforward of the technical challenges in practice. Designers have two options when it comes to meeting fire code with mass timber construction: encapsulation, in line with steel construction, and exposure with a char layer, in line with heavy timber construction.

While small sticks of wood can catch fire easily and burn up quickly, large cross sections of wood are not as combustible as smaller sticks. Many have likened this to starting a small fire in a fireplace: attempting to start a fire using only large logs is very difficult, which is why when we make fires, we typically use paper and smaller sticks to ignite the large logs. Wood members with large cross sections also have a benefit when it comes to fire performance: once burning, the outside of the member chars and protects the inside, which enables structural members to retain their strength and performance[1]. Moreover, in fire testing it has been determined that large wood members char at a predictable rate[2]. If designers choose to expose structural mass timber elements, the code solution is to increase the cross section of the exposed members according to the length of time of fire rating desired. Sprinkler systems are also often specified in projects with exposed mass timber elements, though not always. The case studies H4 (p. 85) and H8 (p. 89) are examples of projects with some exposed timber that avoided having to incorporate a sprinkler system.

It is common to employ the "char method" in the "post-and-beam" construction strategy. For **CASE STUDIES** that primarily employed the "char method," see the post-and-beam section (p. 19), North Vancouver City Hall (p. 75), hotel room interiors of Alpenhotel Ammerwald (p. 107), floor slab underside exposure in H8 (p. 89) and Ronald McDonald House BC (p. 101), and interior glulam columns of Ölzbündt Housing Development on (p. 71).

If exposing the mass timber structural elements is not a priority, the design solution is similar to that of steel construction. Steel performs poorly in fire since it melts and begins to lose strength at relatively low temperatures[3]. Steel must therefore be encapsulated by gypsum wallboard or a similar material, or covered with a high-tech paint called intumescent paint that protects it in fire[4]. If designers choose to encapsulate structural mass timber elements, it is common to do so using gypsum wallboard.

It is common to employ the "encapsulation method" in the "panelized" construction strategy. For Case Studies that primarily employed the "char method," see Brock Commons (p. 79), H4 (p. 85), H8 (p. 89), and hallways connecting hotel rooms in Alpenhotel Ammerwald (p. 107). For an encapsulation strategy that still celebrates mass timber construction through the type of encapsulating interior finishes, see Vorarlberg Mittelschule (p. 93).

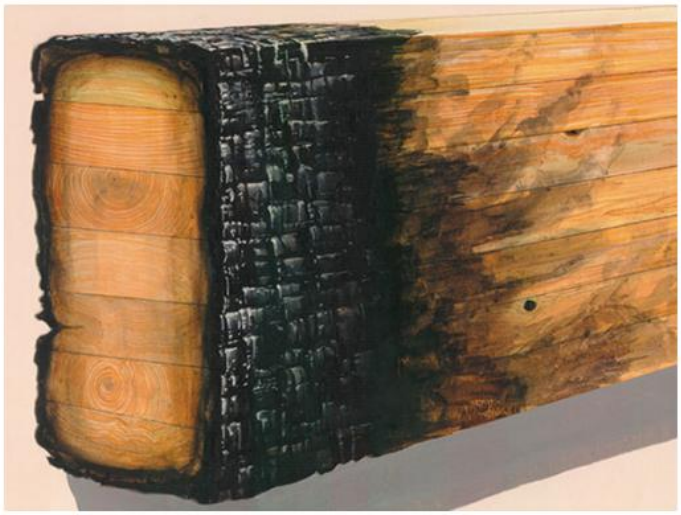


Illustration of charred glulam beam. Source: www.StructureMag.com[5]

This CLT specimen survived almost 100 minutes of exposure in a standardized test reaching nearly 1000°C. The unexposed side of the specimen remained at less than 50°C for the entire test. Source: USDA Forest Products Laboratory[6]

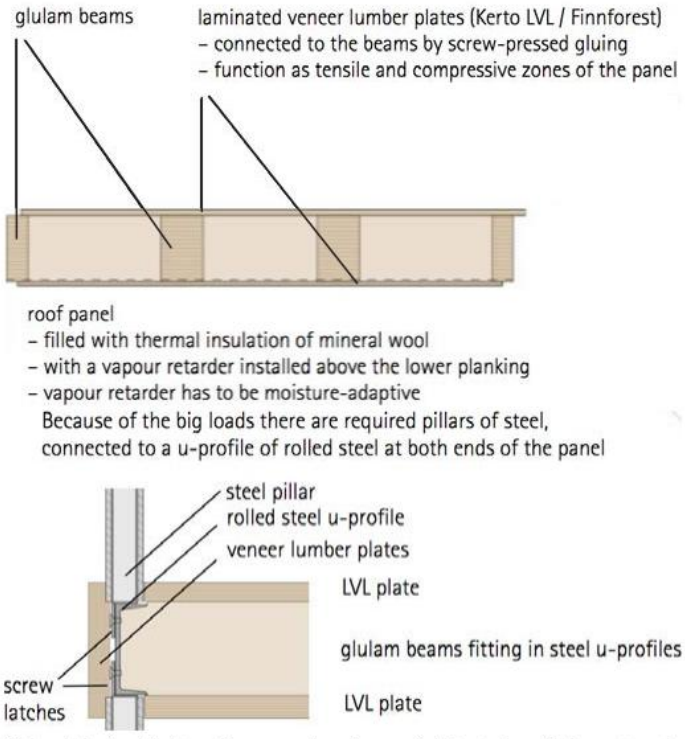
Construction Assembly showing encapsulation method, similar to steel construction. Source: Acton Ostry Architects

Moisture

Many interviewees during this research effort expressed that while fire safety gets the most attention, moisture protection is actually a bigger challenge with mass timber construction. Wood rots when exposed to too much moisture for too long a period of time and it is unable to dry out adequately. The good thing about wood is that coloration changes and other signs alert users and maintenance professionals to a potential problem, so it is possible to address the issue early. If the wood is encapsulated, however, moisture problems cannot be detected visually.

Some interviewees expressed concern with the encapsulation strategy of the Brock Commons student dormitory project in Vancouver (p. 79), given that if there is moisture infiltration into the structure it would be difficult to detect and repair. A construction professional on the Brock Commons project said that while Vancouver had a wet summer during the construction period, the moistened mass timber elements were able to dry out at a consistent rate, both before and after encapsulation with gypsum wallboard. Brock Commons is on the UBC campus, where there is a strong interest in mass timber construction, and according to interviewees there the building's construction and operation are both part of ongoing research efforts by academics on campus and elsewhere. As a part of this research, sensors have been incorporated into the assemblies throughout Brock Commons, enabling moisture and other changes to be monitored. This data will contribute to a greater understanding of mass timber construction and detailing going forward.

In some cases, moisture infiltration has caused problems for mass timber buildings once complete. One example of this occurred in a Schankula Architekten project, though not a case study project in this document. Schankula has employed



Schankula Architekten diagrams showing prefabricated roof element and assembly detail. Reprinted with permission.

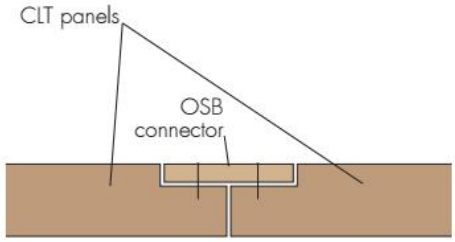
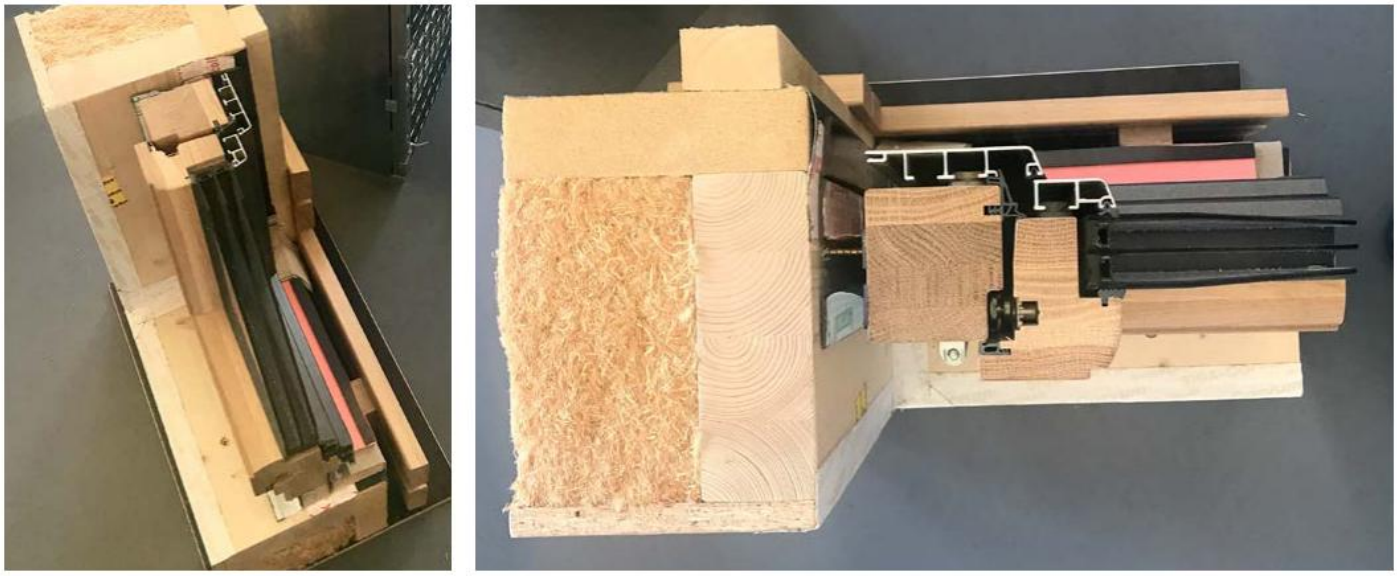


Diagram showing the OSB connector between CLT panels that failed after too much moisture exposure.



Images above show a best-practices moisture barrier mock-up of a window opening in a mass timber exterior wall

prefabricated hollow box elements using mass timber products. In one school project, contractor error led to an incorrectly built detail, which led to a leak into a roof module. The leak went unnoticed for two years, and once it was discovered it was necessary to dry out the panel with microwave technology, a complicated and difficult process. This anecdote ties in with an insight from a TUM researcher in the building technology group. Architectural details that prevent moisture exposure function well if executed perfectly, but the most decisive problem is human error during production. Prefabrication helps to mitigate this vulnerability as long as there is quality control throughout the process. It is especially important to make sure moisture does not infiltrate an assembly and have contact with insulation material. According to interviewees, the prefabrication process enables small, easy measures that prevent such infiltration.

With larger mass timber buildings, there are longer times when the construction is open and the wood structure is unprotected. In these larger buildings it is important to be aware of moisture. A 2017 project in Germany used CLT for the floor plates, with panels connected together using OSB (see diagram at left). After some days of heavy rain, there was standing water on the floor, softening the OSB and effectively disabling the connection between the CLT panels. The OSB connectors had to be replaced. By protecting the construction from above with a thin polyethylene foil, this problem can be avoided.

The building technology group at TUM has recently finalized a report on the moisture safety of tall timber buildings[1]. Part of this research involved creating three mock-ups of critical joint details, for example window openings. These details are important because they interrupt the normal defense layers and barriers for water safety. Researchers either developed special solutions or identified best practices for detailing these joints from existing projects. They then created models where the parts connect together with magnets in order to demonstrate how they are assembled (see images above). This study shows that there are viable solutions to the technical challenge of moisture protection of mass timber construction. As with any construction type, the details must be executed by qualified workers to prevent problems down the line. For more information on the importance of quality and experience see the Industry Infrastructure challenge (p. 135).

Acoustics

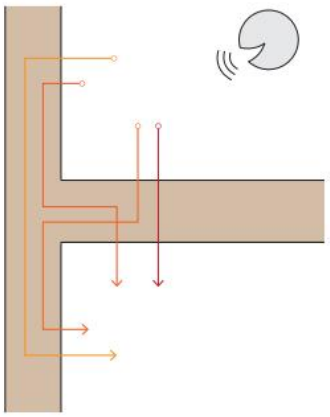
Interviewees, especially those in Europe, consistently expressed that all technical challenges have viable solutions ready for implementation. That said, the technical challenge that most interviewees mentioned as most difficult is acoustics. Acoustic vibrations are either airborne or impact-based and they can transfer sounds and noise between rooms via wall and floor assemblies (see diagrams below).

Mass timber products are notable for their light weight, relative to concrete and steel. This lightness is a benefit in many situations; for example, it enables smaller foundations. However, lightness is also at the heart of the challenge with acoustics in mass timber construction. Because wood is so light, even small airborne sounds and light impacts can cause vibrations in mass timber products.

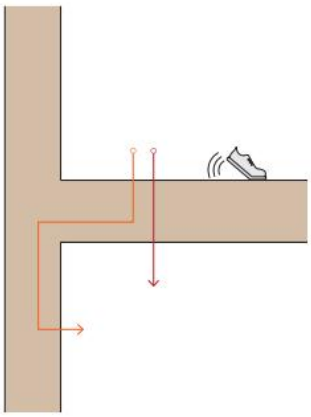
There are three primary strategies when it comes to improving acoustic performance of mass timber buildings, and each is reflective of differing priorities. The first strategy is encapsulation, similar to the encapsulation approach with fire. If exposing the mass timber structure is not a priority, acoustic protection becomes easier, as finish materials can be applied to all surfaces to dampen acoustic vibrations. See the case study of Brock Commons (p. 79) as an example of this strategy.

If exposing the mass timber is a priority, there are two options: adding mass, or using a resilient material at all structural connections. Adding mass is typically accomplished by topping a mass timber floor slab with two to three inches of concrete or gypcrete. This layer can serve multiple purposes as it is frequently used to incorporate radiant heating and/or cooling, and it also improves the fire rating of a floor assembly. See the following **CASE STUDIES** for examples of this strategy: Albina Yard (p. 53), Carbon12 (p. 57), Framework (p. 61), and the Bullitt Center (p. 65). With hollow, prefabricated floor and roof "box element" modules, mass can be added by adding a layer of sand or gravel inside the boxes. See the following **CASE STUDIES** for examples of this strategy: Tamedia Headquarters (p. 33) and Ölzbündt Housing Development (p. 71).

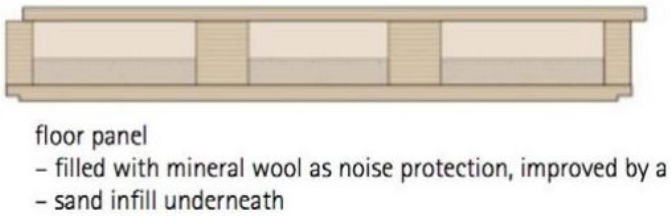
Designers and owners who prioritize the use of wood in their projects, as opposed to concrete or steel, sometimes seek to avoid using concrete as much as possible. For these projects another option to add mass is to incorporate a resilient material between mass timber building elements that dampens acoustic vibrations. This material is often called an "acoustic underlayment" or "acoustic isolation material" in detail drawings, and tends to be a petroleum-based foam-like product. These products isolate sound vibrations at the source. If employing this strategy, it



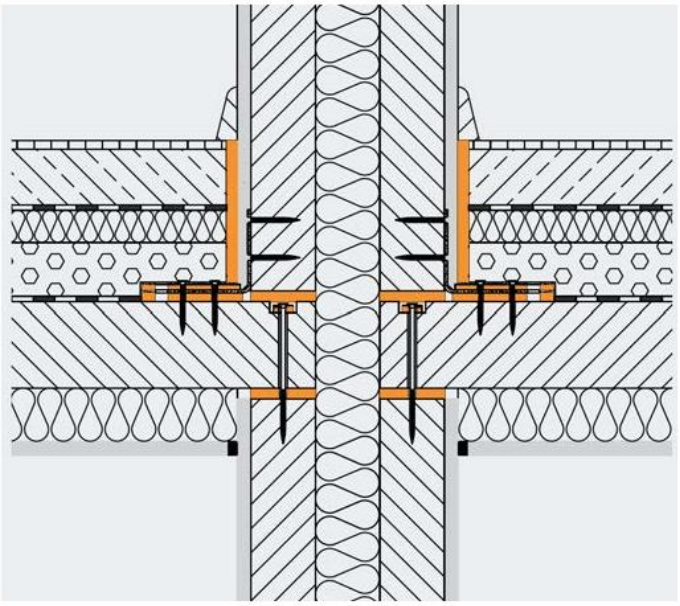
Airborne sound transmission between wall and floor assemblies.



Impact sound transmission between wall and floor assemblies.



Schankula Architekten diagram showing sand- and insulation-filled prefabricated box element. Reprinted with permission.



Sample floor assembly showing acoustic isolation material application in orange. Source: Getzner[1]

Floor-wall panel connection in a Tirol, Austria apartment building showing acoustic isolation material integrated. Source: Getzner[2]

is important to make sure the products are used at as many locations as possible where acoustic vibrations can be transferred. This includes, for example, at the hardware that connects CLT panels to one another (see image above). Often the hardware elements that integrate resilient material are proprietary products, and this expense must be taken into account in product budgets. See Alpenhotel Ammerwald (p. 107) for an example of this strategy. That project was the first mass timber room-modular project for all involved, and the acoustic isolation material was not used at all connections.

Code requirements for acoustics vary by country and region. For example, according to an American architect interviewed, the code guidelines for the U.S. are based on stick frame construction and are therefore less strict than those of Europe that are based on masonry construction. Architects interviewed in Canada also discussed how cultural and population shifts have made acoustics more challenging with mass timber construction. For example, there is an increased preference for hardwood floors rather than carpet. Carpet is much more dampening acoustically than hardwood floors, so the increasing use of hardwood floors demands increased performance from the rest of the assembly in terms of acoustics. These architects also discussed how increased density in urban areas also puts pressure on assemblies to have a better acoustic performance. For more information on differences between countries and regions when it comes to mass timber, see **INSIGHT #3** (p. 145).

Seismic

Sites visited in Alpine Europe are not in a seismic zone, but the Pacific Northwest very much is. While "Seismic" is listed in this document as a technical challenge, ensuring that mass timber structures are seismically safe is actually not a very big challenge, especially not after recent testing. The real challenge here is prejudice, which is explored on p. 134.

The primary reason why mass timber structures have the potential to perform well in a seismic event has to do with their light weight. Forces in an earthquake are proportional to the structure's own weight, meaning that a wood structure has an easier job than heavier concrete and steel structures at resolving seismic forces. While mass timber products can perform well in seismic events, it is important to ensure that mass timber assemblies, including connections between elements, can also do so. In this area steel has proven valuable—steel connectors contribute the ductility of this material to the seismic performance of the entire assembly.

The Framework project in Portland (p. 61) has pursued seismic testing of its assemblies, thanks to funding from the USDA TallWood Building Prize grant it won in 2015. The Framework team tested their custom-developed column-to-beam connection, and after successful tests it became the first two-hour fire rated seismically-performing joint of its type[1]. Seismic testing ensured that Framework could undergo the maximum anticipated seismic drift and remain undamaged. The CLT lateral system is post-tensioned and is equipped with steel connectors that can be replaced in the event of an intense earthquake.

One of the companies visited on this research trip is

Image of a Framework poster displayed at Albina Yard, explaining its seismically resilient design.

Screen grab from a Framework Portland YouTube video[2] showing column-to-beam joint during seismic testing.

Screen grab from a Katerra YouTube video[5] showing closer view of the steel CLT panel connection, flexing from the movement of the panels.

Screen grab from a Katerra YouTube video[6] showing two-story CLT assembly during seismic testing.

Katerra, a technology company looking to transform the way buildings are developed, designed, and constructed. Katerra is helping fund the seismic testing of CLT assemblies. A shake table test of a two-story CLT assembly with CLT panel connections designed by Katerra took place on July 27, 2017 at UC San Diego. The test demonstrated that the CLT assembly performed as well in all degrees of intensity as steel and concrete, with no damage under moderate intensity and damage only to connections in extreme intensity[3].

These seismic tests are important for the ability of mass timber construction to compete with concrete and steel in the North American market. This is not only because they are ensuring that mass timber assemblies can perform adequately in a seismic event, but also because they may show that mass timber has a competitive advantage over concrete and steel construction in this area. Current codes are written to ensure life safety in the case of the earthquake, but many if not most code-complying structures will likely suffer so much damage that they will need to be demolished and rebuilt after the fact[4]. Katerra's CLT wall assembly allows the damaged connection devices to be easily replaced, which cannot be done with steel and concrete structures.

Regulatory

As discussed in the previous section on technical challenges, many interviewees expressed that all technical challenges, even the more difficult ones, have viable solutions. The biggest barrier for many regions in the advancement of mass timber construction is regulatory in nature. Regulatory challenges are closely tied to the challenge of Prejudice, discussed on the facing page. Officials with regulatory power may have prejudice against the mass timber construction type, which is new and unfamiliar.

In many countries, building codes were developed based on a legacy of building with concrete and steel. The International Building Code (IBC) breaks down buildings into five main Types. Type I is high rise and there is no code provision to enable these structures to be built of anything other than concrete and encapsulated steel[1]. Types I and II require that structural materials be non-combustible, thereby excluding wood[2]. Construction Types III, IV (Heavy Timber), and V may be framed exclusively with wood framing[3]. Types III-V are limited to five stories or 65 feet tall, with the option to increase the height to 85 feet with the addition of an automatic sprinkler system[4]. Designers wanting to use mass timber construction, which is not currently classified in the IBC, must be savvy. Using mass timber often requires that designers take advantage of particular provisions for specific occupancies, construction types, and building configurations that increase the allowable building size and/or height.

Designers can also pursue permitting through the IBC's "Alternative Materials, Designs, and Methods of Construction"[5]. This process is both costly and time-intensive, as it requires engaging with building officials to demonstrate the planned construction assembly's performance.

There are two examples from this research of regulatory environments that are more friendly to mass timber construction. The State of Oregon's Building Codes Division (OBCD) actively supports the development of advanced wood products like mass timber, and has a vested interest in seeing projects built. This is because the state sees opportunities to revitalize rural economies through the creation of jobs in mass timber product manufacturing[6]. The OBCD introduced a "Performance-Based Path" to permit approval[7]. It is through this provision that Framework (p. 61) was approved.

Switzerland is the country whose building code is most friendly to mass timber construction. One of the interviewees on this research trip was Dr. Andrea Frangi at ETH Zurich, who helped develop a new technical guideline for Europe within a research project called Fire Resistance of Innovative Timber Structures (FireInTimber)[8]. As a result of this effort, Switzerland's building code now has no prescriptive limit on the use of wood in any building type. Rather, the code is performance-based. This was made possible by a close collaboration over many years between regulatory officials, engineers, and researchers. Over time, regulatory officials have come to trust the performance of wood assemblies based on completed testing. The Swiss organization for the forestry and timber industries, Lignum, provides wood construction best-practice resources that meet code. According to Dr. Frangi, these resources for architects and engineers have made Zurich a "small mecca" of timber buildings.

Prejudice

As discussed on the facing page, the regulatory challenges that mass timber faces are closely related to the challenge of prejudice. U.S. cities that have suffered devastating fires, such as Chicago (1871), San Francisco (1906), and New York (1835) and 1845) have particularly strict codes when it comes to the use of wood in larger buildings. Fire is the driving force of much prejudice when it comes to skepticism of building with wood. Ironically, as discussed in the "Technical" challenge section of this Insight, fire is the easiest technical problem to solve with mass timber construction.

The 2015 TallWood Building Prize, a competition hosted by the U.S. Department of Agriculture, is a useful example of the role that prejudice can play in making mass timber buildings more difficult to build. It was this prize that has enabled the Framework project in Portland, OR (p. 61) to move forward, with $1.5 million in prize money funding research and testing. When the Framework team won the Prize in 2015, they split the total of $3 million with the team behind a New York City luxury high-rise project known by its address, 475 W. 18th[1]. In early 2017, the NYC project was scrapped. While a reduction in the luxury condo housing market is partially to blame, fire officials in New York were also incredibly skeptical of the project[2]. The head of the Uniformed Fire Officials Association sent letters to the New York City Department of Buildings and the New York Fire Department expressing grave concerns, based on historic fires in the city. This opposition ultimately made the project impossible[3].

It is worth noting the differing economic and cultural contexts at play between Portland, OR and New York City. New York is much more associated with the steel industry than Portland is[4]. As discussed on the facing page, the State of Oregon has a vested interest in supporting and advancing the timber industry. If prejudice is a primary challenge facing mass timber building, vested economic interest is the antidote.

Industry Infrastructure

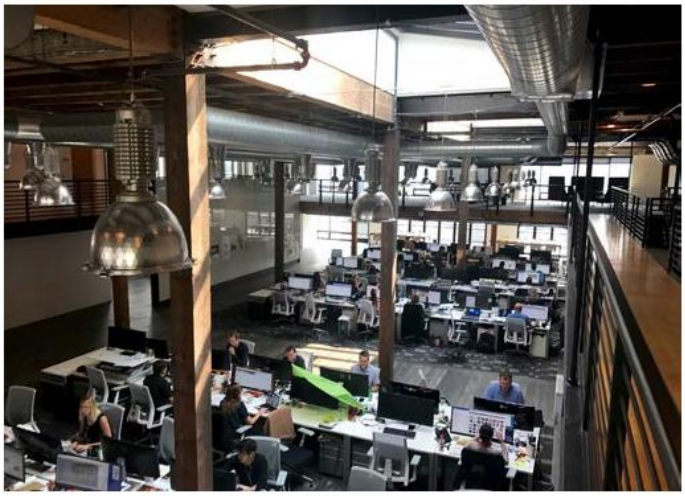
Mass timber construction faces an uphill battle when it comes to industry infrastructure. What is meant here by industry infrastructure is everything from the expertise of designers and engineers, to the factories producing mass timber products, to the experience of contractors and subcontractors putting the building together, to the market competition in all areas that drives costs down. With concrete and steel, there is a lot of inertia: everyone in the industry knows how to detail the building and to construct it. This foundation of knowledge is not yet present with mass timber construction.

An example of this challenge from the research trip comes from Framework (p. 61). One of the concepts behind Framework is "Forest to Frame," a play on the "farm to table" movement that increased demand for local food. The Framework team is hoping to use Oregon-produced CLT for the project. Another project is underway in Corvallis, OR at Oregon State University, by Michael Green Architecture (MGA), and is on approximately the same construction schedule. It was unclear whether or not the sole domestic CLT producer, DR Johnson, will be able to meet the demand of both projects. Issues of supply-and-demand also tie in here with cost—it would actually be cheaper for Framework to use CLT produced overseas in Austria and shipped across the world to Oregon. This is because CLT has been in commercial production there for so long, and the economy of scale is such that panel prices are significantly lower.

Another area where the lack of industry infrastructure presents a challenge is with contractor and subcontractor bids. These companies tend to be risk-averse, and if a company has never built a mass timber project before, they are likely to increase their bid price to offset their perceived risk. This can make projects prohibitively expensive.

Many interviewees in North America expressed how the industry is still very much in the "demonstration project" phase. There is not yet such a thing as a "run-of-the-mill" mass timber project in North America. Until more demonstration projects provide building industry professionals with more expertise, and create more of a market for mass timber products

Showroom on the second story of the Albina Yard project (p. 53), showing open-source details, assemblies, and testing videos from the Framework project (p. 61).



Katerra design office in Seattle, WA, USA.

and construction systems, it will be an uphill battle to get mass timber projects built. Getting over this hill is one of the goals of Framework in Portland. All of their assemblies and details are open-source, and they are actively disseminating information about the project and its success. In this way the project team can combat prejudice against mass timber construction while making expertise more accessible.

As for increasing the market, Katerra is the company in the United States with the most promise to bring mass timber construction into the mainstream. Katerra's interest in improving the efficiency of the construction industry has led to more interest in mass timber and its possibilities for prefabrication and speedy installation. The company is backed in part by Silicon Valley investors, and it is headquartered in Menlo Park, CA. Katerra also has factories in Phoenix, AZ, one planned in Spokane, WA, and an architectural office in Seattle, WA. Fritz Wolff of the large development company The Wolff Company is on Katerra's board, providing the firm with a multi-family housing market. Katerra's enthusiasm for CLT, their investment in research and development, and their access to the multi-family housing building market make for a potentially game-changing situation for mass timber construction in the United States.

Even though the mass timber industry is more developed in Alpine Europe than it is in North America, there are still efforts to make expertise more accessible there. One of these efforts is underway at the Technical University of Munich (TUM), where the Kaufmann Chair's "leanWOOD" research project's goal is to "develop new cooperation and process models for prefabricated timber construction"[1]. Professors at TUM also recently published a book called ATLAS: Mehrgeschossiger Holzbau (English translation ATLAS: Multistory Wood Construction), a fantastic resource that will be explored more in **INSIGHT #2**.

Conclusion

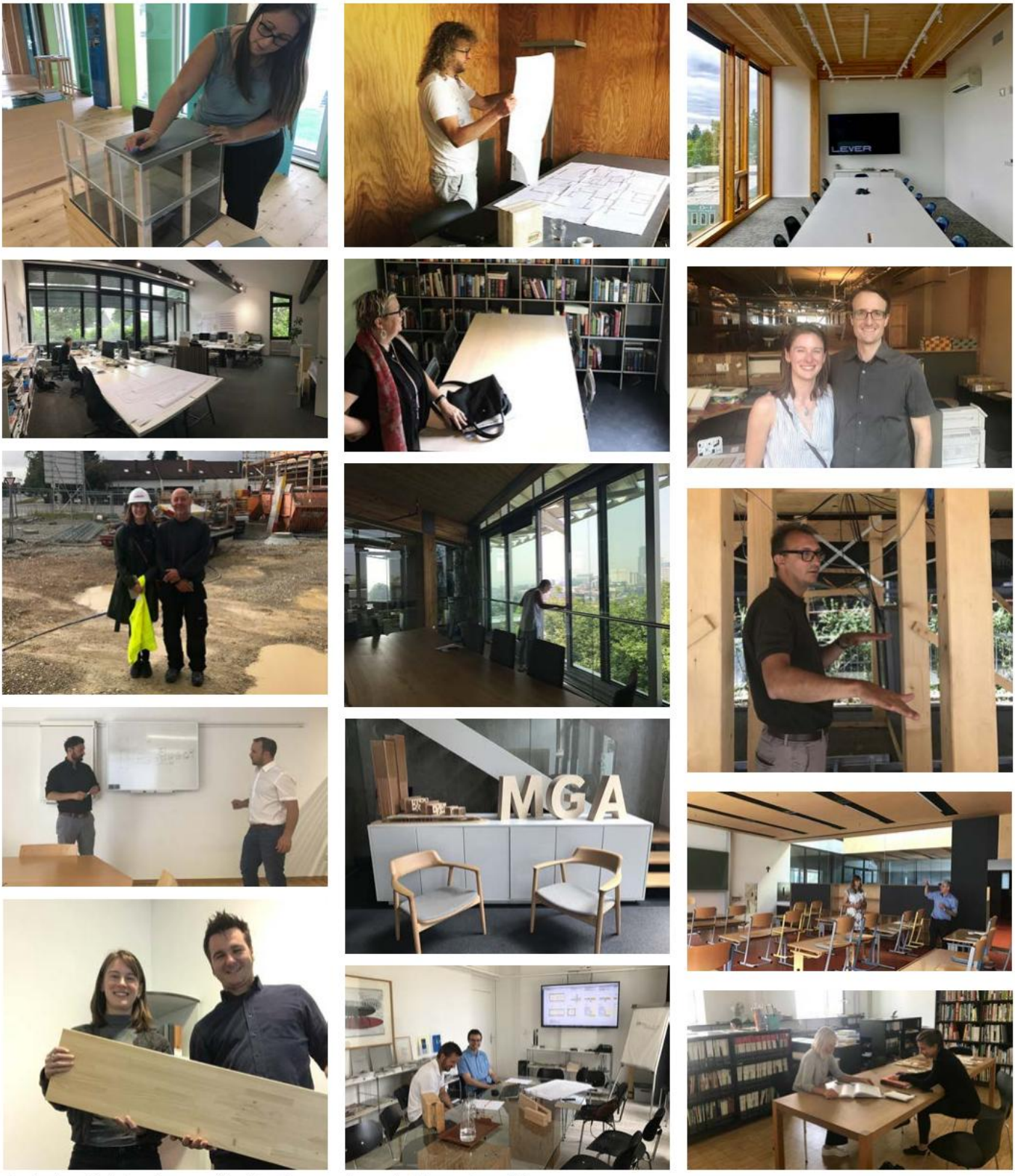
In sum, this report has explored the consistent themes regarding the best ways to approach the challenges associated with mass timber construction and products.

All interviewees emphasized the importance of leveraging prefabrication in mass timber construction. Designers and builders enjoy the benefits of the fast construction time while employing a small team of laborers. Since wood is light weight in comparison with steel and concrete, prefabricated elements can be installed on site with relative ease. Prefabrication is also the best way to improve the performance of mass timber assemblies since factory conditions enable a higher level of quality than on-site construction when executing details.

All interviewees also emphasized the importance of collaboration, especially early in the design process. Collaboration between all stakeholders, especially designers and builders, enables the project team to carry out prefabrication effectively, and to maximize the benefits and navigate the challenges of mass timber construction.

When it comes to the technical challenges, most interviewees insisted that the technical challenges all have viable solutions. However, there are differences in expertise between designers and builders and in different locations, and these differences can challenge the implementation of the solutions to the technical challenges. Additionally, the solutions change when the mass timber structure is exposed versus when it is encapsulated, and if exposure is desired the technical solutions can become more challenging.

Finally, many interviewees talked about the importance of making mass timber construction resources and information increasingly accessible. Steel and concrete construction have been around for a long time, and many industry workers are familiar with how these systems work. In order to move the mass timber construction industry forward in larger buildings, it is important to increase the accessibility of mass timber design and construction strategies and methods. This will enable the industry to grow and become more competitive.



A selection of photos of many of the interviewees who made this report possible.

Bestseller
Sachbuch
MUSIK

INSIGHT #2:

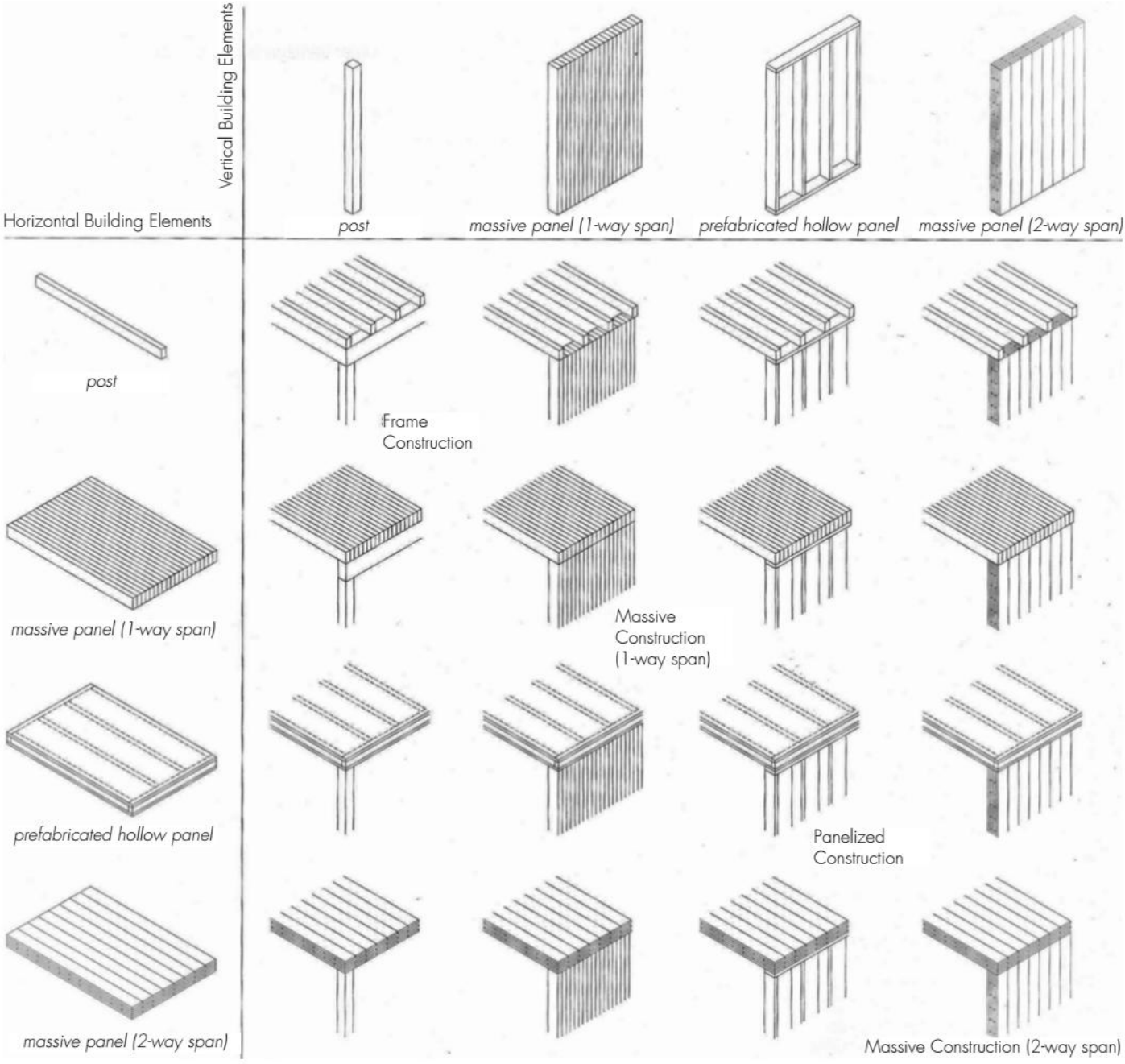
The Variety of Assembly Options

- Construction Strategies: Frame, Hollow Panel, Massive Panel, Room-Modular, Combinations
- Hybrid Solutions with Concrete and Steel
- Degrees of Timber Structure Exposure

Construction Strategies

Part 2 of this document categorizes the case study buildings by construction strategy: post + beam, post + plane, panelized, room-modular, and computer-aided design. The diagram below[1] shows the first three of these categories in more detail, and elucidates the variety of construction strategies possible with mass timber construction.

The top row and first column of the diagram show mass timber building elements. Starting from the left and top, it starts with the most simple stick-like element. Moving to the right and down, respectively,



multiple sticks can be arranged into hollow prefabricated "box elements," or fixed together to form two types of solid wood "massive" panel elements: one-way spanning (for example, NLT) and two-way spanning (for example, CLT). The rest of the columns and rows of the diagram are populated with all possible combinations of these posts, boxes, and panels.

The diagram is from the recently published book ATLAS: Mehrgeschossiger Holzbau (English translation ATLAS: Multistory Wood Construction), by Hermann Kaufmann, Stefan Krötsch, and Stefan Winter. All three authors are professors at the Technical University of Munich (TUM), and the book was one of the interview topics during a visit to TUM on this research trip. Hermann Kaufmann is also an architect who designed several of the case studies in this report, and whose office was also visited during this research trip. This book is the most complete guide to wood construction in large buildings to date. Unfortunately for those of us who do not speak German, there is not yet an English edition, but the book is full of excellent diagrams like this one and those in the following pages.

Hybrid Solutions

While mass timber construction is unique in that wood is the primary structural material, the grand majority of mass timber buildings will incorporate concrete and steel in key areas to improve performance. As discussed in the seismic section in **INSIGHT #1**, steel is often incorporated into connections between mass timber structural elements to make the connection more ductile, or to avoid the bearing of structural elements on wood perpendicular to the grain. Concrete is often used to add mass, and/or improve fire performance, as discussed in the acoustic section (p. 129) in **INSIGHT #1**. Concrete can also be used to avoid bearing perpendicular to the grain, as was done in the case study H8 (p. 89). The diagrams below, again from ATLAS: Mehrgeschossiger Holzbau, illustrate various ways that concrete and steel can be used in mass timber construction.

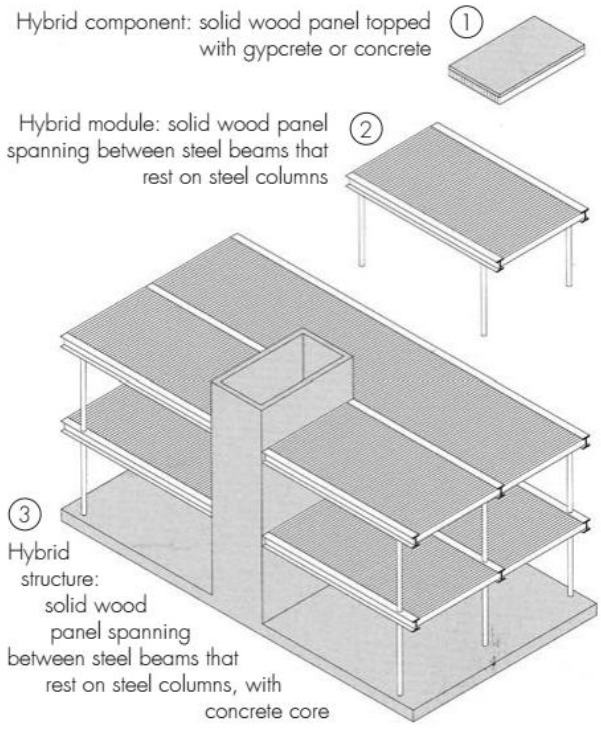
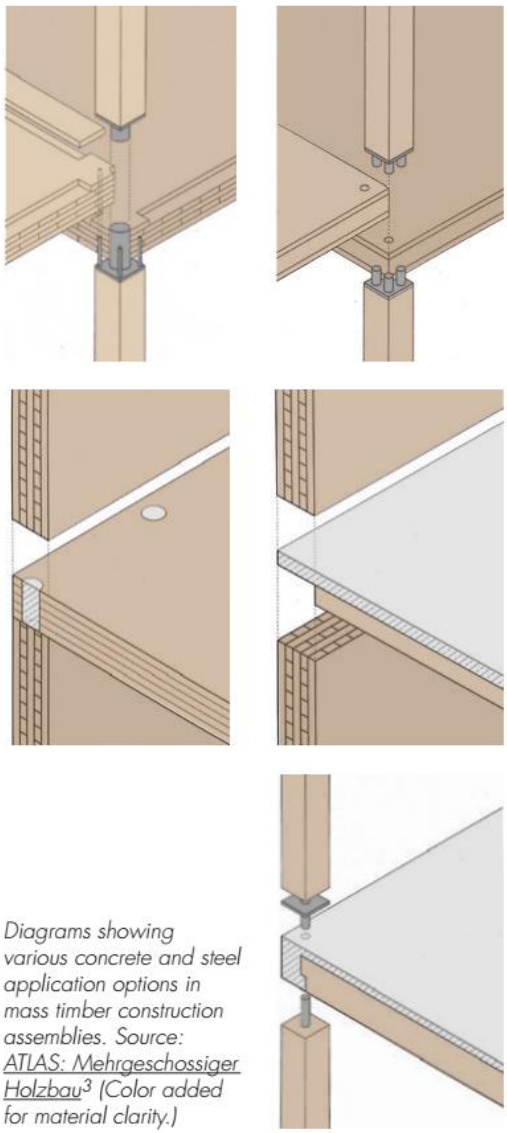


Diagram showing an example of a hybrid component, a hybrid module, and a hybrid structure. Source: ATLAS: Mehrgeschossiger Holzbau[2]

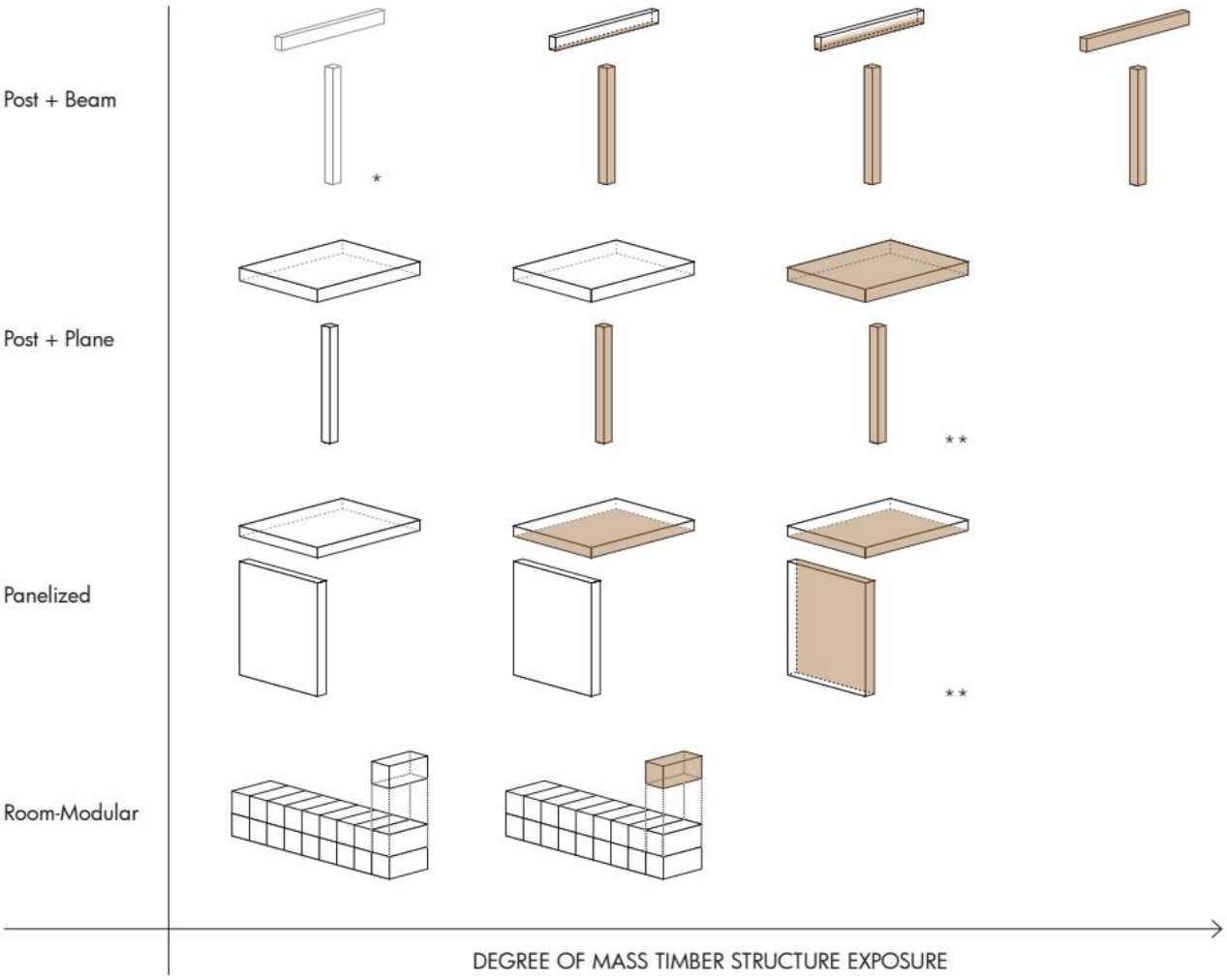


Diagrams showing various concrete and steel application options in mass timber construction assemblies. Source: ATLAS: Mehrgeschossiger Holzbau[3] (Color added for material clarity.)

Exposure of Mass Timber Structure

The mass timber construction strategy employed depends on many factors, as discussed in the **INSIGHT #1** section. Exposing mass timber structural elements can either be a priority that influences the choice of construction strategy, a side benefit of a strategy chosen for other reasons, or not done at all. The diagram below outlines the exposure approaches of case studies in this report.

Case study projects (and other projects not profiled here) that choose not to expose any timber structure do so primarily for two reasons: 1) The project team wants to use wood but code prevents wood exposure. 2) These projects are using mass timber construction for reasons that have more to do with its other benefits, such as prefabrication, speed of construction, sustainability, and benefits coming from wood's light weight rather than with the benefits of visible wood.



* *This icon is at half-opacity because there are no case study projects that fully hide "post + beam" structure. This is likely because this construction strategy lends itself well to the char (+ sprinkler) method of fire protection, explained in more detail in the Insight #1 "Fire" section.*

** *The most exposed versions of "post + plane" and "panelized" were only employed on the top floor of case study buildings due to fire restrictions.*

PORTLAND ORE.
TANNER
GOODS

INSIGHT #3:

North America versus Alpine Europe

- Mass Timber Knowledge + Product Use
- Culture + Economy
- Regulatory Environment

Regional Differences

Wood facade enclosing hybrid glulam/concrete post-and-beam structure. Green Center under construction in Kaufbeuren, Germany, July 2017.

Glulam post + beam structure with conventional facade. Carbon 12 under construction in Portland, OR, USA, August 2017.

Introduction

Through visits to case studies and interviews with professionals in Alpine Europe and the Pacific Northwest (PNW) of North America, patterns emerged revealing differences between the state of the mass timber industry in each location. CLT, along with other mass timber products including DLT and glulam, were first developed in Alpine Europe. The mass timber industry, therefore, is more advanced in many ways in Alpine Europe than it is in the PNW, however that is not the only factor that distinguishes mass timber in the two regions. Cultural and economic forces as well as differing regulatory environments have created differing contexts for the development of the industry. Moreover, certain mass timber products like CLT were in their infancy in Europe in the 1990s. These products are now in their infancy in North America today. The way that the North American mass timber industry moves forward will be shaped not only by what Europe and other regions have done before, but also by unique factors within the North American mass timber ecosystem.

Mass Timber Knowledge + Product Use

The vocabulary used during conversations with professionals in Alpine Europe and those in the PNW illustrated the differing levels of mass timber industry development. When discussing "mass timber" in Alpine Europe, professionals tended to refer to the full range of mass timber products and construction options, from LVL to CLT to glulam to prefabricated box elements and beyond. In the PNW, starting a conversation about "mass timber" almost inevitably ended up as a conversation only about CLT. It was as if "mass timber" and CLT were synonymous, rather than CLT being just one of many mass timber products. When it comes to CLT, it is almost as if professionals in Alpine Europe have "moved on" from CLT to other mass timber construction options. CLT was frequently derided as "material intensive" and expensive, and industry professionals often said that there are other options that are more convenient.

This difference in degree of the sophistication of mass timber vocabulary reveals a difference in degree of mass timber knowledge and experience between the two regions. Indeed, an Austrian architect interviewed described how seeing construction photos of Brock Commons in Vancouver (p. 79) felt like looking at photos from Germany 20 years ago. This was not meant as an insult; rather, it simply showed the differing states of the industry across many miles, years of experience, and cultural contexts.

Culture + Economy

Key cultural differences between the two regions combine with the differences in experience and industry infrastructure to affect industry development in each region. While both regions share a close proximity to timber-filled forests, this relationship with timber manifests itself in different ways economically.

Vorarlberg, Austria, is especially known for its long history of building with wood. During my travels there, it often felt like every local had a family member or friend who was a carpenter. While CLT is practically synonymous with "mass timber" in the PNW, an Austrian architect described how his practice actually avoids CLT when possible. This is because local carpenters do not have the expensive equipment necessary to make the product, so using CLT excludes them from the manufacturing process.

This avoidance of CLT in Vorarlberg contrasts with one of the key motivators for CLT production in the PNW. As discussed in the Albina Yard and Framework case studies (p. 53 and p. 61, respectively), the State of Oregon is embracing CLT as a part of its "Forest to Frame" initiative. Officials hope that increasing CLT production in the state will boost rural economies by revitalizing the depleted mill towns through the creation of manufacturing jobs. Rural CLT manufacturing can also draw economic connections between rural communities and urban ones, as mass timber products made in rural areas are increasingly used to build urban buildings. The company Katerra discussed in the **INSIGHT #1:** Industry Infrastructure section is building a manufacturing facility in Spokane, WA that it says will provide hundreds of jobs, while stimulating growth that will end up creating thousands more jobs

regionally[1]. While CLT is seen in Vorarlberg, Austria, as problematic for some sectors of the local economy, many in the PNW view CLT production as having the potential to significantly boost local economies.

Another cultural distinction between Europe and North America, particularly the U.S., has to do with environmentalism and the bottom line. In Europe, sustainability and CO_2 reduction came up more often in interviews and literature research as significant motivators for using mass timber construction. While these environmental reasons were also frequently discussed in association with North American projects, climate change as a motivator was not often discussed as directly as it is in Alpine Europe. This may be due to the political pattern unique to the United States of climate science denial. An American architect interviewed expressed another potential reason as well. As a whole, he said, the U.S. is much more "bottom-line driven" than Europe. This focus on the bottom line means that getting the first generation of mass timber projects built is more difficult because these projects are often (but not always) more expensive than conventional construction.

Regulatory Environment

Another major pattern to emerge when it comes to differences between the mass timber industries in Alpine Europe and the PNW is the regulatory environment. As was discussed in **INSIGHT #1: Technical Challenges** (p. 125), Switzerland has the fire code that is most friendly to mass timber construction. While Austria and Germany have fire codes that are more prescriptive like that of North America, regional and local code differences are still significant. These differences make it impossible, for example, to simply copy-and-paste details from a German building to a project in Oregon. While North American designers can take larger lessons into account by studying European case studies, specific details and assemblies must be re-created to succeed in the local regulatory environment.

Conclusion

The different ways that the mass timber industries have developed in Alpine Europe and in the PNW have been influenced by historical, cultural, economic, and regulatory factors. These factors have resulted in different patterns between regions with regard to whether and to what extent mass timber products and construction systems have been used.

Alpine Europe and the US are not the only regions utilizing mass timber products and construction. While this research effort focused on these two regions, Japan, the UK, Scandinavia, Australia, and New Zealand all have growing mass timber industries with their own particularities. Joseph Mayo's 2015 book Solid Wood details case studies in these regions, as well as in Alpine Europe and the PNW.

An Gusto & Mahlzeit

INSIGHT #4:

Survey Results

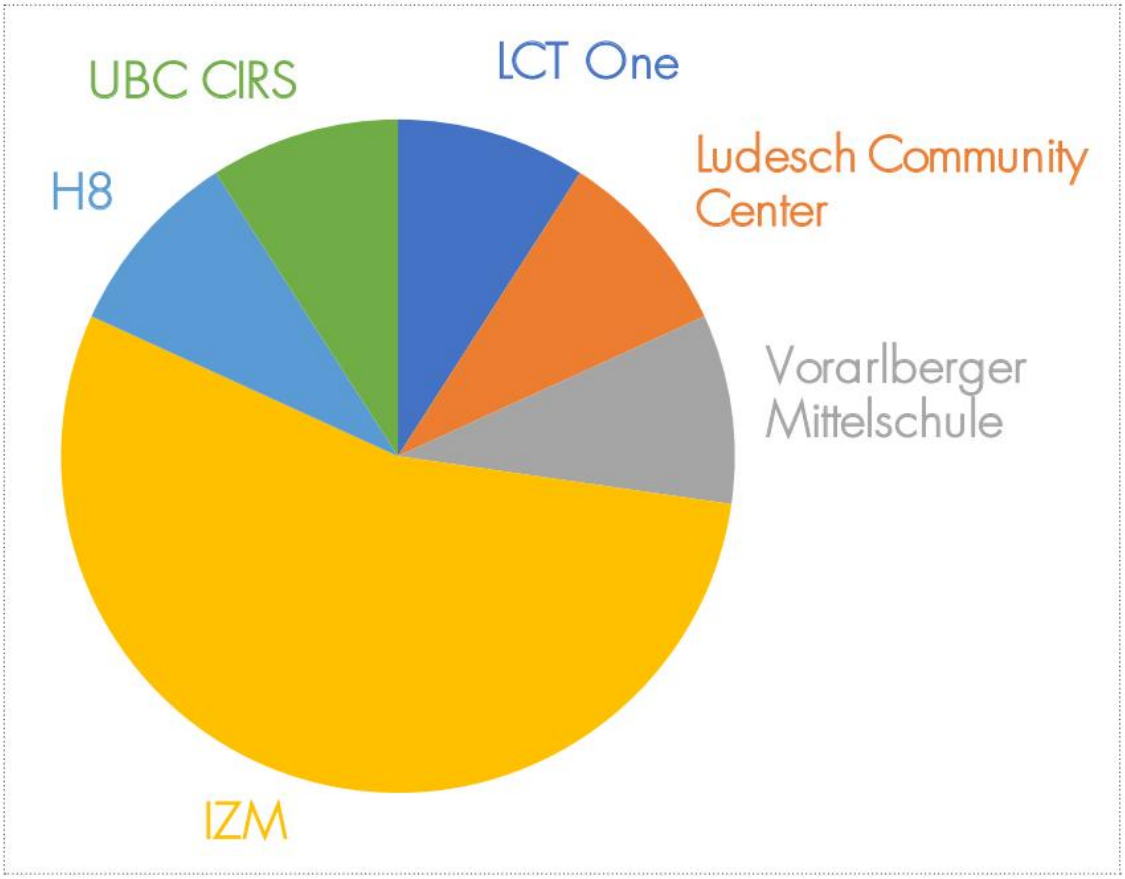
- Use of Wood in Case Study Buildings
- Structure versus Finish
- Case Study Spatial Design

Introduction

A supplement to the in-person interviews and literature research of this investigation was an electronic survey. The survey had an English version and a German version, and a physical card with a link to the survey website was distributed to users at as many case study sites as possible. The link was also distributed through email when possible. A $50 or €50 gift card raffle was used to advertise the survey on posters. Despite these efforts, only 11 people filled out the survey. Most of these respondents were from IZM, where through my AirBnB host I got a contact at the company.

While the survey had limited reach, it was still helpful as a way of getting more stories from building users and gaining a better understanding of what people found important about these buildings. Below are some survey highlights in the form of graphs, as well as quotes from free-form answers.

The results from this survey are not meant to contribute to generalizable knowledge; rather they provide small-scale, preliminary information about these 11 users and how they feel about these six mass timber buildings.

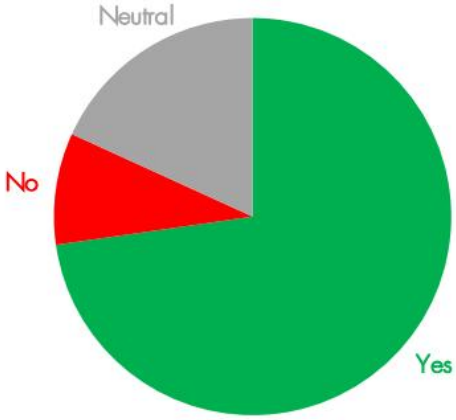


Overall Results

This page shows survey responses from the group as a whole, including all buildings reviewed. See the following page for all IZM survey responses.

- Respondent gender is an even split between male and female
- All respondents think that their feelings about the building reviewed affect their mood
- All but one respondents think their feelings about the building reviewed affect their physical health
- All know or can guess that the primary structural material of the building reviewed is wood/wood hybrid

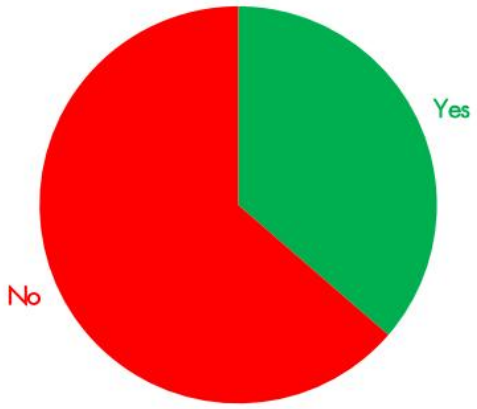
Do you like this building?



How do your feelings about this building compare to other buildings where you spend time?

Do you like being able to see the building's structural material?

Is your job involved with building design and/or construction?

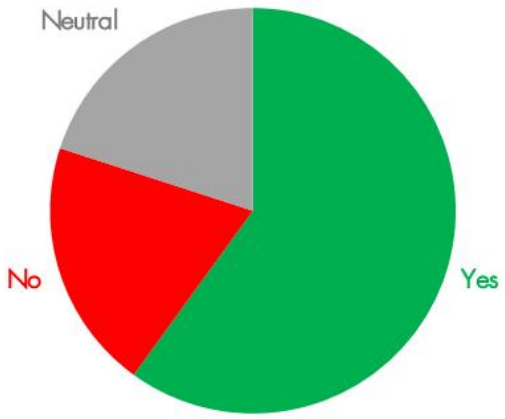


IZM

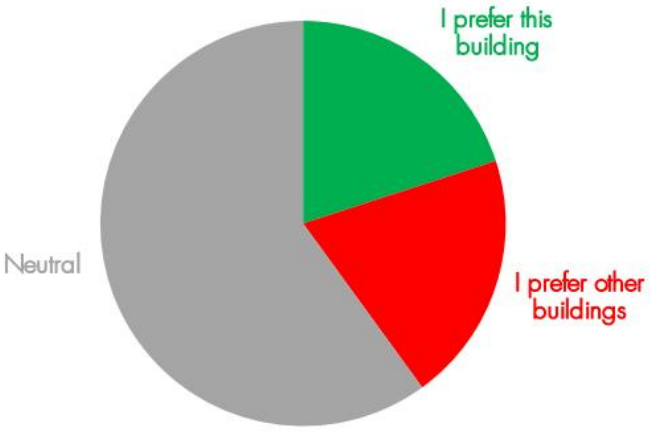
Five of the survey respondents were from IZM (p. 29), the only building with more than one survey respondent. This page shows all survey responses from this group.

- Four men, one woman
- All work at the building
- All think their feelings about the building affect their mood (all respondents for all buildings agree)
- All think their feelings about the building affect their physical health
- All know that the primary structural material is wood/wood hybrid, with two saying they know because they learned about the building and three saying they can figure out the structure by looking.
- Most like and some have neutral feelings about the wood on the interior and exterior

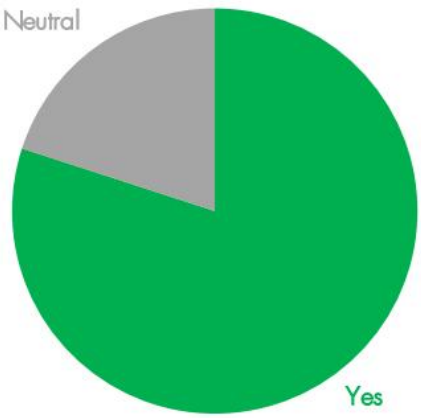
Do you like this building?



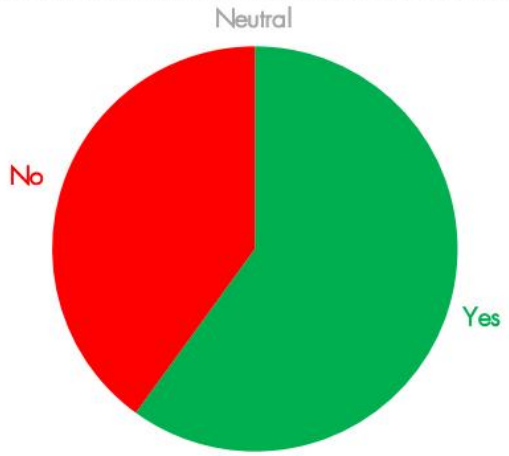
How do your feelings about this building compare to other buildings where you spend time?



Do you like being able to see the building's structural material?



Do you like the spatial design of this building?



Quotes About Wood

The survey asked respondents to say how they felt about wood in the building as a structural material and as a finish material. They were asked yes/no questions as well as open-ended questions that requested elaboration on their yes/no answers. Below are quotes from respondents' comments.

"When you compare this building to other buildings where you spend time, what factors are you considering?"

- "Warmth; naturalness" (LCT One)
- "Cosiness, peace" (Ludesch Community Center)
- "Atmosphere & room climate (light, acoustics, temperature), if there were natural materials used, functionality, design" (VMS)
- Window design (IZM)
- "Soothing" (IZM)
- "What I do in these buildings and experience; design" (H8)

Wood on the Interior

- "Wood is **calmative**." (LCT One)
- "Wood gives a **bit of life** to the room." (LCT One)
- "The wood radiates a certain **warmth and security**." (Ludesch Community Center)
- "The building radiates a **harmony**. The materials used **fit together well**." (IZM)
- "Wood is **pleasant**." (IZM)
- "[I like the wood on the interior because I like] Wood and **nature**." (IZM)
- "[I like the wood on the interior] because I like [seeing] the **local wood**." (IZM)

Exposed Wood as Structure

- "[Seeing the structure] gives a **feeling of security** and it's **interesting to see how the building works**." (LCT One)
- "I like [seeing the wood structure] because it is **simple**." (IZM)
- "Wood [structure] is **calming**." (IZM)
- "[I like seeing the structure] because it is **beautiful**." (IZM)
- "[I like seeing the structure] because **the materials behave differently**." (Ludesch Community Center)
- "Wood [structure] **does not have to be hidden**." (IZM)
- "Wood is a material that conveys **warmth and naturalness**." (H8)
- "It's my favourite – glass and birch wood. This **makes me feel at home**." (VMS)

The Exterior Materials

- "Wood **fits** in our area." (IZM)
- "I do not like concrete." (IZM)
- "[I like the exterior materials because there is] **a lot of wood**." (IZM)
- "[I like the exterior materials because they are] only wood. **Good insulation material**." (H8)
- "The recycled aluminium is a good **contrast to the wood inside** and it is a "urban" aspect in the design" (LCT One)
- "A good mix of different material. I...would prefer a **combination of wood and glass only**, but [concrete when necessary] is fine" (VMS)

CONCLUSION

While mass timber construction still has a long way to go before it is able to compete with concrete and steel construction systems on a large scale, certain take-aways from this investigation help shed light on the path forward. These are the primary solutions professionals currently employ to address the challenges facing mass timber construction and take advantage of the following opportunities:

1) Leveraging prefabrication with mass timber components

2) Close collaborating between designers and builders

3) Promoting the accessibility of solutions to common problems

This document has attempted to contribute to the third point by sharing all that has been learned over the course of this investigation. It is the hope that this research on mass timber methods, in addition to the focus on ties between visible wood and human wellness, will inspire others to explore the intriguing world of mass timber.

It is important to emphasize that the geographical focus of this investigation is Alpine Europe and Pacific Northwest of North America. While these areas are home to exciting developments in mass timber, there is much to be learned from looking at other regions all over the world. From urban CLT in the UK to an enduring emphasis on hand craft in Japan, there is no shortage of fascinating mass timber projects to investigate. Please make note of the Reference section (p. 159) to explore further reading.

Photo and graphic credits are noted in each photo caption, and cited with additional information here where deemed necessary. All photos and graphics not otherwise credited are created by this author, Molly Taylor.

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