



SUMMARY REPORT: SURVEY OF INTERNATIONAL TALL WOOD BUILDINGS

MAY 2014



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(From left to right; top to bottom)

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Architecture by Perkins+Will
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2. 3XGRÜN
Architecture by Atelier PK, Roedig Schop Architekten and Rozynski Sturm
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3. Bridport House
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Architecture by Lend Lease
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Photo credit: Huber&Sohn
9. Tamedia
Architecture by Shigeru Ban Architects
Photo credit: Didier Boy de la Tour
10. Limnologen
Architecture by Arkitektbolaget Kronoberg
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SUMMARY REPORT

EXECUTIVE SUMMARY

Over the past several years, a number of tall wood projects have been completed around the world, demonstrating successful applications of mass timber technologies. Learning from the experiences of early adopters is essential for establishing opportunities for tall wood buildings in North America and other parts of the world.

A survey of ten tall wood building projects in several countries (the Survey) was undertaken to determine and present some common lessons learned from the experiences of four key stakeholder groups involved in the projects. The Survey was focused on the experiences of each project's Developer/Owner, Design Team, Authorities Having Jurisdiction (AHJ), and Construction Team. It also examined the topics of project insurance, project financing and building operations and performance. This report presents the results of the Survey.

The Survey methodology included having key individuals from the stakeholder groups complete a short online questionnaire and participate in individual face-to-face or telephone interviews. More than 50 individuals participated in the Survey. The face-to-face interviews were conducted at the stakeholders' offices at nine of the ten project sites during the month of November 2013.

The majority of building projects surveyed are located in Europe, and the results revealed some important distinctions about building construction practices. There is a strong regulatory grounding in Europe that supports the use of low carbon content materials, renewable resources and energy efficiency in construction. These policies directly and indirectly encourage tall wood and mass timber construction. As well, for the buildings surveyed, there is a greater blending of professional roles across related sectors, creating a strong ethos of collaboration between developers, designers, timber fabricators and researchers. These nuances appear to be significant for advancing strong and credible solutions for tall wood buildings.

The results of the Survey indicate that there are a number of strong and common lessons learned across the projects in addition to specific considerations for each. Many of these elements can be considered to be critical for achieving success. All projects were developed and presented to the relevant authorities having jurisdiction in some form of an alternative solution.



Project Name: 3XGRÜN
Architecture by: Atelier PK, Roedig Schop Architekten and Rozynski Sturm
Photo credit: Stefan Mueller

For the purpose of presentation in this report, the common lessons learned and specific project considerations are categorized and summarized as:

- **Commitment**

All stakeholders stressed the importance of committing to a timber solution at the start of the project. Having an owner/developer's commitment to a wood solution from the outset of a project maintains a clear focus for all involved. Entering into a new, complex building product field that inevitably comes with challenges requires strong focus in order to achieve satisfactory results. The design team in the project also needs to have a similar commitment but, in addition, the designers need to remain flexible in their approach in order to adjust to the budget and expectations of the owner/developer, the requirements of the authorities having jurisdiction and the site conditions during construction.

- **Planning**

All stakeholders consistently indicated the importance of pre-planning and investing significant effort early in the design development process in order to identify and resolve design and construction-related issues and conflicts. An owner/developer should understand, from early on, the project's business case and the impact and constraints presented by the regulatory environment and should account for additional effort to cover complexities and costs of innovation.

The design team must be cognizant of the extra engagement and time required to successfully research, design, obtain approval for and construct a tall wood project. In-depth analysis during the design development process coupled with pre-planning and coordination of prefabrication details and construction can significantly help execute a successful project.

- **Collaboration**

Stakeholders groups were directly linked to or had strong collaborative ties with each other, researchers and timber fabricators.

It was demonstrated that the project construction timeline could be shortened by having prefabrication and system integration embraced by the design team, main contractor, principal subcontractors and material suppliers.

In several cases, engaging early with the authority having jurisdiction and directly involving them in the design development process was a key to the approach required for approvals for fire protection and acoustic performance.

- **Holistic Innovation**

Most stakeholders emphasized the need to approach mass timber/tall wood projects as wholly innovative, rather than with a focus on only an application, a component or a system that is related to wood elements.

From an innovative process point of view, unlike conventional construction, it is beneficial to engage the construction team early in the process to align design concepts, regulatory requirements and construction realities. This interaction begins to identify critical issues related to site, material selection and construction coordination and leads to more efficient and practical design solutions.

For the authorities having jurisdiction, the approval process could be expedited by the presentation of detailed research and well-developed design details that clearly achieve or exceed building safety standards and demonstrate equal or better overall building performance levels.

The Survey results also revealed several interesting details about undertaking tall wood projects, particularly in regard to project initiation and selection of wood as the principal structural material. They include:

- **Motivators**

Interestingly, the common motivations for pursuing a tall wood project were found to be innovation, market leadership and carbon reduction. Energy efficiency and healthy indoor environments that promote a sense of well-being were indicated to be complimentary design objectives.

- **Shared Objectives**

Most owners/developers and design teams shared similar objectives at the outset of their projects.

- **Supportive Governing Policies**

It appears that, in jurisdictions where governing policies exist in support of the use of low carbon content materials, renewable resources and energy efficiency in construction, the acceptance of mass timber solutions is developing more rapidly. In such cases, the governing framework motivated all stakeholders to innovate with wood solutions, and incentive funding was able to be accessed by some.

However, challenges remain in developing, designing, approving and constructing tall wood buildings. They include:

- Work to further test, refine and establish robust and replicable solutions by researchers, material suppliers and the construction industry is still required for mass timber building systems.
- There appeared to be a lack of uniformity of how projects are approved by the authorities having jurisdiction. The degree of difficulty and effort associated with obtaining project approvals was largely dependent on the extent to which the authorities collaborated with the project teams, as well as general familiarity with mass timber, large wood structures or tall wood solutions.
- No single solution was common or typical across all projects to strategically address durability, fire protection or acoustics. Project teams relied on research partnerships, published reports or available test results to support proposed design solutions.
- Perspectives and approaches on weather protection during construction varied widely.

Experiences regarding financing and insurance costs or conditions suggest very little deviation from typical requirements for conventional tall reinforced concrete or steel buildings or for low-rise wood structures. No Owner/Developer experienced challenges obtaining financing attributable to the use of mass timber. In all cases, stakeholders reported they managed to overcome any approval, design or construction obstacles without exceeding the projected project budgets. No Owner/Developer indicated any irregularities regarding building operations or performance.

In summary, the projects collectively have

- explored, initiated and developed new mass timber construction methodologies
- generated novel design solutions and material usage ideas
- presented useful test data
- expanded the capacity of the building construction industry in general, particularly the capacity in the design and construction of tall wood buildings
- streamlined approval pathways for subsequent projects
- provided market recognition for tall wood construction

Overall, the results confirm that wood is a viable option for attaining safe, cost-equivalent, high-performing tall buildings.

ACKNOWLEDGEMENTS:

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For questions with regards this report, please contact:

Canada and International:
Sonya Zeitler Fletcher
Director, Market Outreach
Forestry Innovation Investment
Phone: (604) 601-5305
Email: sonya.zeitlerfletcher@bcfii.ca

United States:
Cees de Jager
General Manager
Binational Softwood Lumber Council
Phone: (604) 536-7730
Email: dejager@softwoodlumber.org

GLOSSARY

Alternative Solution is a design solution through which compliance with a building code is achieved by demonstrating that the proposed solution provides an equal or better level of performance to the prescribed acceptable solution given in the building code.

Authority of Having Jurisdiction (AHJ) is the agency that regulates the local, regional or national building industry.

Brettstapel in this document, is the term commonly used for solid timber construction that does not generally use glues or nails. The system works by using dowels with a moisture content lower than that of the posts; over time the dowels expand to achieve moisture equilibrium thus 'locking' the posts together and creating a structural load-bearing system.

Builder-Owner Collective In this document, the term refers to a method of organizing individual owners as a formal, legally recognized group for the purposes of acquiring land to design and construct a multi-family dwelling. This arrangement is relatively common in Germany, and eliminates the traditional role of Developer, allowing the group of individual owners to work directly with the design, often resulting in highly customized suites.

Carbon footprint is the total amount of carbon dioxide emitted into the atmosphere as a result of an activity or process.

Cross-Laminated Timber (CLT) is a laminated timber panel consisting of a minimum of three layers of boards stacked crosswise (typically at 90 degrees) and fastened with glue, dowels or nails.

Char layer is the added thickness of a timber component which exceeds required structural dimensions, designed to protect the timber components in case of fire.

Embodied Carbon is the total amount of carbon dioxide released from material extraction, transport, manufacturing, and related activities.

Grey Water is untreated waste water, which has not come into contact with toilet waste or kitchen sinks, typically from bathroom sinks, bathtubs, and showers.¹

Hybrid construction in this document, refers to building structures where mass timber products are used in combination with steel or concrete.²

Lateral stability is the capacity of a structure to resist the lateral forces without overturning, buckling or collapsing, while maintaining a given position in space.

Mass Timber in this document, refers to a form of construction which uses large prefabricated wood members such as Laminated Veneer Lumber (LVL), Laminated Strand Lumber (LSL), and Cross Laminated Timber (CLT) for wall, floor and roof construction. Glulam can also be used in beam and column applications.³

Mixed use is used to describe a project or development typology that integrates more than one use such as residential, commercial and retail spaces.

Panelized System in this document, is a method of constructing with prefabricated panel elements such as CLT or other solid timber panel products, as opposed to a post and beam framing system.

Passive House a rigorous, voluntary energy performance standard for buildings, which aims to reduce the requirement for space heating and cooling, whilst also creating excellent indoor air quality and comfort levels.⁴

¹ LEED Canada-BD+C 2009 Reference Guide.

² FP Innovations. (2011) CLT Handbook

³ <http://www.masstimber.com/>

⁴ <http://www.passivehouse.ca/>

Post + Beam in this document, is the structural framing system in which the structural members (vertical posts and horizontal beams) are anchored and joined with structurally engineered mechanical fasteners.

Prefabricated refers to shop manufactured components that are transported to a site and assembled in situ.⁵

Systems integration in this document, is used to describe how electrical and mechanical systems are incorporated into the overall building design.

Self-financing refers to the internal investment sources that owners or developers are able to draw upon to fund the development of a project, without soliciting outside funding from traditional lending sources.

Tall Wood Building in this document, is a structure consisting primarily of Mass Timber of 5 storeys or more.

⁵ Green, Michael. (February, 2012) The case for Tall Wood buildings. How Mass Timber Offers a Safe, Economical, and Environmentally Friendly Alternative for Tall Building Structures.

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Project Name: Tamedia
 Architecture by: Shigeru Ban Architects
 Photo credit: Didier Boy de la Tour

1.0 INTRODUCTION

The purpose of this report is to summarize the results of a Survey of International Tall Wood Buildings (the Survey) conducted by Perkins+Will on behalf of Forestry Innovation Investment (FII) and the Binational Softwood Lumber Council (BSLC). FII and BSLC believe that collaborating with global leaders in taller wood construction to share experiences and information may help to reduce risk and accelerate early adopter projects around the world – bringing credibility to all advancing the area of tall wood buildings.

The goal of the Survey was to collect lessons learned and experiences from built projects around the world that have utilized various tall wood building technologies. This report presents common themes and trends among project stakeholders including Owner/Developer, Authorities Having Jurisdiction, Design teams and Construction teams. The aim is to share this information with potential North American project stakeholders to help simplify their processes, increase their comfort and potentially lower their risk of designing tall wood structures, ultimately broadening the uptake of wood systems used in tall wood construction. It is also likely that a compilation of these lessons learned and experiences will assist stakeholders of new projects yet to be built around the world.

1.1 SCOPE

The Survey examined ten international built projects identified as buildings using mass timber to construct buildings of five stories or more, and sought to compile the experiences of four key stakeholder groups including the Developer/Owner, Authority Having Jurisdiction, Design team and Construction team. The Survey focused on four distinct but related areas of inquiry:

- Lessons Learned
- Project Insurance
- Project Financing
- Building Operations and Maintenance



Project Name: Limnologen
Architecture by: Arkitektbolaget Kronoberg
Photo credit: Midroc Property Development

1.2 METHODOLOGY

Ten built projects were chosen based on a variety of criteria including building typology, timber structure type, date of completion, willingness and availability of stakeholders to participate and extent of information already published. The ten built projects examined are summarized in Table 1 below.

Table 1: Survey of International Tall Wood Buildings - Participant Projects

PROJECT NAME	LOCATION	BUILDING TYPE	STOREYS	WOOD CONSTRUCTION TYPE	COMPLETION DATE
E3	Berlin, Germany	Commercial / Residential	7	Post and Beam	2008
Limnologen	Vaxjo, Sweden	Residential	8	Panelized	2009
Bridport House	London, England	Residential	8	Panelized	2010
3XGRÜN	Berlin, Germany	Residential	5	Combination Panels / Post and Beam	2011
Holz8 (H8)	Bad Aibling, Germany	Commercial / Residential	8	Panelized	2011
Forté	Melbourne, Australia	Commercial / Residential	10	Panelized	2012
University of British Columbia Earth Sciences Building (ESB)	Vancouver, Canada	Institutional	5	Combination Panels / Post and Beam	2012
LifeCycle Tower One (LCT One)	Dornbirn, Austria	Commercial	8	Combination Panels / Post and Beam	2012
Tamedia	Zurich, Switzerland	Commercial	6	Post and Beam	2013
Cenni di Cambiamento	Milan, Italy	Commercial / Residential	9	Panelized	2013

Key individuals representing each of the four stakeholder groups were identified and contacted by email and/or telephone, with a formal invitation to participate in the Survey. Stakeholders were asked to complete a short, online questionnaire to establish the basis for a more detailed one hour in-person or telephone interview with two researchers. Subject matter and questions posed in the online questionnaires and interviews were based on known knowledge gaps and perceived challenges and risks of constructing tall wood buildings in the North American market place. Relevant results from the online questionnaire have been included throughout the report in graphic format to further portray trends and findings of the survey.

Researchers visited all of the project locations in person during the month of November 2013, with the exception of Forté in Melbourne, Australia. Where a participant was either unavailable or could not be identified to represent a specific stakeholder group, information and feedback was acquired from participants in other project disciplines and stakeholder groups or from published documents. It should be noted that stakeholders representing the Authorities Having Jurisdiction (AHJ) were generally more challenging to access, and as such, depth of information and strength of trends are limited. Where appropriate, relevant experiences and lessons associated with the AHJ and approvals process were compiled from other project stakeholders.

2.0 LESSONS LEARNED

2.1 OWNER / DEVELOPER

Participants within the Owner/Developer stakeholder group included conventional development companies, building owner-occupiers, and Building-Owner Collectives who were also acting as project designers. In all cases this stakeholder group was engaged extensively with the details of the project development and execution from the early stages of research and due diligence, through planning, design and construction.

Survey participants were asked to comment on the rationale for pursuing a tall wood project, project risk considerations, budget and cost considerations as well as management processes and strategies. Overall challenges, successes and lessons learned were also solicited. The following section summarizes themes and trends common across all ten projects, and identifies unique scenarios where relevant.

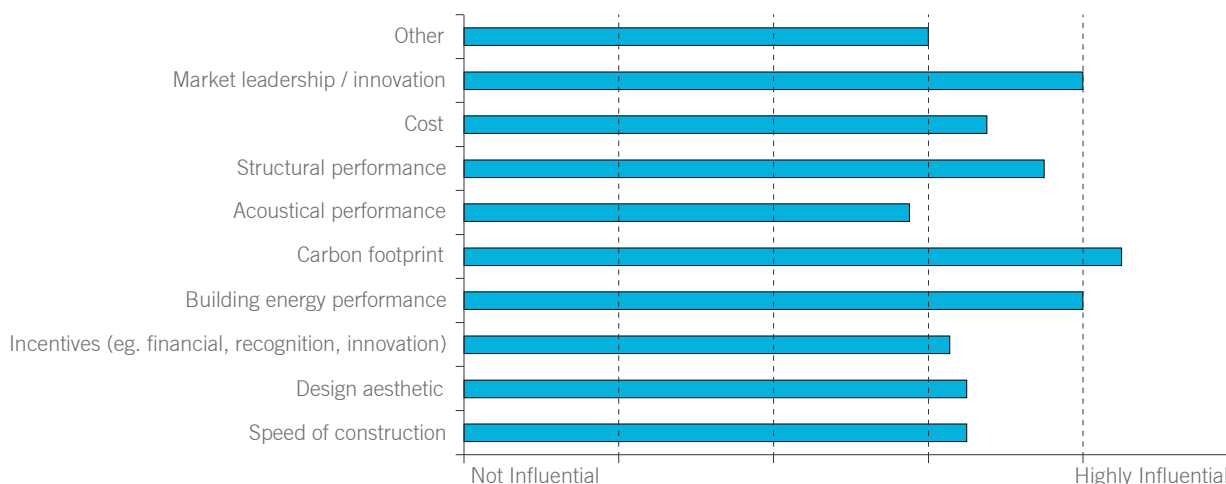
LESSONS FROM TALL WOOD

From the perspective of the Owners/Developers, the Survey results point to the following as factors for successful completion of tall wood projects:

- A commitment to a wood solution was clearly communicated by the Owner/Developer to all project stakeholders from the outset.
- The project business case and budgets recognized and allowed for the cost of innovation.
- The Design Team's vision was aligned with the Owners/Developers' vision.
- The Authority Having Jurisdiction were engaged early in the project process and worked collaboratively with the Owner/Developer and Design Teams to resolve issues and develop acceptable solutions.
- Construction Teams and key timber suppliers, in most cases, were engaged early in the design process in order to help align concepts, regulatory guidelines and construction realities.

Owner/Developer: Online Questionnaire Participant Responses

Influential Factors on the Owner / Developer's Decision to Use Structural Wood Technology:



WHY TALL WOOD

Based on the feedback gathered from the Owner/Developer of the ten international projects, the following were identified by participants as the most influential reasons for pursuing a tall wood project:

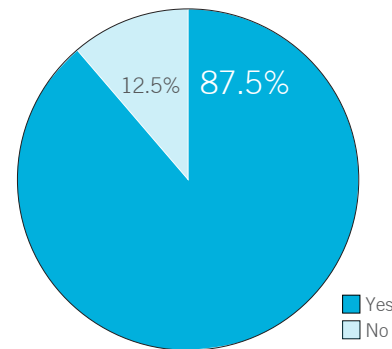
- **Low carbon footprint**
Realize significant carbon savings compared to conventional structural materials such as steel and concrete, by using more timber in construction. In several cases carbon reductions were pursued in response to governing regulatory policy.
- **Innovation and market leadership**
The opportunity to test a new structural typology with the objective of creating a leading position in the market place for future development.
- **Building energy performance**
Benefit from the relatively good thermal performance of mass timber products compared to concrete or steel structure to support efficient building energy performance.

Additional motivations identified by the participants that are particularly relevant within the contexts of each project:

- **Light weight structure**
Two projects with sensitive site conditions (Bridport House and Forté) identified that mass timber was particularly appealing for its lighter weight compared to a concrete or in some instances, a steel structure. One participant identified the potential for widespread use of mass timber products in renovation and densification projects where a lighter weight structural material is beneficial for adding storeys to existing buildings.
- **Durability**
Participants from residential building projects indicated they believe mass timber to be a very durable structural option, appropriate for long-term capital and operational investment and to support high-quality finishing in a high-end residential context.

Owner/Developer: Online Questionnaire Participant Responses

Are you pursuing new projects using similar wood technology or systems?



Project Name: E3
Architecture by: Kaden Klingbeil
Photo credit: Bernd Borachrt

DEVELOPING TALL WOOD

Participants were asked to summarize important project process considerations, and to identify special or unique aspects of managing a tall wood project, different from a conventional project. The following common themes were strong among all participants:

- **Commit**

Begin with the intention to use a wood structure and commit to innovation holistically. Project teams emphasized the need to approach the work as wholly innovative, rather than focusing on wood innovation only.

- **Understand the Market**

Investigate the market and understand any negative perceptions associated with the use of mass timber such as fire risk, acoustics, or durability. All survey participants focused on finding solutions to address or resolve market perception, and cultivate credibility for mass timber buildings.

- **Research**

Establish a partnership or collaborate with a research body to support innovation and design solutions. Research collaborations with academic institutions or other research organizations were integral to evaluating and testing design solutions for all survey participants.



Project Name: Cenni di cambiamento
Architecture by: ROSSIPRODI ASSOCIATI srl
Photo credit: Riccardo Ronchi

- **Collaborate**

Create a strong, integrated and collaborative design process early. Choose knowledgeable professionals willing to innovate.

- **Engage the Authority Having Jurisdiction**

Engage the AHJ early in the research and due diligence process to establish a collaborative and respectful relationship based on learning and evolving solutions. In all cases with the exception of one, successful approvals were based on an open and evolving dialogue with the Authority to evaluate and implement satisfactory solutions for each unique jurisdiction.

- **Account for Innovation**

Create a realistic budget that accounts for innovation and experimentation, testing of new design solutions. Use a full cost accounting methodology that recognizes long term operational savings, durability, environmental and social benefits. In all cases, while budget constraints and costs were identified as challenges, participants reported they managed to overcome any design or construction obstacles without exceeding the project budget.

- **Share**

Monitor, document and share information, experiences and lessons related to developing tall wood buildings. In all cases, participants emphasized the importance of sharing the results of their work to educate the industry, refine design solutions and move toward widespread use of wood in tall construction.



Project Name: Tamedia
Architecture by: Shigeru Ban Architects
Photo credit: Didier Boy de la Tour

2.2 DESIGN TEAM

Design team members surveyed and interviewed included project architects, structural engineers, timber product fabricators and academic research partners. Survey participants were asked to comment on the rationale for pursuing tall wood construction, the design process, design strategies, challenges, successes and lessons learned.

The following section summarizes themes and trends common across all ten projects, and identifies unique scenarios where relevant.

LESSONS FROM TALL WOOD

From the perspective of the Design Teams, the Survey results point to the following as factors for successful completion of tall wood projects:

- Owner/Developers committed to a wood solution early.
- Test results from relevant research helped create acceptable design solutions.
- Additional design development time was given at the beginning of the project to resolve design details.
- Design Solutions were in some cases developed with direct input from the Authority Having Jurisdictions, local fire officials, Construction Teams and material suppliers.
- During construction, unexpected and non-code compliant design details were cooperatively and safely resolved with other stakeholder groups.



Project Name: Forté
Architecture by: Lend Lease
Photo credit: Lend Lease

WHY TALL WOOD

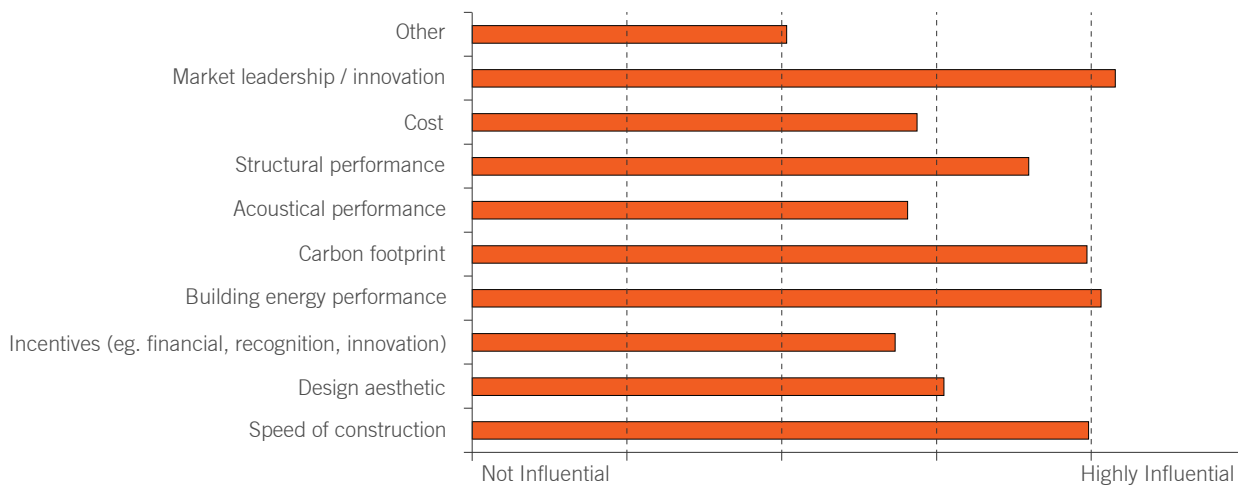
Based on the feedback gathered from design teams for the ten international projects, the following were identified as the most important motivators for pursuing a tall wood project:

- **Market Leadership and Innovation**
Developing design solutions for a new structural typology with the potential for a place of importance in the market in the near future was a key motivation.
- **Building Performance**
Energy efficiency and healthy, indoor environments that promote a sense of well-being were indicated to be complimentary design objectives easily achieved by using mass timber.
- **Carbon Footprint Savings**
Realize significant carbon savings compared to conventional structural materials such as steel and concrete, by using more solid timber in new construction.
- **Speed of Construction**
Realize construction schedule savings afforded by constructing with prefabricated elements.

In addition to the list above, residential project participants emphasized their desire to demonstrate solid wood construction as an affordable, alternative to conventional concrete or steel, with comparable or better durability and quality.

Design Team: Online Questionnaire Participant Responses

Influential Factors on the Design Team’s Decision to Use Structural Wood Technology:



DESIGNING TALL WOOD

In most cases design teams had previous experience with wood construction, although not necessarily with mass timber. Similarly, in most cases, the projects were approached as wood buildings from the start, that is, the decision to use wood as structure was made prior to the commencement of design.

Participants were asked to summarize their project design process and identify special or unique aspects, different from a conventional project. The following common themes were strong among all participants:

- **Commit**

Begin with the intention to use a wood structure and commit to innovation holistically. Project teams emphasized the need approach the work as wholly innovative, rather than focusing innovation on wood only.

- **Create Research Partnerships**

Establish a partnership or collaborate with a research body to support innovation and design solutions. Research collaborations with academic institutions or other research organizations were integral to evaluating and testing design solutions for all participants.

- **Collaborate**

Create a strong, integrated and collaborative design process early. Include the timber product fabricator and construction team during design to ensure details are resolved and logistics and sequencing are considered.

- **Engage the Fire Protection Authority**

Engage the fire protection authority early in the design process to establish a collaborative and respectful relationship. In almost all cases, participants proposed new and untested design solutions that were not recognized within local building codes, and educating Authorities on the merits of alternatives was critical to securing buy in and alleviate risk concerns.

- **Anticipate Effort**

Be prepared to invest additional effort to resolve design details. Both architectural and structural designers experienced an increase of design time of 10 – 50% compared to a concrete structure, and indicated that detailing interfaces between materials was most time consuming.

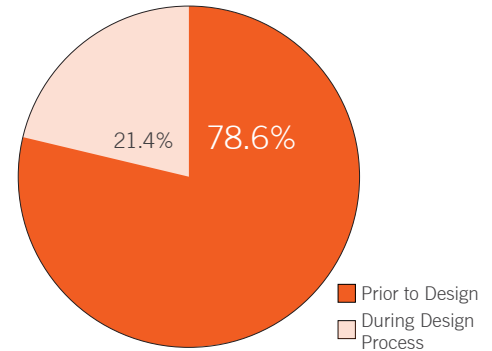
- **Simplify**

Design should attempt to simplify solutions as much as possible. Focusing on simple solutions can reduce effort in design detailing, eliminate unnecessary material costs, facilitate prefabrication for more components and shorten project delivery time.

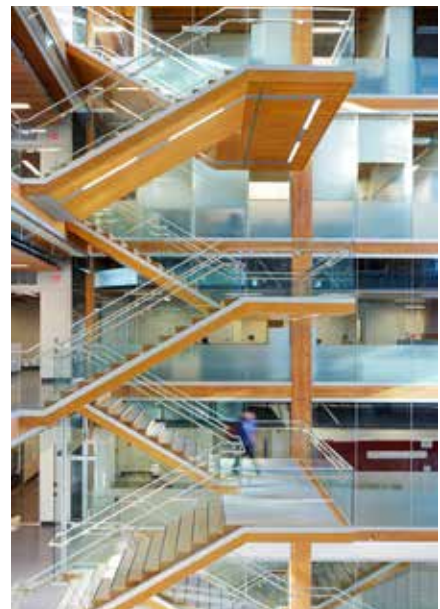
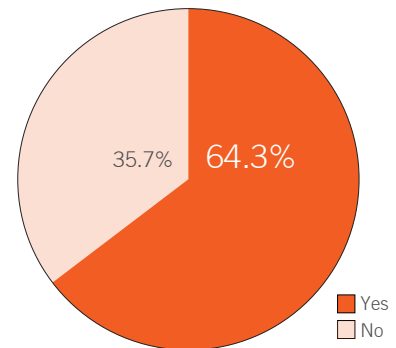
Design Team:

Online Questionnaire Participant Responses

When was the decision made to use structural wood?



Did you require additional resources or design time to support this project?



Project Name: UBC Earth Sciences Building
Architecture by: Perkins+Will
Photo credit: Martin Tessler

DESIGN SOLUTIONS

Design solutions related to known knowledge gaps or perceived challenges of designing for tall wood were explored with all ten project teams. Strategies varied across all teams, and no clear or universal design solutions were evident in any suggesting the industry is still very much evolving. Applied strategies are typically the result of research, trial and error. However, trends are emerging and in some cases a temporal trend toward refined solutions is evident. Construction experience is summarized for corresponding solutions in section 2.4.



Structure

Post and beam with a combination of panel products appear to be the favoured solution for commercial application, to achieve more flexible and open spaces, while a pure panelized application is more common in residential typologies where a regular layout of fixed walls is commonly available. All three commercial buildings included in the Survey (ESB, LCT ONE, Tamedia) applied a post and beam structure to achieve large spans and open floor areas that can be easily customized and changed. Panelized structures appear to work well in residential buildings where compartmentalized suites are desired (Bridport House, Holz8 (H8), 3XGRÜN, Limnologen, Cenni di Cambiamento, Forté).

In all cases project teams prioritized prefabrication of structural timber elements. Although the degree of prefabrication varied across projects, it is clear that fully committing to prefabrication is integral to realizing the benefits of constructing with mass timber. Feedback emphasized that where prefabrication was maximized (Tamedia, Holz8 (H8), 3XGRÜN) the benefits of precision cutting and assembly were realized in quality of construction, accelerated schedule and reduced site disruption during construction. In addition, all participants agreed that where concrete was used in combination with a mass timber system, precast elements must be used or the major benefits of prefabrication are lost (precision, schedule, clean and dry site).

Projects where a mix of structural systems and materials were applied (concrete, steel, glass, mass timber) grappled with complexity which impacted the schedule to different degrees. Every design team identified detailing interfaces between materials as a major effort and challenge, due to the variation in tolerances between materials, and advocated simplified solutions and approaches in all respects.



Lateral Stability

Among the projects surveyed, lateral stability is achieved by one of two strategies, either a concrete core or CLT load bearing walls, some reinforced with steel tie-down rods. The Earth Sciences Building with exposed, ductile heavy timber chevron bracing, is the only exception.

Connection solutions vary and are unique in almost all project examples, although solutions appear to be evolving and focusing quickly. Early projects such as E3 grappled with complex steel connections between wood elements as well as wood-concrete connections. More recent buildings such as LCT ONE focused on simplifying design details to benefit from a modular approach to fabrication, assembly and building configuration.



Tamedia post and beam structure
Architecture by: Shigeru Ban
Photo credit: Blumer-Lehmann AG



Prefabricated panel installation at Holz 8
Architecture by: Schankula Architekten
Photo credit: Huber & Sohn



Exposed view of glulam chevron braces at
UBC Earth Sciences Building
Architecture by: Perkins+Will
Photo credit: Equilibrium

Pure timber connection strategies also vary and appear to be evolving quickly. Each project created a unique solution to avoid compression at perpendicular to grain at horizontal joints, however, self-tapping, angled screws appear to be emerging as an economical and reliable strategy to secure joints, along with steel plates as a tie down method (Forté, Cenni di Cambiamento, Bridport House).



Fire protection

The fire protection strategies for each project included various combinations of measures to meet the specified fire rating imposed by each AHJ. Testing was required of each project to demonstrate compliance, and in most cases, projects relied on research partnerships to build mock-ups and execute testing.

In all cases, timber elements were oversized to include a char layer as part of the fire protection strategy, in addition to encapsulating timber elements with gypsum to some degree. Sprinkler systems and intumescent paint applied to exposed timber were also common fire protection strategies. Most projects chose not to install wood cladding on the exterior, and opt for non-combustible façades; where wood façades are installed (Holz8, Limnologen), fire protection strategies were more challenging and complex.

Fire protection was particularly challenging in the case of Tamedia where fire rated glass surround the stair and intermediate zone. Where timber beams penetrate the fire rated glass, they are notched and layered with gypsum to create a noncombustible barrier at the interface, then covered with wood veneer to maintain the aesthetic quality of the timber. This unique detail involved extensive effort to design and execute.

Finally, survey responses suggest that as Authorities become more informed and engaged with mass timber projects, fire protection strategies can be streamlined. In two cases, participants indicated that the AHJ permitted some fire protection to be eliminated as the project construction progressed and on-site inspections eased concern. LCT ONE reported that the sprinkler system was determined to be redundant and Limnologen was allowed to eliminate gypsum on walls in some living spaces in two of the four buildings.



Acoustics + Vibration

Design solutions to address acoustics and vibration are the most varied across projects. Meeting local building code requirements, which also varied widely across participant jurisdictions, was identified by most teams as a major design challenge.

Isolating floor and ceiling assemblies with the use of resilient pad material emerged as a viable and effective strategy in pure wood, panelized structures (Limnologen, Holz8, 3XGRÜN). Strategies appear to be less complex in projects where concrete layers are applied in floor slabs (LCT ONE, Bridport House, ESB, E3). Almost all participants indicated that acoustic solutions were researched and tested through research partnerships.



Holz8 exterior wood façade with metal flashing between each storey prevents the spread of fire
Photo credit: Huber & Sohn



Exterior of Limnologen
Architecture by: Arkitektbolaget Kronberg
Photo credit: Midroc Property Development



Composite floor panel used for testing
Project Name: UBC Earth Sciences Building
Photo credit: Equilibrium



Systems Integration

Design solutions for systems integration were varied across projects. In projects where structural elements are covered or concealed, participants indicate that resolving systems is relatively easy. In cases where structure was exposed (Earth Sciences Building, Tamedia), integrating systems was identified as more challenging. Feedback from all project teams stressed the importance of early consideration of systems in design, especially where prefabricated elements must accommodate penetrations.

In the majority of residential cases, system penetrations were done during prefabrication, and concealed within walls and ceilings where structure was not exposed. Where complex cutting was done on-site, problems with precision and scheduling were reported (Limnologen). In the case of Forté, bathroom pods were completely prefabricated and installed as modular components, greatly streamlining systems integration for both design and construction.

In commercial applications, raised floors and dropped ceilings accommodated the majority of systems (LCT ONE, Tamedia). In the unique case of Tamedia, where the design relied on extreme precision and the majority of timber structure was exposed, 3500 penetrations were cut on-site to ensure they were accurately located.



Moisture Protection and Durability

In general, moisture protection is not perceived as a major risk by design teams. In all cases, any exposed structural wood elements are either inside the building envelope, protected by an overhang (ESB) or in the case of cantilevered panels (3XGRÜN, Limnologen, Holz8 (H8)), exposed only on the underside. In two cases, moisture sensors were installed to monitor envelope performance (Limnologen, Forté, Earth Sciences Building).

During operation, moisture is addressed in most cases by a mechanical ventilation system. Residential project teams highlighted the importance of educating occupants on optimal operation strategies.



On-site milling for hydronic heating pipes at
Limnologen
Photo credit: Martinsons Byggsystem



Ceiling panel to conceal systems at LCT ONE
Photo credit: Martinsons Byggsystem



Exposed timber on underside of balconies at 3XGRÜN
Architecture by: Atelier PK, Roedig Schop
Architekten and Rozynski Sturm
Photo credit: Stefan Mueller

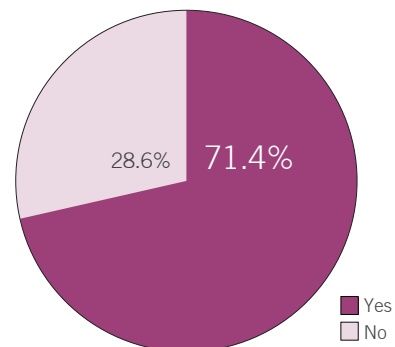
2.3 AUTHORITY HAVING JURISDICTION

Authorities Having Jurisdiction (AHJ) play an integral role in the evolution of mass timber construction solutions, and although representatives of this stakeholder group for each project were contacted and invited to contribute to the Survey, only three of ten were available to share their experience. Where direct contact with AHJs was not possible, relevant information provided by other project stakeholder participants has been included.

In the majority of surveyed cases, multi-storey mass timber buildings exceeding three or four storeys are not specifically provided for in local building codes. Survey participants were asked to comment on requirements and processes related to obtaining approval of mass timber projects, any special or unusual requirements, limitations or conditions, time and effort required to finalize approvals, risks, special expertise accessed, challenges, successes and lessons learned. The most significant outcome from the Survey reveals that each project has positively impacted its local jurisdiction and has led to the adoption of streamlined solutions on subsequent projects.

Design Team: Online Questionnaire Participant Responses

Frequency of Special / Additional Documentation Required by AHJ due to Use of Structural Wood Technology



LESSONS FROM TALL WOOD

From the perspective of the Authorities Having Jurisdiction, the Survey results point to the following as factors for successful completion of tall wood projects:

- Local, regional or national government policies in support of low carbon construction, energy efficiency, or renewable resources encourage an efficient approvals process.
- Owners/Developers and Design Teams created ‘Alternative Solutions’ with supporting test data that met or exceeded building and fire code or local condition requirements.
- Owner/Developers, Design Teams and Construction Teams, in addition to key suppliers, demonstrated a high level of cooperation in establishing strategies and resolving construction-related variances.



Wall panel fabrication for Holz8
Photo credit: Huber&Sohn

The following summarizes themes and trends that emerged from the survey, and identifies unique scenarios where relevant.

- **Collaborate and Consider Details**

- Both project team and AHJ survey participants indicated engaging with each other as early as possible in the project process is necessary to establish a shared knowledge base and an open and collaborative working relationship.
- Work with the project team to reach out to other jurisdictions or research institutions to access relevant information or testing data.
- Invest the time to understand details and strategies early.

- **Establish a Methodology**

- In most cases, the projects in this Survey were the first tall wood buildings to be approved within their respective jurisdictions. All project teams conveyed that the process of obtaining approvals was not different than other projects where new and untested design solutions are proposed, although most did experience a lengthier and more onerous approvals process.
- Where jurisdictions had an established 'alternative solutions' process in place, projects followed this protocol (Forté and Earth Sciences Building).
- In several cases, supportive government policy for low carbon construction, energy efficiency, or renewable resources, made the approvals process more straightforward, given that officials were more educated and motivated to support successful examples of policy application (Limnologen, Holz8).
- In the case of the 3XGRÜN project in Berlin, the design team reported a unique process whereby the AHJ requires two independent fire code consultants to be engaged by the project team to consult on design strategies as well as manage the approval process directly with the Authority. This appears to be similar to the peer review process used by the AHJ for the Earth Sciences Building; stakeholder groups from both projects communicated that these processes were smooth and successful.

- **Test**

- In all cases, testing for proposed materials and assemblies was required to demonstrate code compliance and in some cases, testing was conducted in partnership or conjunction with a research program, facility or organization.

- **Inspect**

- On-site inspections during construction, in addition to performance testing, were also crucial, not only to confirm strategies were executed as expected and making adjustments as necessary, but to experience and learn for future applications.
- In at least two cases (Limnologen and LCT ONE), fire protection strategies were simplified as the project progressed and the Authority became more informed.
- In one case (Cenni di cambiamento), the approval process took place during design only; AHJ involvement during construction was limited.

2.4 CONSTRUCTION TEAM

Construction team members surveyed and interviewed included contractors, timber erectors, and timber fabricators involved the construction of the projects.

Survey participants were asked to comment on the rationale for pursuing mass timber construction, the construction process, solutions related specifically to constructing in the context of a tall wood building, challenges, successes and lessons learned. The experiences gathered from construction team members focused mainly on the importance of the planning process rather than individual technical construction solutions. The following section summarizes themes and trends common across all ten projects, and identifies unique scenarios where relevant.

LESSONS FROM TALL WOOD

From the perspective of the Construction Teams, the Survey results point to the following as factors for successful completion of tall wood projects:

- Project/Site/Construction managers were invited to provide input early in the design development process of the project.
- Design Teams, Construction Teams, material suppliers and building trades embraced prefabrication and system integration which shortened timelines.
- Tolerances and complexities of details at interfaces between wood structural elements and other structural materials were the greatest challenges but were recognized and accommodated during design or construction.
- Construction personnel were productive in a good work environment on site.
- Project sub-trades and suppliers of materials and systems were able to adapt easily their product specification and scope of work to the wood structural solutions.
- Weather-related issues that could affect wood product appearance and performance were accepted and budgeted for.



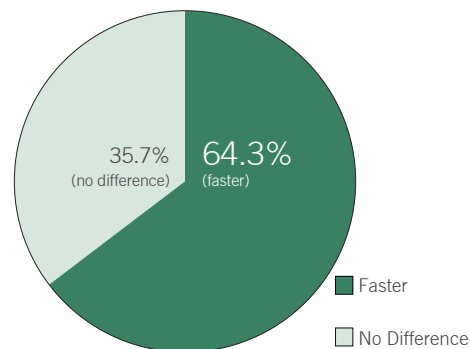
Project Name: UBC Earth Sciences Building
 Architecture by: Perkins+Will
 Photo credit: Martin Tessier

WHY TALL WOOD

Based on the feedback gathered from the construction teams, the following were identified as the most important reasons for pursuing a tall wood project:

- **Build a strong business case**
Proving a strong, profitable business case for mass timber construction was a key motivation for construction teams.
- **Increase capacity**
Gaining experience and developing industry capacity were indicated to be complimentary objectives for construction teams.
- **Innovation**
The desire to contribute to the potential for innovation in design and construction of mass timber buildings.
- **Sustainable Construction Material**
Expanding the market for a sustainable construction material with a low carbon footprint.
- **Compliance**
In some instances, supporting a local government policy to encourage timber or renewable resources in new construction was a strong motivation for constructing with mass timber.

How did using structural wood impact the construction schedule compared to a conventional project?



CONSTRUCTING TALL WOOD

Stakeholders were asked to summarize the construction process and identify special or unique aspects, different from a conventional project. Based on the participants' experience, the following are key items to consider when constructing a tall wood building:

- **Collaborate early**
Most participants stressed the importance of early collaboration with the design team, Authority Having Jurisdiction, and sub-trades. Such collaboration ensured that the construction team and fabricators contribute to the design process to support the best execution during construction. In several cases, fabricators contributed significantly to the design process, supporting architectural and structural teams with very specialized material and process specific engineering.
- **Resolve details at design phase**
The majority of participants emphasized the importance of resolving details during the design process to ensure accurate and precise prefabrication of elements. For example, resolving interfaces between different materials, considering systems, and connections between elements. This early effort led to a more efficient and faster construction process with fewer on-site changes that are often difficult and costly.
- **Logistics**
Most participants stressed the importance of considering the construction plan in parallel with the design process in order to coordinate material deliveries, resolve issues with limited staging areas on tight urban sites, reduce changes during construction and ensure appropriate sequencing of trades to minimize damage to installed materials. Careful early planning led to, in most cases, a reduction in the overall construction schedule.

- **Define trades scope and engage early**

Carefully consider and define scope requirements for trades to ensure accurate pricing. Engage skilled trades early to confirm logistics of the construction schedule, and identify any variation in scopes of work that may arise in the context of a mass timber project. Some participants acknowledged a lack of clarity or gaps within various trades' scope which led to overpricing of work. In some instances, expert timber erectors were engaged to provide expertise, complement the construction team, and facilitate a smoother and efficient construction process. In other instances, the contractor provided training to trades to assist with growing industry capacity.

- **Access expertise**

Eight of the ten projects are located in Europe, where experience and market capacity is further advanced across all stakeholder groups. In less developed markets, project participants noted that accessing experienced timber erection expertise was paramount. In the case of Forté, the construction manager and foreman spent time in the UK to work on building sites using CLT prior to commencing work. The erection crew was also formed under the direction of an experienced site supervisor from the UK who spent time on-site for the initial weeks of construction. In the case of the Earth Sciences Building, a specialized timber erection crew with experience in log structure construction was engaged to work in parallel with the more inexperienced installation crew.

CONSTRUCTION SOLUTIONS

Construction solutions related to known knowledge gaps or perceived challenges of constructing tall wood buildings were explored with all ten project teams. Although, most construction teams had some experience with constructing mass timber buildings or supplemented their teams with a wood expert, each building was unique and resolved on-site construction issues slightly differently. The following experiences include:



Structure

Experience with structure varied across all projects, however all teams identified that careful attention was given to connection details particularly in instances where the wood structure was connected with concrete structural elements. Variation in tolerances between materials was identified by all teams as a challenge of assembly.

Some construction teams indicated that prefabricated timber components maximized the opportunity to realize gains in the construction schedule. In projects where concrete elements were combined with mass timber, all participants they would avoid cast-in-place concrete if all possible; precast eliminates time required for curing, accelerating the construction schedule, and maintains a clean and dry site.



Installation of precast concrete element at 3XGRÜN
Photo credit: Rozynski Sturm Architekten



Fire Protection

In several instances, construction teams were key to resolving fire protection. Early engagement with the fire authority along with on-site construction consultation to inspect progress and resolve any fire protection issues during construction resulted in a successful project outcomes. In the case of Limnologen, collaboration on-site with the Authority actually led to a simplified approach for the last two buildings constructed in the complex.

In the unique case of Tamedia, executing the fire protection strategy was particularly onerous and costly to execute. Where timber elements penetrate fire rated glazing, timber is notched and layered with gypsum to create a non-combustible barrier, then covered with wood veneer to maintain the aesthetic quality of the timber. Survey participants reported that executing this detail was exceptionally time consuming.



Notched interface conceals non-combustible barriers on timber beams at Tamedia. Architecture by: Shigeru Ban
Photo credit: R. Holt



Moisture Protection + Durability

Weather protection strategies varied across all projects, and was largely dependent on whether the timber structure was to be exposed or concealed. Applied strategies represent both extremes of the spectrum from a full, permanent tent structure during construction to no protection at all, confirming opinions on the need for weather protection are not aligned across the industry. Regardless of strategy, all participants of projects where timber was to be exposed emphasized that completely avoiding staining during construction is unrealistic. In the case of the Earth Sciences Building, participants communicated that when removing stains on fully finished wood components in the field, it is very difficult to match colour and finish quality. The team recommended installing unfinished or lightly finished wood and applying final coatings at the end of construction.



Weather protection at Limnologen. Moveable rising tent structure. Photo credit: Johan Vessby



Systems Integration

In all cases, construction teams emphasized the importance of detailed planning to ensure smooth integration of systems. In cases where wood elements were exposed, systems were more challenging to conceal (ESB). In most of the residential projects, systems were identified as generally easy to incorporate, particularly at Forté, where penetrations for plumbing were cut in CLT at the factory, and prefabricated bathroom pods were installed as complete, modular components, contributing greatly to a shorter construction period.

Survey participants for the Limnologen project indicated that where grooves for the in-floor hydronic heating system were cut in the timber panels after installation, it greatly slowed construction progress. Similarly, Tamedia reported exceptional on-site effort to cut 3,500 penetrations for systems.



Installation of prefabricated bathroom pod at Forté. Photo credit: Lend Lease

3.0 PROJECT INSURANCE

Survey participants in all stakeholder categories were asked to provide details on various aspects of their insurance policies to examine how insurance-related issues may impact the design of, the approval process for and indirect project costs of a tall wood project. Participants were asked to describe their regular insurance policies related to professional practice and identify any differences in policy coverage or premium cost to cover work associated with tall wood construction. See Table 2 for a summary of insurance policy changes by stakeholder group.

Table 2: Summary of Insurance Policy Changes by Stakeholder group

PROJECT NAME	OWNER/ DEVELOPER	DESIGN TEAM	CONSTRUCTION TEAM	AHJ
E3	No Change	No Change	No Change	No Change
Limnologen	No Change	No Change	No Change	No Change
Bridport House	No Change	No Change. Professional Indemnity for design activities	No Change. Required to advise insurer of timber frame construction, no premium or policy change	No Change
3XGRÜN	No Change	No Change	No Change	No Change
Holz8 (H8)	No Change	No Change	No Change	No Change
Forté	No Change. Construction Works (during construction), Professional Indemnity, Public Liability, Employee Insurance and Body Corporate Insurance (insurance of the building on completion)	No Change. Public Liability and Professional Indemnity	No Change	No Change
Earth Sciences Building	Yes (required). Course of Construction insurance premium (see above)	No Change	No Change	No Change
LifeCycle Tower ONE (LCT ONE)	No Change	No Change	No Change	No Change
Tamedia	Yes (required). Owner carried builder-owner third-party liability insurance and contractors' all risks insurance (see above)	Yes (Voluntary). Executing architect/ planner opted to separate policy from blanket coverage (see above)	No Change	No Change
Cenni di Cambiamento	No Change	No Change	No Change	No Change

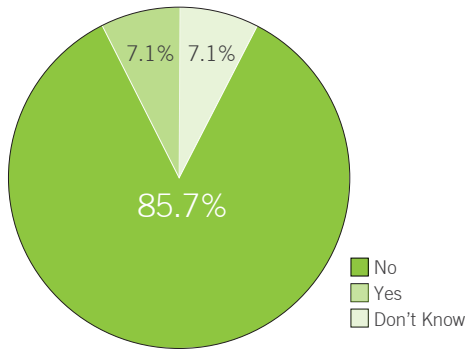
The majority of participants were not able to elaborate on the specifics of policy coverage, but were able to confirm that no additional insurance or modifications to existing policies were required as a result of pursuing design or construction work on a tall wood building. Only one stakeholder (Bridport House Construction Team) advised that they were required to inform the insurer of timber construction, although the policy premium was not increased.

Three stakeholders identified unique situations:

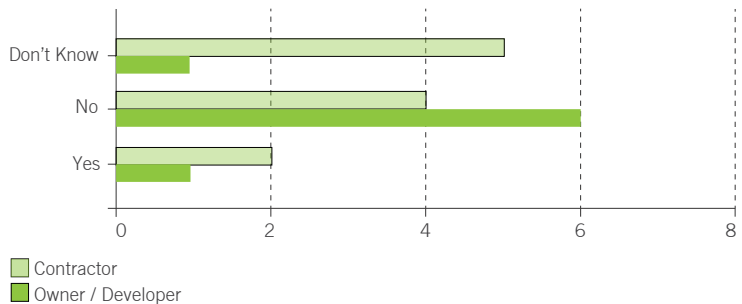
- The Course of Construction Insurance provider for the Earth Sciences Building required the Owner/Developer to carry the same policy as a light frame timber construction project, which represented a cost premium of 2.5 times more than the cost of the same insurance for a comparable concrete building. The perception of risk within the local insurance industry does not distinguish between mass timber construction and light frame timber construction.
- The Tamedia Owner carried Builder-Owner Third-Party Liability insurance and Contractors' All Risks insurance. The insurer charged higher premiums specifically due to the use of timber given their lack of experience judging risk with this type of construction. The premium was nominal.
- The executing architect for the Tamedia project elected to arrange a separate insurance policy for this project, separating it from blanket professional insurance carried by the firm. Feedback from the participant stakeholder emphasized that separating the policy was not related to the use of mass timber, but rather the risk associated with developing a prototype design and collaborating for the first time with an international design architect. The cost of the policy was approximately 25% more than separate coverage for a conventional building, but the cost of blanket coverage was reduced by separating this project which brought the average cost of the policy down for all the projects covered.

Project Insurance: Online Questionnaire Participant Responses

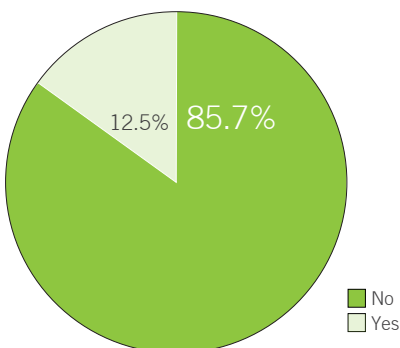
Design Team: Were you required to inform your insurance company that you were undertaking the work on an innovative project with a wood solution?



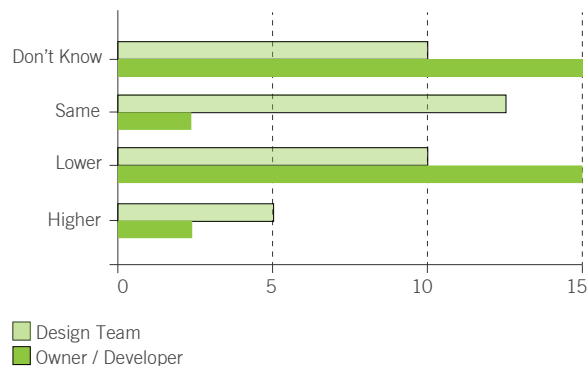
Was the required insurance coverage different from a conventional project?



Owner: Did the project face any barriers or challenges obtaining project insurance?



Were insurance premiums higher, lower or the same as a conventional project?



4.0 PROJECT FINANCING

Project financing questions were included as part of the Survey to determine if mass timber construction affected financing options or opportunities. Participants were asked to comment on how their project was financed, whether the process was different from other projects, if any limitations or premiums were placed on financing or if any advantages or incentives were accessed. Information was gathered as part of the online questionnaire and in-person interviews from the project owners or developers, and from design team members where applicable.

In all cases, within the context of each project's jurisdiction, no participants reported that any unusual financing protocols were required and no project experienced any challenges obtaining financing attributable to the use of mass timber. The most common method was self-financing, and some projects did access additional funding through incentive programs. A tabular summary is provided below in Table 3:

Table 3: Financing Summary

PROJECT NAME	FINANCING METHOD	ADDITIONAL FUNDING
E3	Traditional lending through Builder-Owner Collective	
Limnologen	2 buildings: Self-financed by the developer 2 buildings: Traditional bank lending	None.
Bridport House	Homes and Community Agency (National Government)	None.
3XGRÜN	Traditional lending through Builder-Owner Collective	
Holz8 (H8)	Self-financed by the developer	€120,000 incentive from German Federal Environment Program during planning phase
Forté	Self-financed by the developer	None.
Earth Sciences Building	Self-financed by the University of British Columbia	Canada Wood Council / NRCan Wood First incentive of \$750,000 CAD.
LifeCycle Tower ONE (LCT ONE)	Self-financed by the developer	Received public funding for general innovation
Tamedia	Self-financed by the owner	None.
Cenni di Cambiamento	Government funded through government managed real estate investment fund (pension fund)	None.

There appears to be a relationship between self-financed projects and those approached as prototypes or pilot projects. Feedback from project developers for Limnologen, Holz8 (H8), Forté and LCT ONE clearly indicated that financing was approached as an investment in future development; these projects were undertaken to test design, systems, materials, process, performance and market uptake. Participants described the financial risk of a prototype approach to be within acceptable range given the perceived impact a successful built example of mass timber construction could have on the market.

Incentive funding was accessed by three Survey participants. In the case of the Earth Sciences Building, these additional funds were critical to the successful implementation of the solid wood design solution. A sum of \$750,000 CAD funded fire modeling and alternative solution documentation, engineering, acoustic and vibration testing, in addition to augmenting project contingency. Both owner representatives and design team members described the acquisition of these additional funds as the critical factor in the decision to pursue a mass timber solution. In the case of Holz8 (H8), a €120,000 (~\$180,000 CAD) incentive was accessed by the design team on behalf of the developer, from the German Federal Environment Program. While the sum contributed to offsetting some project costs, the design team indicated that the effort associated with preparing the documentation to apply for the funds was particularly onerous, reducing the significance and impact of the award. For Holz8 (H8), the additional funding opportunity did not play an important role in the project.

Builder-Owner Collective arrangements were established for both E3 and 3XGRÜN, a relatively common arrangement in Germany for residential development. Feedback from Survey participants for both projects indicate that Builder-Owner Collectives can easily obtain financing through traditional lending because lenders perceive buildings developed through this process to be more durable, actively maintained, and therefore retain high value. However, feedback from E3 indicated that property valuation on mass timber buildings is lower than comparable non-timber buildings in the jurisdiction by about 20% due to the perception in the marketplace that mass timber is less durable and carries a higher risk of fire.



Project Name: Forté
Photo credit: Lend Lease
Architecture by: Lend Lease

5.0 BUILDING PERFORMANCE

The Survey gathered information from project participants about building performance and operations in order to identify any unique issues, benefits or challenges of operating a tall mass timber building that arise after occupancy. Participants were asked to comment on building systems, any monitoring devices or programs in place, occupant concerns, operation costs, as well any positive or negative experiences with regular maintenance as compared to a building with a conventional structure.

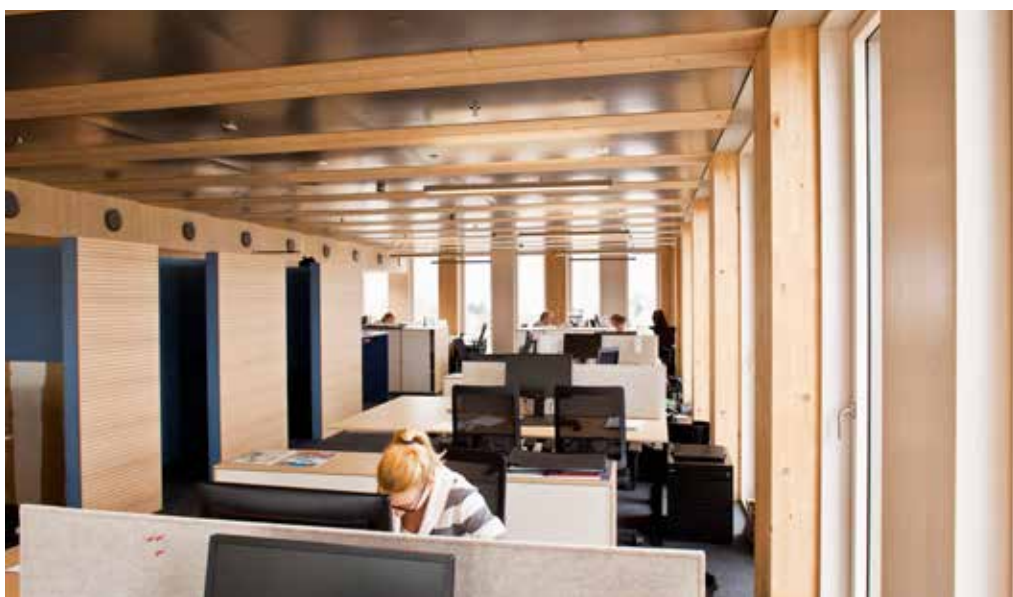
Participants available to speak to operational aspects of the projects were limited in part by availability, as well as by the age of the buildings. The majority of projects have only recently been occupied and as such, operational experience and actual performance data is limited for most. Information was gathered as part of the online questionnaire and in-person interviews from the project owners or developers, and from design team members where applicable. In two cases, interviewers spoke to individual residential tenants, however, no participant specifically responsible for maintenance was available to contribute.

PERFORMANCE IN TALL WOOD

The information gathered from participants focused mainly on aspects of building performance rather than maintenance. For the purposes of this report building performance refers to building energy and water efficiency, ventilation and humidity control, air quality, as well as occupant satisfaction. It is important to note that good performance results from considering and implementing a range of complimentary and interdependent strategies and systems that respond to local climate and context, rather than one single mechanical, electrical or architectural system. Participant comments refer to issues of performance that they believe relate to the use of timber for the building structure.

Survey responses emphasized three performance issues more strongly than any other and include:

- 1) the benefits of mass timber for an efficient envelope;
- 2) the importance of occupant education in a mass timber structure; and
- 3) the high level of satisfaction and well-being reported by occupants.



Project Name: LCT ONE
 Architecture by: Hermann Kaufmann ZT GmbH
 Photo credit: www.creebuildings.com

Other common issues of performance raised include thermal comfort and ventilation. The following section summarizes the details of these common themes, and provides relevant project examples to best contextualize trends and unique scenarios.

- **Envelope**

In all cases, participants indicated that mass timber was perceived as a beneficial material to support a high performing envelope. As a poor conductor of heat, it minimizes thermal bridging, improving the effectiveness of the insulation compared to many conventional envelope assemblies.

In several instances participants identified the complementary advantage of achieving good airtightness owing to the precise cut and fit of prefabricated elements. These advantages were emphasized most by participants of buildings with panelized timber structures, where there are fewer joints, gaps and penetrations that require sealing as compared to other systems (3XGRÜN, Cenni di cambiamento, Bridport House, Limnologen).

In the case of Tamedia where the mass timber post and beam structure is within a glazed envelope, achieving the code required air tightness and energy performance was identified as particularly challenging.

In addition, Cenni di Cambiamento reports temperatures within the comfort range on hot summer days without operation of the mechanical system, confirming a thermally efficient envelope. Moreover, a cost analysis confirmed that while the project cost was 3-5% more expensive to build than a concrete building, the efficient envelope minimizes heating and cooling loads to result in an operational payback period of only eight years.

- **Occupant Education**

In all cases, participants emphasized occupant education as an essential part of a robust maintenance plan that supports the best building performance. In several residential projects cases, training sessions for tenants and new owners were provided on how to effectively and efficiently operate their space. Participants reported this as a very effective strategy not only to facilitate efficient use of building systems, but also to foster appreciation for the unique aspects of the space among tenants, and encourage a community of care-takers.



Project Name: 3XGRÜN
 Architecture by: Atelier PK,
 Roedig Schop Architekten and Rozynski Sturm
 Photo credit: Stefan Mueller

- **Quality of Space and Occupant Satisfaction**

In all cases, participants reported high levels of occupant satisfaction, based in most cases on anecdotal feedback from residents or tenants. In the two cases where interviewers spoke to building occupants, feedback was overwhelmingly positive concerning thermal comfort, utility costs and their general feeling of well-being in the space. At Limnologen, only one noise complaint has been received in a complex of over 130 suites since the buildings were occupied.

- **Thermal Comfort**

In several residential cases, participants indicated that spaces were very thermally balanced. The 3XGRÜN building reports that suites that are part of the concrete structure on the main floor experience slightly cooler temperatures in the summer time given the added mass from the concrete, however the suites above within the timber structure are still very comfortable and balanced.

Cenni di Cambiamento reports that measurements conducted in the month of August, after project completion and before occupancy, indicated a comfortable indoor temperature of 24 degrees Celsius in suites with southern exposure, despite an outside temperature of 32 degrees Celsius.

- **Ventilation**

To avoid any impacts of humidity in residential projects, several participants indicated that at least some humidity control through mechanical ventilation is prudent, rather than to rely completely on natural ventilation operated by occupants.



Project Name: Forté
Architecture by: Lend Lease
Photo credit: Lend Lease

As part of the Survey, participants were asked to elaborate on any systems or strategies included in the projects to enhance building performance. Information made available was not consistent for all projects, but in all cases buildings surveyed shared the complementary goals of optimizing energy performance and creating high quality spaces for occupants. The basic strategy of maximizing passive systems (efficient envelope, daylighting, natural ventilation) to minimize the requirement for active systems was common to almost all projects. Several projects noted design strategies were based on Passive House concepts, although only LCT ONE is attempting official certification.

For additional context, summaries of advanced systems details made available as part of the Survey are presented here for each relevant project:

- LCT ONE incorporates a range of advanced systems and monitors performance extensively, reflecting the prototype approach, and goal to test a wide range of technology and strategies and share experience and outcomes. LCT ONE is connected to a wood-waste fueled biomass district heating system, the building includes a photovoltaic array, heat recovery on ventilation systems, CO₂ sensors, LED lighting technology, occupancy sensors on lighting, and an intelligent building monitoring system.
- 3XGRÜN intentionally limited the application of advanced technology in the initial design in order to maintain the project budget; however, the team thoughtfully planned for future installation of systems where beneficial. The building is heated by a very efficient on-site biomass system, fueled by wood waste, and was designed to accommodate future photovoltaic panels on the roof to supply the majority of the building's electrical demand. Finally, to limit the cost of discharging stormwater to the municipal system, a portion of the roof includes a green roof system. The building is not currently monitoring performance, but plans to implement a monitoring program in the coming year.
- Cenni di cambiamento advanced systems include grey water reuse for water closets and garden irrigation, heat recovery on domestic hot water and continuous ventilation with air pollution filtration deliver high quality air to each suite.
- E3 is connected to a district heating system and includes rainwater collection for irrigation and photovoltaic panels to offset electrical demand.



Project Name: Cenni di cambiamento
 Architecture by: ROSSIPRODI ASSOCIATI srl
 Photo credit: Riccardo Ronchi

MONITORING TALL WOOD

Survey participants were requested to describe any building performance monitoring programs in place for their projects. No consistent method of performance measurement or monitoring exists across the projects, and only two buildings report comprehensive post construction building performance monitoring programs:

LCT ONE plans to implement an extensive measurement and verification program, and to share data as part of the LifeCycle Hub

<http://www.lifecyclehub.com/>.

Forté: Moisture sensors are located within the CLT panels to monitor façade performance.

Limnologen: As part of the strong research partnerships established at the project outset, extensive research on structural systems, timber performance, energy and lifecycle analysis has been conducted and published for Limnologen. Completed studies can be accessed here:

<http://www.cbbt.se/website3/1.0.3.0/31/FULLTEXT01.pdf>

Ongoing monitoring includes energy performance, and Survey Participants report results of 50 kWh/m², close to Passive House performance and significantly better than the design goal to meet a target of 80 kWh/m². Limnologen is also monitoring humidity in the structure to determine if any moisture penetrates the envelope and if it affects long term durability of the timber structure. Approximately 25 sensors are located behind wall insulation on the surface of CLT panels, and around weak points such as window penetrations.



LCT ONE Lifecycle Hub
 Architecture by: Hermann Kaufmann ZT GmbH
 Photo credit: www.creebuildings.com

6.0 CONCLUSION

This industry scan of ten international tall wood buildings demonstrates mass timber as a successful and emerging construction method. It can be concluded that all stakeholders involved in these projects, regardless of geographic region, are early adopters motivated by common goals of market leadership, innovation, carbon reduction, and improved building performance. Results also suggest where strong governing policies exist, particularly in Europe, that support low carbon construction, energy efficiency, or renewable resources the market for mass timber is developing more rapidly than in North America.

Although design and construction solutions are still evolving, there is a clear trend across the projects that design and construction teams, local authorities, and in some cases fabricators, are working collaboratively and early during the design process to plan complex details prior to construction, and resolve issues such as fire protection and acoustic performance. As a result of this early collaborative process, the majority of projects confirmed that they experienced overall construction schedule savings.

The majority of participants confirmed that no additional insurance or modifications to existing policies were required as a result of pursuing design or construction work on a tall wood building. Similarly, in all cases no unusual financing protocols were followed, and no project experienced any challenges obtaining financing attributable to tall wood projects. Finally, in all cases, participants reported they managed to overcome any design or construction obstacles without exceeding the project budget.

In summary, the results of the Survey reveal the experiences and leadership of a select number of stakeholders who are committed to building capacity, credibility and market acceptance in this emerging industry. Overall, the results confirm that a cost equivalent, high performing building with a timber structure is a viable option.



Project Name: E3
Architecture by: Kaden Klingbeil
Photo credit: Bernd Boracht