EMERGING BUILDING SYSTEMS

AND WOOD INNOVATION

Solving technical and regulatory challenges and encouraging industry collaboration

March 31st, 2019

Executive summary

There is emerging interest in innovative wood systems supported by modern design and construction processes as a means to deliver efficient, affordable and sustainable buildings. The opportunities for British Columbia's architecture, engineering, construction (AEC) and wood product manufacturing sectors that arise from being a leader in low carbon wood buildings could be significant. To nurture that leadership requires the prompt resolution of technical and regulatory issues that arise from engaging with new technologies and processes. It requires an understanding of how information grows and what it takes for leading professionals to share what they know.

Background and objectives

The timing of this project is significant. The global market for green infrastructure is in the trillions of dollars and roughly 20 per cent of global GHGs are from buildings with a further 20 per cent estimated to be embodied in construction materials.[1] New wood solutions – such as mass timber – and the technologies that are being developed to deploy them (virtual design and construction tools, etc.) have the potential to disrupt the way buildings are designed and constructed. Innovations in wood are driving the transformation of British Columbia's building industry as a whole both technologically and procedurally. It is changing the way buildings are designed, fabricated and assembled which, in turn, is opening up opportunities to modernize regulatory processes.

It is hard to overstate the importance of construction to British Columbia's economy. As a $16.5 billion industry, construction provides 8 per cent of the province's GDP and employs more than 230,000 workers, making construction British Columbia's largest employer. A vibrant R&D ecosystem is essential for improving project performance, industry productivity and competitiveness, and for growing a culture of wood. British Columbia leads the country in the adoption of green and energy efficient building design, construction and associated technologies. It is the first province in Canada to chart a course towards Net Zero Energy buildings (by 2032).[2] There is currently more square footage of certified Passive House buildings in British Columbia than in the rest of Canada combined.[3] The City of Vancouver is the first (and still only) jurisdiction in North America to require reporting for embodied carbon in buildings: a step that forces designers to consider the environmental impacts of construction materials and thereby places British Columbia's wood products at an advantage.

However, this leadership position is built upon a small group of experts and the mainstream construction industry has yet to fully engage with the British Columbia's world class wood design capabilities.[4] AEC companies largely learn "on the job" - new products and new ways of doing things are introduced, developed and refined on a project by project basis. Considering the scale of industry transformation represented by these advances, there is a need for more investment in innovation and better innovation deployment systems.[5]

Given these constraints, this project explores the viability and merits of establishing a peer-to-peer collaborative process to efficiently expedite knowledge sharing between innovation leaders for broader dissemination across industry. The objectives of this study are to develop:

- A selection of accepted code compliant best practice solutions (details, spec language, etc.), with some of the most pressing issues addressed,
- Identify solutions that require further research/testing,
- A summary of regulatory pathways to resolution, and
- A list of industry specialists.

Approach

The project was organized into three phases:

Phase 1: Research (October 2017 - February 2018)

An in-depth review of publicly available reports, studies and websites was undertaken to provide context for the project, select target building typologies, document general trends in innovation management, and identify and assess barriers and opportunities to innovative wood buildings. Technical and regulatory issues were identified and then further refined and validated based on interviews with 20 innovators, building industry leaders, researchers and policymakers.

Phase 2: Workshop of experts (April 17, 2018)

A one-day “experts’ workshop” was held at the Vancouver Regional Construction Association (VRCA) that brought together 24 of British Columbia’s leading authorities in wood design and construction, regulation and research from a variety of disciplines including: architects, structural engineers, building code consultants, building envelope consultants, construction contractors and R&D. Preparation for this workshop was extensive and involved the development of four “almost real” case study projects that captured the technical and regulatory issues identified in Phase 1.

The hands-on workshop format was devised as a means to offer a practical yet engaging experience for industry leaders to resolve and validate solutions afforded by emerging building systems and wood innovation that may be applicable to the broad construction industry. The workshop allowed insights to be gathered into the concept of establishing a "faculty" of experts. The faculty is respected by mainstream industry and could be retained on an ongoing basis to review and, where necessary, develop information prior to sharing publicly.

The workshop was fully documented with note takers at each of the four tables. To encourage free and frank discussion, the workshop was conducted under Chatham House Rules.

At the start of the workshop, each project case study team was provided with the following information:

1. **Project scenario -** the project brief that sets out:

a. A brief statement of owner's requirements, the building location and assumptions
b. the building zoning requirements including setbacks, height limitations etc., and the energy performance objectives for the building
c. Any key design assumptions to help expedite the workshop process

2. **Schematic drawings** - baseline package as provided to the participants are provided in Appendix C.1 (reduced; originals were provided in full-size drawing sets)
3. **A checklist of key project considerations** - intended to help groups to identify and prioritize design strategies and construction details, and remind participants details must be:
    a. **Transferable:** Solutions should be reproducible by most practitioners, in as many jurisdictions as reasonably possible.
    b. **Efficient:** Solutions should be realistic in their use of materials, labour and expertise.
    c. **Affordable:** Solutions should be aware of the budgetary constraints of typical owners.

The decision to develop four case studies was made based on the number of available workshop participants and the desire to keep the workshop sufficiently intimate that participants would be aware of developments at other tables - something that was to be encouraged. At the same time, challenges were designed to be manageable issues that can be solved on the day. The objective of the workshop was to bring forward a package of solutions that industry experts may consider as no-brainers or short-term solutions but that may not have permeated mainstream industry.

Phase 3: Development of solutions (May – July 2018)

The solutions developed at the workshop were worked up into diagrams, drawings and models, and then shared with the workshop participants for their review and comment.

Phase 1 results: Research

Industry leaders identified a number of contextual and practical considerations when seeking to implement new solutions. These are organized into four high level topics: concept and context, system selection, optimization and details. These themes are highly nuanced with strong inter-relationships. However, they resonated with practitioners as a way to articulate innovation opportunities in the early ideation phase, within the design process, and/or during construction.

1. Concept and context

Contextual issues can either support or constrain innovative concepts. These include entrenched industry practices, the regulatory constraints and market influences (awareness, cost, etc.), all of which can influence the environment in which AEC firms operate.

1. **Industry norms:** Key barriers that stand in the way of market adoption of new ideas include the complex and fragmented nature of the building industry and the large number of different,

siloed stakeholders (insurers, finance, etc.), information asymmetry resulting in risk variability across stakeholders, diffusion failure because knowledge is concentrated within a few experts and difficult to find, and fee structures that do not support learning, education and innovation development.

2. **Authorities having jurisdiction:** Local, provincial and federal authorities having jurisdiction (AHJs) regulate the industry in the interest of public safety. Authorities take a broad view of public safety, often far beyond the scope of industry. Key considerations and constraints are what is permissible under the Building Code, the effectiveness and efficiency of approval pathways and the degree to which innovative regulatory solutions are transferable or repeatable.
3. **Market influences:** There are two sides to market influences: internal (i.e. how businesses are setup and their capacity to invest in education, equipment and R&D, or the ability to future-proof for possible changes in the future) and external (i.e. owners' and public expectations), that must be addressed to encourage adoption of innovative wood technologies and practices.

2. System selection

This report focuses on technical or regulatory, but other factors affect system selection by influencing owners and other project stakeholders. From a technical perspective, almost all of the interviewees stated that a project's structural and envelope systems are selected based on using the "best material for best use", regardless of peripheral environmental, economic or social benefits that a particular material might provide. This choice is affected by the building typology and requirements, the awareness and education of the owner and project team and market forces (product availability and cost).

1. **Building typologies and requirements:** The target building typologies were confirmed as mid and high-rise residential and non-residential buildings. The following were identified as warranting further investigation:
    a. A mass timber structure over 6 storeys (Metro Vancouver, ubiquitous with market apartments).
    b. Hybrid, mid-rise Passive House certified residential building.
    c. A high ceiling, long span commercial structure (e.g. ground floor retail with offices over).
    d. A high-quality urban office (clear spans, flexible programming, multi-tenant space, Class A rents).
    e. A building with a multi-storey feature atrium.
    f. Assembly uses on the top floor (e.g. a day care, restaurant, etc.).
    g. A non-market affordable housing project.
    h. An urban site adjacent to an existing building (zero lot line).
    i. A mid-rise building (up to 6 storeys) with an upper floor set back (a common zoning requirement).
2. **Market awareness and education:** The successful application of innovative wood technologies often lies with the building owners and building authorities - both of which can

veto the use of innovative wood. Information about the value, practicality and risks of wood must address these two groups' perspective and knowledge, to help manage perceptions of risk.

3. **Market forces (product / labour availability and pricing):** Currently, British Columbia is experiencing a highly inflationary and/or volatile market for construction materials, causing considerable pressure on pricing. For example, there may be insufficient capacity for CLT, yielding price and supply volatility, limiting its attractiveness compared to concrete for mid-rise buildings.

3. Optimization

Once the building systems have been selected, the next step is to optimize the design based on the building characteristics, and to refine the solutions in order to maximize efficiency and best value. It is at this stage that the design team will determine the type and degree to which emerging technologies might be used in the project. This can be challenging because the advantages offered by some of the most exciting innovations do not necessarily fit into existing accepted practices, design assumptions and/or construction methods.

- **Building characteristics:** While the possibilities and permutations are limitless, interviewees were asked to identify their top of mind challenges associated with the implementation of new mass-timber building solutions in a practice environment unfamiliar with the technology. Optimization challenges were categorized as follows:
    - **Building configuration:** optimization of planning and layout suitable for mass timber.
    - **Building envelope:** continuity, construction and build-up of envelope elements critical for optimizing building performance and durability.
    - **Structural design:** load transfer, shrinkage, seismic optimization, cores and connections
    - **BC Building Code:** building height (e.g. above 6 storeys), occupancy separation, fire resistance, acoustics, which can constrain what is possible in wood.
    - **Zoning and building policy:** For example, load transfers challenges due to setback requirements may make wood an inefficient choice.
- **Evolving practices and methods:** A major advantage of wood systems lies in the speed of construction and quality control that is made possible by off-site prefabrication of the structural components. To maximise these possibilities, project delivery must evolve beyond traditional methods such as design-bid-build.
- **Evolving building expectations:** Governments, communities and the general public understand the impacts of buildings as major consumers of natural resources, emitters of greenhouse gas emissions and generators of waste. In the face of rising material and labour costs, developers are increasingly aiming to differentiating their projects, forcing designers and builders to build faster, cheaper and greener.

4. Details

The majority of practitioners interviewed stated that developing the details of innovative solutions is the least worrisome - once all the issues relating to concept and context, system selection and optimization had been resolved. However, leading experts noted this may not be the case for all practitioners given anecdotal reports of difficulty with finding useful information. Experts believe almost any design challenge can be overcome by focusing on first principles and careful analysis, expressing confidence in the level of general architectural and engineering practice, and the ability of any practicing professional in good standing to arrive at a competent detail solution.

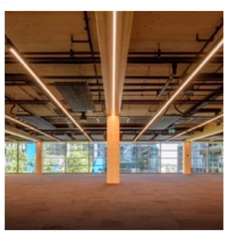
The professionals interviewed noted that they do utilise a wide range of technical resources and call knowledge leader peers for advice on innovative technologies and practices. Indeed, there was a general comment that the overwhelming amount of unfiltered information was often difficult and time consuming to deal with. There is no central innovation management platform where innovation for the building industry.

Phase 2 results: Workshop of experts

The issues identified from the research phase were incorporated into a series of "almost real" case study projects which formed the basis of a one-day workshop of experts. The workshop participants were organized into four multi-disciplinary groups, with each group tasked with identifying prioritising and developing reasonable, cost-effective, best practice approaches and solutions for the case study project. Each case study project was developed to schematic design stage (i.e. simplified floor plans, sections, etc.) and summarized below.

Case Study 1: Mixed-use residential in Vancouver

A six-storey mixed use building with ground floor commercial space, four storeys of residential apartments and a rooftop daycare. The challenges in this project were the need for a Passive House compliant fire rated exterior wall for a zero-lot line condition, thse fire separations between, and access to, the residential and daycare, and zoning setbacks at the fourth and fifth storeys.



Case Study 2: Multi-tenant office in Victoria

A four-storey, multi-tenant commercial office building arranged around an atrium, with a requirement for a high-performance curtain wall with maximum transparency.

Case Study 3: Seniors housing in Surrey

An eight-storey seniors' residence with common areas on the ground floor, and the possibility of future conversion to a care facility. The main challenges in this project related to the code implications of the proposed change of use, and the need for a shallow floor depth to comply with height restriction in the zoning bylaw.

Case Study 4: Commercial mixed use with supermarket in Vancouver

A four-storey commercial building with a supermarket on the ground floor and offices above. The main challenge in this project was the need to transfer loads from the smaller column grid of the upper floor offices to the larger grid required by the supermarket.

Technical and regulatory issues were identified and organized into a spectrum of innovation opportunities that range from what early adopters may consider are "no brainers" but have yet to find their way into the mainstream market all the way to long-term R&D prospects for academic researchers. The types of innovations generally fall into the following categories:

1. **No brainers:** These are typically solutions already used by innovators, which may need to be nominally adjusted before being broadly shared. From field-tested details that need only be compiled, to solutions that require expert confirmation (to existing codes and standards), these solutions require minimal or non-contentious updates and/or adjustments for most projects. For example, CLT balconies and elevator shafts, externally hung balconies and sunshades.
2. **Short-term solutions:** Solutions may exist, but they may be flawed, only partially resolved, or could be improved. Alternatively, solutions may be in effect in other locations but yet to be used successfully in the context of British Columbia. These may include CLT transfer slabs, NLT elevator cores, stair shafts, mechanical shafts, building envelopes, walls, roofs, and balconies.
3. **Medium-term solutions** in this case, technical or regulatory challenges are known but have yet to be solved. However, once identified, a solution may be developed and tested for application. Alternatively, it is possible that the faculty may collectively arrive at a solution, but it may be contentious and will likely require further research to determine a useable solution for British Columbia. For example, European case study projects[6] are being built out of all-wood walls (CLT structural panels, cellulose and wood fibre insulation, a wood cladding system) that meets fire code without chemical treatment.
4. **Long-term opportunities:** This is the "we don't know what we don't know" category. There are many unknowns that industry has simply not come across yet but may come to light during faculty work sessions on advanced case studies. These issues require substantial research or advances in material science, regulations, technology, etc.

Participants were asked to focus on addressing "no brainers" and "short-term solutions" in response to the hypothetical case study projects and to list any other issues for future investigation. The project teams collaborated on the development of a range of diagrams, models, technical and regulatory specifications and details. In some cases, the participants revised the overall design, layout and structural configuration of the case studies.

Phase 3 results: Development of solutions

Following the workshop, these outputs were organized into the four levels of innovation – concept and context, system selection, optimization and details – and refined and reviewed by Associated Engineering Ltd. to ensure that they represented best practices in leading edge wood design.

Conclusion and recommendations

The success of this first workshop was largely due to the participation of the practicing professionals: where they were given the opportunity to work with their peers to solve technical and regulatory challenges, as well as openly discuss broader issues, in a forum that will benefit all industry members. To normalize this feedback loop could mean making workshops available on a regular basis, where project teams can take issues to a faculty of vetted experts for peer support. Future participants might gain experience in innovation and the industry benefitting from the shared information, facilitating a culture of innovation that is responsive and ready for the future.

It is important to stress that encouraging leaders to collaborate to solve technical and regulatory challenges and to share their knowledge[7] should not be seen as a one-off exercise: innovation requires a sustained, formalized process for development and diffusion to work effectively. The following recommendations were derived from industry interviews and a one-hour facilitated discussion with workshop participants.

Objective	Recommendation
1. **Precedent for the workshop format**	Leverage government interest in advancing innovation in buildings to advance the concept of an innovation peer group or faculty of experts. To reassure users of the information that the data has been properly validated, a list of the faculty could be provided on the website where the solutions are published (although there would not be attribution to specific information).
2. **Position innovation as an investment, not an expense**	Building awareness of the value of corporate investments in innovation within the construction industry will be key to engaging more members of the mainstream industry. Incentives and/or financial support programs designed specifically for the construction industry may be necessary.
3. **Build a culture of information sharing**	Targeted information and support are needed to help businesses of all sizes understand the value of and participate in information sharing and collaboration.
4. **The workshop as a platform for collaboration**	The workshop was an effective means for leading practitioners to collaborate and share information. It is important to encourage knowledge sharing among practitioners, so long as by doing so, the author's competitive advantage or Intellectual Property rights are not infringed upon.

Objective	Recommendation
5. **Financial considerations**	There is value in repeating the workshop for another group of practitioners using much, if not all, of the existing materials.
6. **Organize information effectively**	For innovation diffusion to happen, information about new technical or regulatory solutions must be organized in a way that allows practitioners to engage with it in a timely way based on their experience and expertise.
7. **Open discussion environment**	Retain an experienced facilitator with subject matter expertise and ensure the note takers at each table are allowed to focus on documenting the work. Project owners and developers should participate at the workshop.
8. **Real projects**	Real projects as case studies, though difficult to secure, would provide the difficult constraints and challenging trade-offs that encourage innovative, practical solutions.
9. **Accelerate peer to peer learning**	Broaden the application of the workshop format to any practitioner willing to share information.
10. **Utilize Alternative Solutions**	While an Alternative Solution cannot be published and put to use in situations outside that which it was developed to address, a high-level list of Alternative Solutions that have been accepted in generic form, along with a mechanism for identifying common applications, could help both practitioners and policy makers address barriers to innovative design.
11. **Ensure access for small businesses**	When developing innovation resources, consideration should be given to the limited capacity of small businesses to invest in innovation. Published case studies should be balanced in their scope and present project challenges, so that real-life lessons can be learnt. Ensure that construction expertise is available during the workshop and as an integral element of a “faculty” of experts.
12. **Innovation organization**	An organized and curated innovation management platform could help to streamline and target the information flow to be of most use to practitioners.
13. **Develop a component catalogue**	Develop a library of standard, pre-fabricated components and assemblies.
14. **Assign responsibility for addressing innovation challenges**	Given that there is no organization that is mandated to advance innovation in construction in British Columbia, key provincial agencies (e.g. Building Safety and Standards Branch, BC Housing and Forestry Innovation Investment), NGOs and researchers may consider collaborating to address the challenges identified in this report.
15. **Consider mass timber assemblies in BC Building Code**	Develop and incorporate regulations for the design and construction of mass timber structures into the BC Building Code.

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Cover image: Annacis Research Centre, Delta, B.C. **Source:** Associated Engineering

Acknowledgements

The success of this project was only possible because of the availability of technical experts who were willing to get involved and share what they know. British Columbia is fortunate to be home to a closely-knit group of world-class architectural, engineering, construction and manufacturing innovators who bring together expertise in both energy efficient and wood design. Their help and guidance is greatly appreciated.

Interviewees

Name	Title	Organization
Stefan Aepli	Principal	Francl Architecture
Brad Badelt	Acting Assistant Director	City of Vancouver Sustainability Group
Michael Barton	Director of COHO Labs, Research Associate and Sessional Lecturer	UBC School of Architecture and Landscape Architecture
Jennifer Cover	Executive Director	WoodWorks - Wood Products Council (US)
James Emery	Partner	Iredale Architecture and Planning
Graham Finch	Principal	RDH Building Science Ltd
David Gill	Program and policy planner	UBC Community Development
Stephen Good	CEO	Construction Scotland Innovation Centre
Kevin Hanvey	Principal & Director of Architecture	Omicron
John Hemsworth	Partner	Hemsworth Architecture
Peter Hildebrand	Partner	Iredale Architecture and Planning
Rebecca Holt	Senior Sustainable Building Advisor, Associate	Perkins & Will
Jarrett Hutchinson	Director, Building Regulations	Building Safety & Standards Branch
Denisa Ionescu	Senior Manager, Technical Research and Education	BC Housing Research Centre
Steven Kuan	Manager, Building Systems	FPInnovations
Steve McFarlane	Partner	Office of McFarlane Biggar
Ernie Mishi	Supervisor, Plans & Permits	BOABC/City of Richmond
Grant Newfield	Principal	RJC Engineering
Leslie Peer	Principal	RJC Engineering
Dr. Angelique Pilon	Director, Urban Innovation Research	UBC Sustainability Initiative
Tom Plumb	CEO	Kinetic Construction
Dr. Sheryl Staub-French	Professor	UBC Department of Civil Engineering
Dr. James Tansey	Executive Director	Sauder Centre for Social Innovations and Impact Investing and University Sustainability Initiative, UBC

Workshop participants

Name	Title	Organization
Patrick Cuthbert	Associate	Aqua-coast Engineering Ltd.
Andrew Harmsworth	Partner	GHL Consultants Ltd, Building Codes & Fire Science

Name	Title	Organization
John Hemsworth	Principal	Hemsworth Architecture
Adam James	Principal	Ryder Architecture
Steven Kuan	Manager, Building Systems	FPInnovations
Robert Malczyk	Principal	Equilibrium Engineering
Sophie Mercier	Principal	Morrison Hershfield
Derek Newby	Associate Principal	Perkins & Will
Marie-Odile Marceau	Owner	McFarland Marceau Architects
Duane Palibroda	Principal	Fast & Epp
Don Pedde	Senior Codes Administrator	Building Safety & Standards Branch
Mark Porter	National Practice Leader – Buildings	Associated Engineering (B.C.) Ltd
Geoff Triggs	Principal and owner	Evolution Building Science
Paul Warwick	Senior Project Manager	Performance Construction
Doug Wilson	President	Peak Construction Group
Matthew Woodruff	Partner	Local Practice

Observers

Name	Title	Organization
Lynn Embury-Williams	Executive Director	Wood WORKS! BC
Sukh Johal	Technical Advisor, BC Mid-rise Technical Lead	Wood WORKS! BC
Dr. Angelique Pilon	Director, Urban Innovation Research	UBC Sustainability Initiative
Jim Taggart	Researcher, writer, instructor	BCIT
Antje Wahl	Manager, Research & Innovation	Forestry Innovation Investment Ltd.

Facilitation and note taking

Name	Title	Organization
Helen Goodland	Facilitator	Brantwood Consulting
Albert Lam	Note taker	Brantwood Consulting
Matthew Roche	Note taker	Associated Engineering (B.C.) Ltd.
Liva Vallencuka	Note taker	Associated Engineering (B.C.) Ltd.
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Contents

CHAPTER 1 Introduction

There is emerging interest in innovative wood systems supported by modern design and construction processes as a means to deliver efficient, affordable and sustainable buildings. The opportunities for British Columbia's architecture, engineering, construction (AEC) and wood product manufacturing sectors that arise from being a leader in low carbon wood buildings could be significant. To nurture that leadership requires the prompt resolution of technical and regulatory issues that arise from engaging with new technologies and processes and requires an understanding of what it takes for leading professionals to share what they know.

> "When you start looking for people to work on innovative wood projects, you quickly discover that there are really only 2 or 3 (general or trade) contractors, for example, capable of doing mass timber projects. This really constrains future mass timber projects and affects competitive pricing."
> **Design consultant**

> "We are not super-comfortable working with the framing trades as they do not comply with our H&S requirements. We have very strict processes which our trades have come to understand, and we do risk evaluations."
> **General contractor**

> "The time for deciding about whether to be innovative happens in pre-construction."
> **General contractor**

The timing of this project is significant. The global infrastructure market is estimated to be around $57 trillion by 2030[8] and roughly 20 per cent of global GHGs are from buildings with a further 20 per cent estimated to be embodied in construction materials.[9] New wood solutions – such as mass timber – and the technologies that are being developed to deploy them have the potential to be very disruptive. Innovations in wood are driving the transformation of British Columbia's building industry as a whole both technologically and procedurally. It is changing the way buildings are designed, fabricated and assembled which, in turn, is opening up opportunities to modernize regulatory processes.

It is hard to overstate the importance of construction to British Columbia's economy. As a $16.5 billion industry, construction provides 8 per cent of the province's GDP and employs more than 230,000 workers, making construction British Columbia's largest employer. British Columbia leads the country in the adoption of green and energy efficient building design, construction and associated technologies. It is the first province in Canada to chart a course towards Net Zero Energy buildings (by 2032).[10] There is currently more square footage of certified Passive House buildings in British Columbia than in the rest of Canada combined.[11] The City of Vancouver is the first (and still only) jurisdiction in North America to require reporting for embodied carbon in buildings: a step that forces designers to consider the environmental impacts of construction materials and thereby places British Columbia's wood products at an advantage.

However, this leadership position is built upon a small group of experts and the mainstream construction industry has yet to fully engage with the British Columbia's world class wood design capabilities.[12] Relatively little is invested in construction-related R&D. In 2013, British Columbia's building industry spent $7m on R&D[13] which is just 0.05 per cent of GDP. By comparison, Canada's manufacturing sector (which includes wood products) invests almost 100 times more.[14]

AEC companies largely learn "on the job" - new products and new ways of doing things are introduced, developed and refined on a project by project basis. Recognizing the scale of industry transformation represented by these advances, there is a need for a better understanding of how information grows, more investment in innovation and better innovation deployment systems.[15] Given these constraints, this project explores the viability and merits of establishing a peer-to-peer collaborative process to expedite knowledge sharing between industry leaders for broader dissemination across industry. Focussing on large format residential (mid- and high-rise multi-family) and non-residential buildings, the purpose is to identify and address some of the technical and regulatory challenges that are currently hampering the adoption of innovative wood technologies and practices. These challenges may be related to:

- **Building configuration:** so that the planning and structural layout is suitable for mass timber
- **Building envelope:** continuity, construction and build-up of envelop elements critical for optimizing building performance and durability.
- **Structural design:** load transfer, shrinkage, seismic optimization, cores and connections.
- **Building Code:** building height (e.g. above 6 storeys), occupancy separation, fire resistance, acoustics, which can limit what is possible in wood.
- **Zoning and building policy:** For example, load transfers challenges due to setback requirements.

Attached to this report is a suite of diagrams and details that represent current best practices in leading edge wood design that have been developed in collaboration with a number of British Columbia's leading experts. The project also uncovered some solutions that could work but require further research and testing. There is also a summary of the regulatory pathways to resolution and a list of local industry specialists.

1.1 Definition of innovation

For the purpose of this study, innovation has been defined as, "the successful adoption of new technologies and processes".[16] E.M. Rogers' Diffusion of Innovation (DOI) theory[17] explains how, why, and at what rate new ideas and technology spread, in several stages:

1. **Awareness of innovation:** First, a potential adopter must know of technology and procedural innovations and be able to identify gaps and opportunities for innovation in projects.
2. **Ability to innovate successfully:** Having identified both an opportunity to implement, as well as matched a possible innovation to it, the adopter must be equipped with information that allows them to implement, given their level of expertise and experience. (Note that based on our research, we have added an important dimension to this step: that the information must convince or persuade the adopter that the innovation is worth committing to).
3. **Communicating Innovation success/failure:** Feedback is important for perpetuating innovation. Success encourages practitioners and owners to adopt or demand innovation, while failure provides a means to improve innovations, or shelve negative ones. Both ensure that innovation progresses towards net positive outcomes.

1.2 Project methodology

We organized the project into three phases:

1.2.1 Phase 1: Research (October 2017 - February 2018)

An in-depth review of publicly available reports, studies and websites was undertaken to provide context for the project, select target building typologies, document general trends in innovation management, and identify and assess barriers and opportunities to innovative wood buildings. Technical and regulatory issues were identified and then further refined and validated based on interviews with 20 innovators, building industry leaders, researchers and policymakers.

1.2.2 Phase 2: Experts' Workshop (April 17, 2018)

A one-day "experts' workshop" was held at the Vancouver Regional Construction Association (VRCA) that brought together 24 of British Columbia's leading authorities in wood design and construction, regulation and research from a variety of disciplines including: architects, structural engineers, building code consultants, building envelope consultants, construction contractors and R&D. Preparation for this workshop was extensive and involved the development of four "almost real" case study projects that captured the technical and regulatory issues identified in Phase 1.

The hands-on workshop format was devised as a means to offer a practical yet engaging experience for industry leaders to resolve and validate solutions afforded by emerging building systems and wood innovation that may be applicable to the broad construction industry. The workshop allowed insights to be gathered into the concept of establishing a "faculty" of experts. The faculty is respected by mainstream industry and could be retained on an ongoing basis to review and, where necessary, develop information prior to sharing publicly. The workshop was fully documented with note takers at each of the four tables. To encourage free and frank discussion, the workshop was conducted under Chatham House Rules.

At the start of the workshop, each project case study team was provided with the following information:

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    a. **Transferable:** Solutions should be reproducible by most practitioners, in as many jurisdictions as reasonably possible.
    b. **Efficient:** Solutions should be realistic in their use of materials, labour and expertise.
    c. **Affordable:** Solutions should be aware of the budgetary constraints of typical owners.

The decision to develop four case studies was made based on the number of available workshop participants and the desire to keep the workshop sufficiently intimate that participants would be aware of developments at other tables - something that was to be encouraged. At the same time, challenges were designed to be manageable issues that can be solved on the day. The objective of the workshop was to bring forward a package of solutions that industry experts may consider as no-brainers or short-term solutions but that may not have permeated mainstream industry.

The workshop was fully documented with note takers at each of the four tables. To encourage free and frank discussion, the workshop was conducted under Chatham House Rules. Case study outputs were then organized into four broad, interrelated categories along with a summary of the participant discussions.

- **Concept and context**: encompass the professional's practice environment issues arising from the site, regulatory constraints (e.g. zoning bylaws), neighbourhood, market and building industry context.
- **System selection**: considerations that influence the building professional or owner's structural and envelope solutions. Based on "Best material for best use" principle considering constraints such as climate, economics or regulations, to name a few.
- **Optimization** of the design and construction approach: building layout and configuration, and the actual structural and/or envelope solutions that maximum efficiency and best value when utilizing innovative technologies and practices.
- **Details** relating to problematic situations both in terms of building performance and constructability, and how they can be overcome or broken down to be approachable in daily practice of design and construction.

Workshop participants were also asked to assess their ideas based on time to market for the proposed solutions. The complete framework with examples is presented in Appendix A.1.3.

1. **No brainers:** These are typically solutions already used by innovators, which may need to be nominally adjusted for flexibility before being broadly shared.
2. **Short-term solutions:** Solutions may exist, but they may be flawed, only partially resolved, or could be improved. Alternatively, solutions may be in effect in other locations but yet to be used successfully in the context of British Columbia.
3. **Medium-term solutions** in this case, technical or regulatory challenges are known but have yet to be solved. However, once identified, a solution may be developed and tested for application.
4. **Long-term opportunities:** There are many unknowns that industry has simply not come across yet but may come to light during faculty work sessions on advanced case studies. These issues require substantial advances in material science, regulations, technology, etc.

1.2.3 Phase 3: Development of solutions (May – July 2018)

Following the workshop, these outputs were organized into four levels of innovation – concept and context, system selection, optimization and details – and refined and reviewed by Associated Engineering Ltd. to ensure that they represent best practices in leading edge wood design. The solutions were shared with the workshop participants for their review and comment.

CHAPTER 2 Existing barriers and opportunities to innovative wood design

Innovation has been defined as "the successful introduction of new technologies and processes into the industry"[18]. The drivers of innovation in construction are most commonly related to improving performance in either the function or efficiency of the building and/or the processes required to complete it.

"We used to have trouble finding data. Today, we have too much data, and we don't have time to filter through everything."
Design consultant

""For economy, you want to revert back to prescriptive code solutions. That doesn't mean that you can't still have alternative solutions, but the reality is that on a day to day basis, structural engineers don't want to do performance-based analysis on every single project."
Engineer

"For every project. We try to find opportunities wherever they make sense. We are not fanatics but believe that exposed wood creates a unique character. This is a fundamental difference in approach to any other system where building systems can be covered up. Systems integration has to be carried through meticulously from start to finish."
Architect

British Columbia's AEC companies are collectively embarking on an industry-wide transformation. The pace of change within individual businesses varies with a few choosing to get a head start while most are being pushed by stagnating productivity and persistently low margins,[19] changing codes and rising labour and materials prices. There is also growing momentum around zero emissions or zero carbon buildings. Building with wood will be an integral part of a low-carbon future while offering the potential for companies to improve both productivity through off-site assembly and prefabrication and performance due to wood's thermal properties and low environmental impacts. These days, there is little discussion about why change is important, the focus is on how to get there while the industry is experiencing one of its busiest cycles in the last decade.

Barriers to innovation in the building industry are generally rooted in an information dissemination problem. Therefore, it is important to first understand how construction professionals prefer to learn about new solutions and the circumstances in which innovation can be incorporated onto a project. Because buildings are largely designed and put together as "bespoke" one-offs, there is a high degree of creative problem-solving applied on an ongoing basis. The amount of research and exploration applied to a project is therefore determined on a case by case basis and dictated by the owner. As a result, information sharing is team-based, ad hoc and motivated by the interests of individual practitioners. Innovators therefore have to pick their battles. This inefficiency is at the root of problem that AEC firms have with the adoption of innovation and it is further complicated by the fact that there are so many different stakeholders each of whom have their own information requirements.

R&D in the AEC industry is not seen as an investment that delivers a strategic benefit to a firm, but simply as a project expense.

It is in this light that the findings from our industry consultations need to be considered. A number of key contextual and practical considerations were identified by interviewees when they are seeking to implement new solutions. These have been organized into four high level topics – concept and context, system selection, optimization and details. These themes are highly nuanced with strong inter-relationships. However, they resonated with practitioners as a way to articulate innovation opportunities in the early ideation phase, within the design process, or during construction.

2.1 Concept and context

Contextual issues can either support or constrain innovative concepts. These include entrenched industry practices, the regulatory constraints and market influences, all of which can influence the environment in which AEC firms operate.

2.1.1 Industry norms

Key barriers that stand in the way of mainstream adoption of new ideas include:

- The complex and fragmented nature of the building industry and the large number of different, siloed stakeholders (insurers, finance, etc.),
- Information asymmetry resulting in risk variability across stakeholders,
- Innovation diffusion failure because knowledge is concentrated within a few experts and difficult to find, and
- Fee and compensation structures that do not support learning, education and innovation development.

The project-specific nature of innovation diffusion in the AEC industry favours short-term solutions and incremental improvements. However, the application of new technologies may need to be sustained over several iterations to achieve the most efficient and cost-effective solution, and some concepts need to be diffused into the market over timeframes that do not align with the pace of industry, based on needs such as R&D, product availability, regulatory development or market demand. Individual firms rarely have the resources to focus on the development and diffusion activities required for innovation to scale, limiting its benefit to industry or value to owners and the public. At the same time, the risk of failure can mean major consequences in the construction industry, deterring innovation.

2.1.2 Authorities having jurisdiction

Local, provincial and federal authorities having jurisdiction (AHJs) regulate the industry in the interest of public safety. Authorities take a broad view of public safety, often far beyond the scope of industry. Key considerations and constraints are:

- What is permissible under the Building Code,
- The effectiveness and efficiency of approval pathways, and
- The degree to which innovative regulatory solutions are transferable or repeatable.

International examples: dedicated innovation organizations

Construction Scotland's "Innovation Factory" Image source: www.cs-ic.org

In some jurisdictions, innovation is managed at the industry level, where R&D and technology diffusion is carried by dedicated organizations through organized information sharing and coordination. This fosters a culture of innovation by bearing some of the cost, time and effort commitment of innovation outside of the project domain, allowing AEC firms to approach new challenges and develop more profitable or value-driven ways to practice. An example is the Construction Scotland Innovation Centre, which is an industry-led intermediary charged with catalysing transformative solutions for Scotland's building industry.

2.1.2.1 Building Code and approval pathways

Building codes are conservative because they describe the minimum level of compliance for a wide range of jurisdictions, from cities with well-developed emergency infrastructure, to small communities with limited fire services. These regulations in turn impact innovation. For example, an innovative fire safety solution may work in an urban location that is well served with local fire stations, hydrants, etc. but may not be applicable in a remote location.

Amending restrictive building codes is understandably a slow process because they rightly rely on an exhaustive consultation process, testing and/or certification before any changes are approved. This suggests that alternative regulatory "pathways" may be required to enable innovative solutions to be introduced and refined before they are incorporated into the building code. These "pathways" allow for code variations but, currently, they can be time consuming and expensive without guarantee of success. A review of these pathways is presented in Appendix B.

2.1.2.2 Repeatable solutions

At present, alternative regulatory pathways are non-transferable between projects because there are many specific contextual variables (physical, legislative or logistical) unique to each site. Interviews with AHJs suggest that there are opportunities through the BC Building Act for policy "pathways" to support innovation. For example, Site-Specific Regulations allow a bespoke building code to be approved for a given legal lot but require extensive due diligence on the part of the consultant team. In the future, the Act could allow municipalities (or individuals based on their expertise) to do the same.

Repeatable solutions

From our consultation with industry, a frequently sought-after Alternative Solution is for a timber wall assembly with a two-hour fire resistance rated (FRR) separation. Such FRRs are increasingly in demand for Passive House certified projects, as wood construction is the most desirable to meet the thermal performance requirements of the Passive House standard.

2.1.3 Market influences

Market influences can inform the pace and scope of innovation adoption. Influences can be both internal and external to a company or project. Key points brought up during interviews and the workshop are presented in Appendix B.

- **Internal influences:** How businesses or projects are setup, and their capacity to invest in education, equipment and R&D, or the ability to future-proof for possible changes in the future. This is important because Canada's building industry is primarily comprised of small businesses which may not have the resources to fully engage with R&D.
- **External influences:** Owners develop projects based on functional needs and/or market expectations (e.g. what will lease or sell). Other influences include public attitudes, fiscal policies and the economy. These influences affect what is practical for Industry to pursue in terms of services, products and innovation.

2.2 System selection

This report focuses on technical or regulatory considerations but there are many factors that influence a project team's choice of structural and envelope systems.

Almost all of the interviewees stated that a project's structural and envelope systems are selected based on using the "best material for best use", regardless of peripheral environmental, economic or social benefits that a particular material might provide. Interviews highlighted three key considerations that affect this choice.

2.2.1 Building typologies and requirements

While highly specialized or unique institutional buildings are often the first to explore novel ideas, industry-wide innovation diffusion will happen more quickly if new technologies and practices are also directed into common building typologies, such as mid-rise residential projects. Also, the normalization of innovations is important to improve how commonly experienced problems are resolved, rather than "reinventing the wheel" every time. The following typologies and configurations were identified from interviews for potential inclusion in the workshop case studies:

- A mass timber structure over 6 storeys
- Hybrid, mid-rise Passive House certified residential building
- A high ceiling, long span commercial structure (e.g. ground floor retail with offices over)
- A high-quality office building (clear spans, flexible programming, multi-tenant space, Class A rents)
- A building with a multi-storey feature atrium
- Assembly uses on the top floor (e.g. a day care, restaurant, etc.)
- A non-market ("affordable") housing project
- An urban site adjacent to an existing building ("zero lot line")
- A mid-rise building (up to 6 storeys) with a upper floor set back (a common zoning requirement)

2.2.2 Industry awareness and education

> "I once heard someone say that construction moves forward by looking in the rear-view mirror, Chances are we won't see the disruption until it's suddenly everywhere. So, the companies that will have the most impact are not actually construction companies in the traditional sense, they will be tech firms or come suddenly out of left field."
> **Contractor**

The successful application of innovative wood technologies is often dependent upon the building owners and building authorities - both of which can either enable or veto the use of wood. Owners' expectations are often based upon past building examples and expectations that may not be suitable for innovative wood technology or practices. According to interviews and workshop discussions, information about the value, practicality and risks of wood must address these two groups' perspective and knowledge, to help manage perceptions of risk. For example, a common misconception is that mass timber is a direct substitute to concrete, or that common building forms (balconies, window-wall ratios, etc.) are unaffected by system choice.

2.2.3 Market forces: Uncertainty, availability and pricing

According to interviewees, British Columbia currently has insufficient capacity for CLT, resulting in price and supply volatility, and limiting its attractiveness compared to concrete for mid-rise buildings. Projects can sometimes be designed to tallow for alternatives, such as NLT (Figure 1), but this limits the benefits (e.g. NLT panels only span one way). Further, in "hot" markets where profitable work is abundant, such as Vancouver, there may be little incentive to innovate or adopt new wood technologies or practices.

Figure 1 Mass timber product alternatives

Product alternatives

Alternative products, such as NLT, DLT and GLT must be carried forward as options although none is a direct substitute for CLT, with additional accommodations and calculations are required. Both NLT and DLT are one way spanning panels, and CLT can span in both directions, so the need to plan for possible substitution does not necessarily result in the most efficient structural design. CLT from Europe has increasingly become a lower cost substitute for the local product, a situation may meet the objectives of a given project but does not serve the long-term interests of the BC forest industry. Solving the supply/demand conundrum is a crucial piece of the mainstreaming puzzle.

2.3 Optimization

Once the building systems have been selected in broad terms, the next step is to optimize the design based on the building characteristics, and to refine the structural and/or envelope solutions in order to maximize efficiency and best value.

It is at the optimization stage that the design team will determine the type of emerging technologies and practices they might use. This can be challenging because the advantages offered by some of the most exciting innovations do not necessarily fit into existing accepted practices, design assumptions and/or construction methods. Nevertheless, there is pressure on project teams to consider evolving practices that were developed in response to external factors such as increasingly stringent regulations, rising materials and labour costs, and evolving market expectations.

2.3.1 Building characteristics

Interviewees were asked to identify their “top of mind” challenges associated with the implementation of new mass-wood building solutions in a practice environment unfamiliar with the technology. Optimization challenges were categorized into five interdependent categories:

- **Building configuration:** optimization of planning and layout suitable for mass timber
- **Building envelope:** continuity, construction and build-up of envelope elements critical for optimizing building performance and durability
- **Structural design:** load transfer, shrinkage, seismic optimization, cores and connections
- **Building Code:** building height (e.g. above 6 storeys), occupancy separation, fire resistance, acoustics, which can constrain what is possible in wood
- **Zoning and building policy:** For example, load transfer challenges due to setback requirements, making wood an inefficient choice.

2.3.2 Evolving practices and methods

One of the potential advantages of building with wood lies in the speed of construction and quality control that is made possible by off-site prefabrication of the structural components. However, project delivery processes must evolve to maximize these benefits. Out-dated cultural norms are being exposed by mass timber adoption; with the ability of the building industry to evolve and adapt to market realities being stretched by innovations that are testing the limits of existing methods. Current project delivery methods work against mass timber’s advantages, making optimization difficult.

2.3.3 Evolving building expectations

There is no question that governments, communities and the general public clearly understand the impacts of buildings as major consumers of natural resources, emitters of greenhouse gas emissions and generators of waste. Governments, companies and housing developers are differentiating their new projects based on these factors, forcing owners, designers and builders to be more predisposed towards innovation to compete. In turn, these demands will necessitate a shift in expectations on the part of governments, communities and the public – something far more challenging for industry to support.

2.4 Details

Once the building design has been optimized, there remains all the problematic situations that arise as a result of building performance and constructability challenges that need to be overcome or broken down so that they can be resolved.

The majority of practitioners interviewed stated that once all the issues relating to concept and context, system selection and optimization had been resolved, then developing the details of innovative solutions is the least worrisome stage. However, leading experts noted this may not be the case for all practitioners given anecdotal reports of difficulty with finding useful information (see Appendix B). They believed that almost any design challenge can be overcome by focusing on first principles and careful analysis. They expressed confidence in the level of general architectural and engineering practice and the ability of any practicing professional in good standing to arrive at a competent detail solution.

Project delivery evolution

While mass wood possesses advantages, it can only be fully exploited through highly collaborative practices, such as integrated design and delivery processes, where consultants work together with the general contractor, specialist wood fabricator and installer during the design phase of the project. This arrangement runs counter to the traditional procurement methods used by both public and private sector owners.

This significant 'cultural shift' requires the entire project team to adopt a value-based (as opposed to lowest cost) approach to project delivery, introducing the idea of collective responsibility for the design of durable high-performance buildings. Procurement Issues related to the procurement are discussed in the 2017 "Procuring Innovation in Construction" report published by the BC Construction Association, available at www.bccassn.com.

2.4.1 Existing information resources

From the secondary research and the interviews, a wide range of online resources were identified by practitioners as potential resources for learning about innovative wood solutions. The types and levels of information are highly dependent on numerous factors such as the user's interests and level of risk tolerance, the building typology and the stage of the project (Figure 2).

Figure 2 Information use types and descriptions

Use Types	Description	Flexibility	Examples
Synthesis (First Principles)	Solution synthesis, high risk and uncertainty	Most	Inspirational case studies Scientific studies Policy and technical papers
Descriptive (Best Practices)	Solution selection, medium risk and uncertainty	Medium	Technical guides (Note that it is common for designers to refer to technical guides from outside Canada.) Indicative details
Prescriptive (Nuts and Bolts)	Solution implementation, least risk and most certain	Least	Calculators (e.g. CWC Wood Span Book), Formulae, Spec sheets "How to" videos

There is no single centralized information management platform for the Canadian AEC industry, and so practitioners generally find information from a wide array of sources.

> "We used to have trouble finding data. Today, we have too much data, and we don't have time to filter through everything."
> **Design consultant**

> "How do I find information today? Mostly, Google search for information gathering. So, we want more simple, clean and clear sources of information, that get straight to the point of practitioner's needs."
> **Building science engineer**

> "Informally, certain practitioners already meet over drinks to discuss technical and regulatory issues."
> **Authority Having Jurisdiction**

When asked to name websites that are top of mind, interviewees mentioned a selection of local and international web-based resources (listed in Appendix A.4.). In addition to those resources noted by interviewees, there are also several national agencies that support research related to buildings such as the National Research Council (NRC), which undertakes three areas of research in support of national policy interests – namely, for the Arctic, building regulations for market access and high-performance buildings. NRC also coordinates six centres of very targeted technical expertise that offer advisory services to industry.[20]

However, because there are so many information sources, inevitably there is overlap and duplication. Interviewees also noted that information is rarely presented in usable formats for building projects (e.g. too scientific, overly focused on marketing). As a result, many interviewees stated that they start with Google and then, if they are unable to quickly find what they need, they will call a local expert.

To scale up market adoption suggests that a systematic method of centralizing, validating and classifying information may be necessary. The workshop proposed in this project is intended to provide a starting point for this process.

CHAPTER 3 Workshop case studies

3.1 Case Study 1 – Mixed-use residential in Vancouver

A six-storey mixed use building with ground floor commercial space, four storeys of residential apartments and a rooftop daycare. The challenges in this project were the need for a Passive House compliant fire rated exterior wall for a zero-lot line condition, the fire separations between, and access to, the residential and daycares, and zoning setbacks at the fourth and fifth storeys.

An "up and coming" developer has acquired a small corner lot on a side street off Vancouver's Cambie Street, facing south. The intention is to develop a mix of unit sizes ranging from studios to 3 bedroom corner units over a ground floor commercial space that includes a cafe. The site backs onto a lane and there is a "zero lot line" condition with an existing mixed-use property next door.

In line with the City of Vancouver's Zero Emission Building Plan[21], the project is aiming for Passive House certification. The developer is keen to maximize window area and balconies wherever possible. The project is required to conform to applicable zoning and setback guidelines.[22] This means that there are setbacks at the 5th floor on the south (street) side and at the 4th floor on the north (lane) side.

The owner is hopeful that a daycare can be located on the top floor. The question from a technical and regulatory standpoint is whether play space can be provided on the roof of the daycare (thereby maximizing the daycare's floor area) or if it should be on a deck in front – an inferior solution given that it would halve the number of children the daycare can accept.

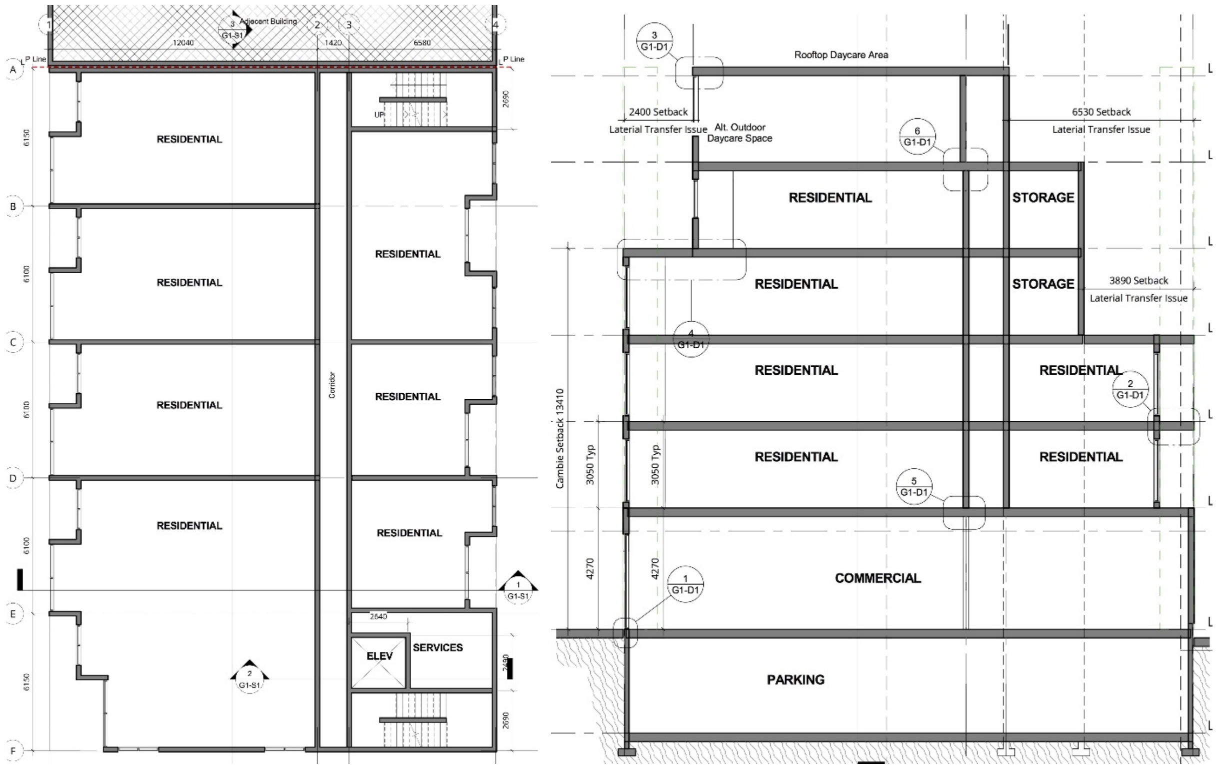
The developer has never built a project with a wood elevator shaft before and is particularly keen to see design details as well as a regulatory review. What will it take for the City to accept this solution?

3.1.1 Concept and context

This 6 storey residential project represents a very common mid-rise building typology in British Columbia. It is tucked into a south facing corner site and, given the cost of developable land in Vancouver, the project has been designed with a very efficient plan to maximize lot coverage.

The project faces several key issues relating to use adjacencies, zoning envelope, and Passive House performance: accommodation of a daycare on the top floor, upper floor "setbacks" and a "zero lot line" condition with the building next door. Baseline schematics are presented in Figure 3 (next page).

Figure 3 Baseline schematic typical floor plan (left) and cross section (right) as provided to the project team.



3.1.1.1 Daycare on the roof - Market influences

The case study encouraged the experts to explore the viability of a rooftop daycare – a desirable public amenity. Despite the fact that locating daycare services close to (or in) residential buildings might make sense from a social policy perspective, the daycare is not permitted under current code.

A smaller daycare might be permissible and splitting the daycare into several areas would change the occupancy classification. Splitting the daycare by providing additional walls would also allow for a continuous structural system from the residential areas below making it more efficient and reducing the torsional effect on the upper floor. Additionally, the daycare outdoor space will require an insulated floor to enclose the building envelope below, posing some challenges for any required penetrations. While technically buildable, the daycare was, in the end, deemed not economically viable: notably for the reason that a second dedicated elevator would be required by code for the daycare.

3.1.1.2 Addressing the setbacks required by the Vancouver Zoning Bylaw - Building Code and approval pathways

Located within Vancouver's Cambie Corridor zoning district, the project is required to step back on the rear and front elevations at the fourth and fifth floor respectively, to reduce the apparent height of the building and transition to the adjacent townhouse scale. These setbacks prevented this project from meeting the requirements of the B.C. Building Code in a rational and economic way because the shear walls in five and six-storey wood frame structures could not easily be vertically aligned without compromising the layout of apartments resulting in poor functionality and higher cost. The wood beams used to transfer loads will typically be deeper than concrete system solutions.

The structural challenges associated with designing the setbacks in wood, we were told in interviews, is the main reason that the six storey buildings in the Cambie Corridor are almost without exception built in concrete. The lack of knowledge or familiarity on the municipality's part, resulted in a building configuration that cannot be economically built out of wood.

3.1.1.3 Alternate Solution for Passive House zero lot line wall - Building Code and approval pathways

The Passive House requirement for the project requires particular focus on the design and constructability of the building envelope and, in particular, on the zero-lot line firewall on the east side. Construction of the firewall must advance by one storey to protect the neighbouring building before beginning construction of the next level. Typically, this would be formed with a sacrificial concrete masonry unit (CMU) wall strictly to achieve the fire rating, then a structural timber wall would be designed inboard to achieve the energy efficiency performance. Accommodating the CMU wall requires more space than a mass wood alternative. However, building a firewall out of CLT could be proposed to the building authority, but would likely require an Alternative Solution.

3.1.2 System selection

The optimum system for achieving Passive House performance, along with fire resistance and constructability at the zero-lot line led the project team to propose a hybrid structure and envelope system.

3.1.2.1 Addressing thermal performance at the transfer slab between residential and commercial occupancies - Building characteristics

The project team assumed that Passive House certification would be sought for the residential portion only. Therefore, a concrete transfer slab was proposed between the commercial and residential level to allow for flexibility in load transfer and for ease of insulating to minimize thermal bridging for Passive House compliance. Further, it was considered advantageous for the wood to concrete interface to occur on the same level since the concrete to wood joint is where the largest thermal loss happens. Nevertheless, insulating the transfer slab and making it airtight so that, overall, it achieves Passive House performance is still a challenge that could result in a raised insulated floor.

3.1.2.2 Addressing thermal performance where the transfer floor meets the elevator shaft - Market awareness and education

If the transfer floors are to be constructed in concrete and the elevator shafts be made out of continuous timber, then an insulation barrier will be required to wrap around the timber to concrete joint to isolate (between the elevator shaft and the residential occupancy) and to reduce thermal bridging. This isolation joint also creates a break in the load transfer between the elevator shaft and the building floors because the connection between substructure and superstructure is non-continuous and local connection points will be required. Alternatively, a mix of core materials could be used for the elevator shaft, including using concrete on the lower levels and wood for the upper levels. This consistency in building materials in each floor simplifies the floor to wall connections and limits the thermal break needs to between the timber and concrete on the lower floor. It is worth noting a two-hour fire rated floor is required for the top floor daycare occupancy. An Alternative Solution could be proposed for an equivalently rated mass timber sandwich panel with mass timber wall panels forming the main structure and being used as a wall with a fire resistance rating.

3.1.2.3 Seismic design - Market awareness and education

It is not possible to address seismic requirements for mid-rise wood buildings where there are transfers in the lateral system in the superstructure because the shear walls must all stacked – potentially affecting internal layouts and leasable space. Therefore, the location of the shear walls in the daycare should be continuous to the lower floors (i.e. residential party walls) and consider the use of the elevator and stair shafts for lateral load transfer.

3.1.2.4 Blindside Passive House timber firewall assembly – Building requirements

Commercial developments require a 2 hour-rated wall at the zero-lot line. This wall cannot be made up of combustible materials, limiting construction to either concrete or 100 per cent grouted concrete masonry units (CMU). However, a CMU wall cannot be designed as a tall self-supported cantilever. It has to be tied back to the main structure. Other complications include:

- The need for the construction of the firewall to advance ahead by one floor for protection
- A seismic gap equivalent to approximately one inch per floor, (total six inches)
- Installation must happen from one side only (i.e. blind)
- The Passive House fire wall requires a minimum of six inches of exterior insulation

The workshop participants developed several options for a possible timber-based passive house performing firewall that could be constructed in a “blindside” situation (Figure 4- Figure 6 next page). At 600mm wide, the CMU option (Figure 4) results in the thickest wall assembly. The other designs are more efficient, encroaching less into the valuable floor area, but each comes with its own complexity. For example, if CLT was proposed (Figure 5), the structural framing typically occurs prior to insulating, hence it would be difficult if not impossible, to install it in the gap on the outside left between the frame and the fire wall. A panel assembly (Figure 6), which has insulation built in on the outside would help with ease of installation but comes with an additional challenge of crane operations next to a zero-lot line.

The various assemblies developed all require some combination of alternate code pathways, testing and construction development. Therefore, further collaboration by a faculty of consultants, builders and suppliers would benefit the industry, as the increasingly stringent energy efficient building policies already on-line today will require such an assembly in the no brainer/short-term innovation category.

Figure 4 Zero lot line CMU fire wall (not to scale)

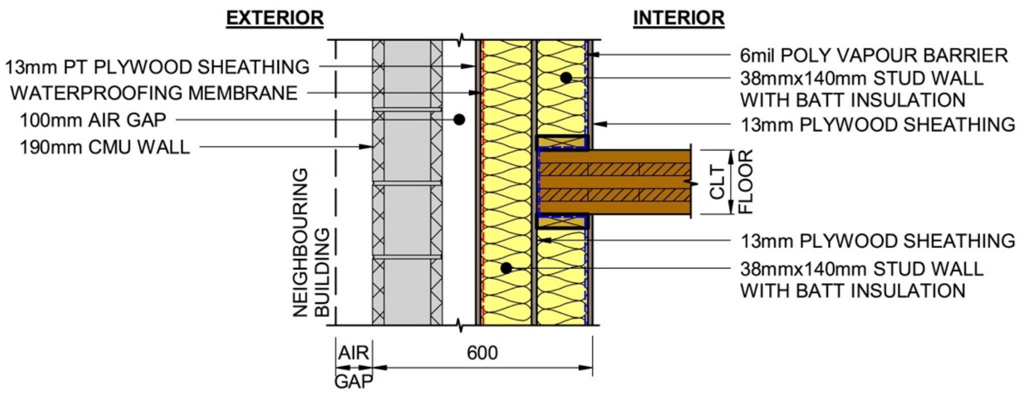


Figure 5 Zero lot line CLT fire wall (not to scale)

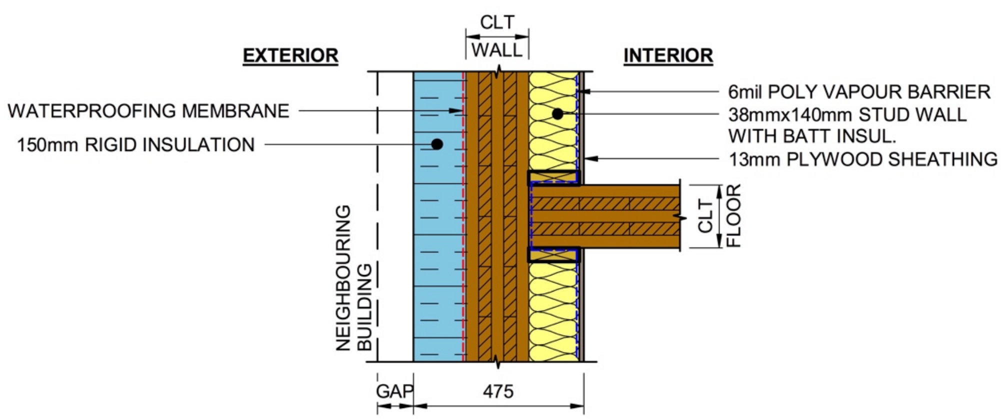
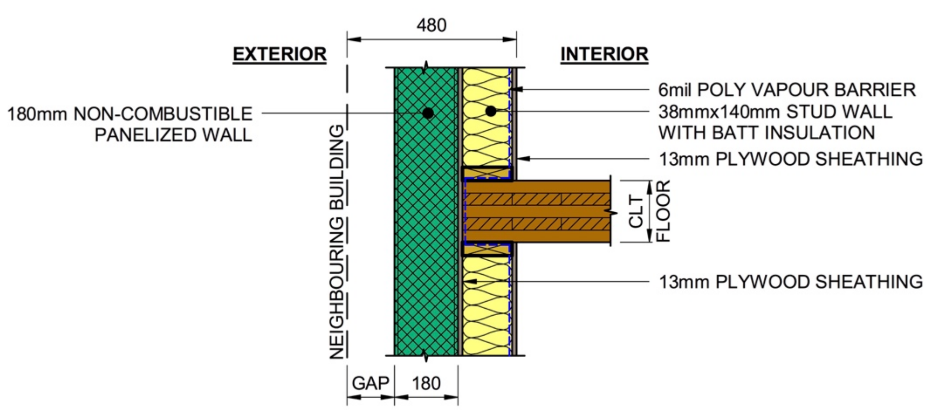


Figure 6 Zero lot line panellised fire wall (not to scale)



3.1.3 Project optimization

The wood frame mid-rise (6 storey) residential building typology is well understood in Canada, although overlaying the requirements for Passive House certification requirements of thermal performance and airtightness is new. The optimizations discussed at the workshop centred around reconciling the constraints of the zero-lot line fire wall with the envelope design while maintaining as efficient a floor plan as possible. The original layout placed the stair cores at on the perimeter. However, the most efficient structural system would use the zero-lot line wall for gravity load transfer columns only. This would simplify construction by using the zero-lot line wall from the interior side between unobstructed column bays, but it means that the stair cores would need to be move away from the perimeter to ensure that and the shear wall system is uninterrupted and continuous.

3.1.4 Details

The following details were developed for this case study and are presented in Appendix C.2.

1. **Detail 1 – No-brainer, Zero Lot Line CMU Fire Wall:** Closest to typical firewall construction while meeting Passive House performance, but 25 per cent thicker than other options. The primary challenge lies in installing the drop-in panels for Passive House performance.
2. **Detail 2 – Short-term, Zero Lot Line CLT Fire Wall:** This solution offers a slimmer thermally high-performance fire wall. The primary challenge lies in dropping in the CLT panels and managing carne operations. The assembly requires an Alternative Solution.
3. **Detail 3 – Short-term, Zero Lot Line Panellised Fire Wall:** This solution offers a slimmer thermally high-performance fire wall and would help with ease of installation. A challenge will be to manage crane operations. The assembly requires an Alternative Solution.
4. **Detail 4 – No-brainer, Passive House Compliant Exterior:** Similar to detail 1, this system is immediately useable, but requires planning for installation on-site.
5. **Detail 5 – Medium-term, CLT Elevator Shaft:** There are specific complexities with structural and thermal performance that will require both further development and project-specific design.

3.2 Case Study 2 – Multi-tenant office in the City of Victoria

A four-storey, multi-tenant commercial office building arranged around an atrium, with a requirement for a high-performance curtain wall with maximum transparency.

The owner is an industry association that serves the real estate and construction sector. Many of its members are leaders in innovative wood design, construction and product manufacture. It is working with a developer to create a showcase building for its own offices and training centre, located in downtown Victoria overlooking the Upper Harbour.

The owner will occupy the ground floor, with offices, meeting spaces and a training room. There will be a gallery and coffee shop in the atrium, with the upper floors being available for lease. The downtown class A office category is in demand, with vacancy rates around 1.5 per cent. The owner intends to show that an innovative wood building can attract high-end tenants. However, no tenants have been signed up yet, so the floorspace will need to be designed for flexibility. Further, the leasing agent has stated that the building must aim for LEED Gold at a minimum and be glazed on all four sides to maximize views of the waterfront and adjacent green space. the City of Victoria has adopted Step Code 3 for commercial buildings.

The floor grid is currently proposed at 6m x 6m. The owner is keen to showcase the wood structure and expose the underside of any wood floor systems. However, the owner is also aware of the need to optimize the design for the materials to ensure the most efficient and cost-effective solution. Ideal layouts and spans are to be proposed (recognizing the need for flexibility). The assumption is that the stair cores are concrete – but can they be made of wood?

In addition, the owner has been made aware of an innovative wood curtain wall system that is being developed in a partnership between a local BC curtain wall and window company and a European company with an established track record of very high-performance curtain wall systems. The curtain wall system can be pre-fabricated into large panels for ease of installation, but it has not been used in BC before. Further, the project schedule dictates that the curtain wall and cladding installation will likely happen during the winter months.

3.2.1 Concept and context

This project highlighted issues relating to introducing a wood structural design into a building typology that has primarily been built out of concrete. The baseline design looks like a concrete building because of traditional leasing expectations. It comprises a standard floor layout built on a 6m grid and a high window-to-wall ratio to maximize light and space - but is not ideal for energy efficiency. This project represents how past design and construction assumptions work against the potential benefits of a wood solution, such as leveraging standards sizes of prefabricated panels for speed and cost.

The multi-storey atrium in the centre of the building, while not an uncommon desire, translates better to a concrete or steel solutions. Resolving the structural complexities of a multi-storey atrium in the centre of the building is not realistic using wood construction alone. For example:

- A fire separation is required between multi-tenanted units; therefore, an open concept design to an atrium below cannot be accommodated with combustible materials such as wood.
- To create a central atrium, steel braces would be needed to tie the wooden structural diaphragm together, which can add substantial overall project cost.
- If CLT core shafts are considered this will likely transform into an increased cost factor roughly three times the price.

The experts felt strongly that most commercial owners need to be educated on the fact that while commercial wood buildings are possible (and indeed beautiful), they cannot assume mass timber is a direct substitute for concrete in terms of how the building is configured. Owners need to understand the differences (some major, others quite subtle) with other structural materials, and to avoid forcing wood into concrete or steel design/construction assumptions. For wood to be successful in the multi-tenant office market, owner expectations must match the practical realities of wood design and construction - exploiting different opportunities.

Building Code requirements are beginning to change. Where the lower floor atrium which contains a gallery and coffee shop in the atrium would once require non-combustible materials (assembly occupancy, BC Building Code 2012/NBCC 2010), it can now be made with combustible materials in the BCBC 2018/NBCC 2015 code (same occupancy, up to 2 storeys)

3.2.2 System selection

3.2.2.1 Reconciling flexibility – Building typologies

Responding to the prevailing speculative office market expectations, the initial premise of this project proposed curtain walls and open concept floor plans, affecting the structural and building systems chosen. The experts felt strongly that the market needs to evolve to performance-based design criteria for functional, economic and occupant wellbeing parameters (among others) as opposed to the traditional checklist of features (such as window to wall ratio).

3.2.2.2 Fire and acoustic separations - Building requirements

The experts considered the fire and acoustic separation requirements and noted significant design challenges. In particular, floor plates that are open to the atrium are not feasible when accommodating different tenants on each floor and there are significant acoustical issues associated with an open atrium that is servicing vertically defined tenant spaces. The baseline layout as proposed by the owner was determined to be highly impractical.

3.2.2.3 Seismic design – Building requirements

The open concept floor plans and curtain walls favour stair core shafts over the use of shear walls for a lateral seismic system. Balloon framing required for the core shaft in CLT is not permitted within the code and, structurally, shear walls are preferred between glazing instead of relying solely on stair core shafts under seismic conditions. A wood building design prefers shear wall lateral load resisting systems at the perimeter and the interior of the building unlike concrete, which can rely on a core wall system.

3.2.3 Project optimization

3.2.3.1 Plan re-organization – Evolving building expectations

The optimization emerging from this case study revolved around envelope performance and structural optimization to make the building more suited to a wood solution, while offering the floor plan flexibility the developer and leasing agent will likely desire. The proposed building design changes include:

- 2-storey atrium on the long (south facing) side of the building
- 2nd floor mezzanine to be 40 per cent of the typical floor area
- Mezzanine floors receives lighting from the large south facing atrium
- Stair cores shifted inwards from the ends of the building
- Relying on stairs cores as lateral resisting system
- Half storey 4th floor

Workshop discussions regarding these design changes focussed on practical considerations: what will be most difficult for the AHJ to accept? What details will be easier and cheaper to build? Being cognisant of the owner's objectives, "picking your battles" and selecting "state of the shelf" solutions where possible reduces owner/AHJ resistance to innovative technology and practices.

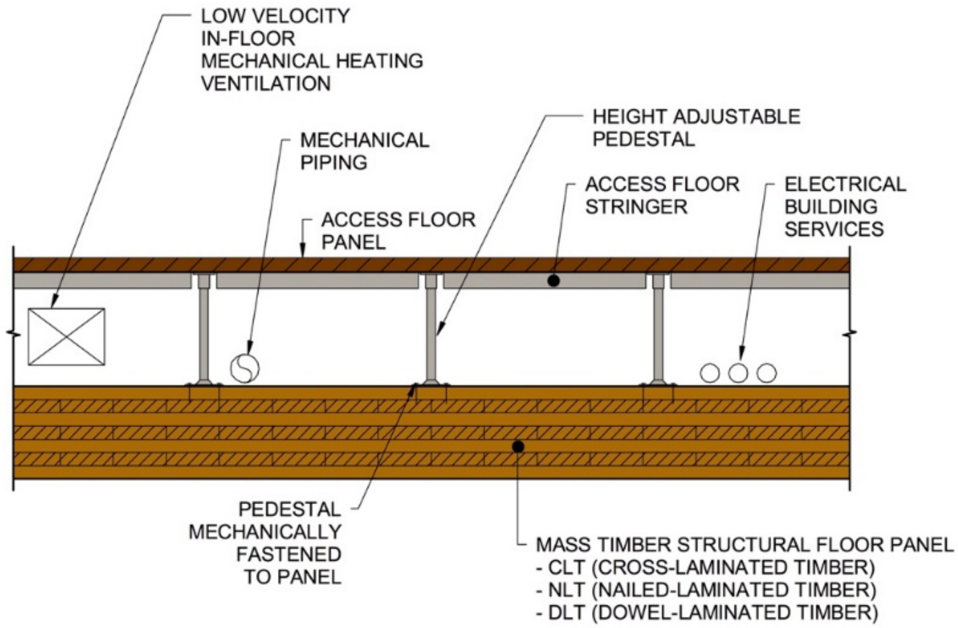
"Picking your battles" and "State of Shelf" vs. "State of the Art"

There was a room-wide discussion about "state of the art" vs "state of the shelf", where it was generally agreed that decisions to push the limits of wood should be weighed against both the owner and building authorities' threshold for innovative uses of wood and the practitioner's ability to utilise wood. Carefully "picking your battles" allows the project team to utilise as much wood as possible while minimizing risk of delays and reducing the likelihood of the owner vetoing the use of wood. Over time, as aggregate industry experience advances to be more comfortable with wood, the significance of this issue will likely diminish.

3.2.3.2 In-floor services – Building characteristics

The floor assemblies in state-of-the-art offices have to accommodate an increasingly wide array of services that include mechanical, electrical, life safety systems and a growing amount of data and electronics. Traditionally, a suspended ceiling is installed below the slab. However, with a wood building, the desire is to show off the wood soffit, with in-floor services being more practical, as well as being more flexible for future tenant fit-outs (Figure 7 next page).

Figure 7 CLT floor assembly to accommodate building services (not to scale)



3.2.3.3 Envelope implications – Evolving building expectations

For a wood design to make sense for this project, the project team essentially started the planning process from scratch as the baseline layout was not approriate. To make the envelope, environmental performance and structural systems all work efficiently together, they proposed to remove some curtain walls around the west building perimeter. Not only would this reduce the solar gains and provide a more consistent and efficient energy performance system, it would also allow for a mix of glazing and shear walls to be arranged optimally (Figure 8 and Figure 9 next page).

Figure 8 Group 2 proposed 3D exterior view (not to scale)

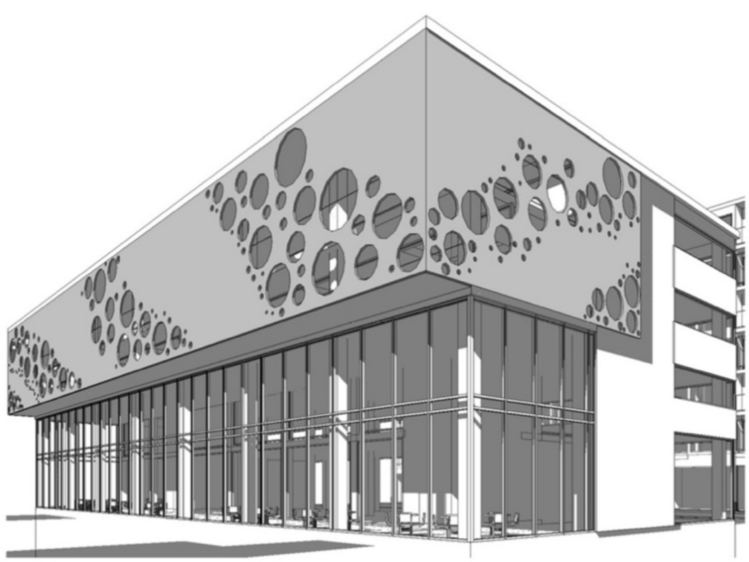
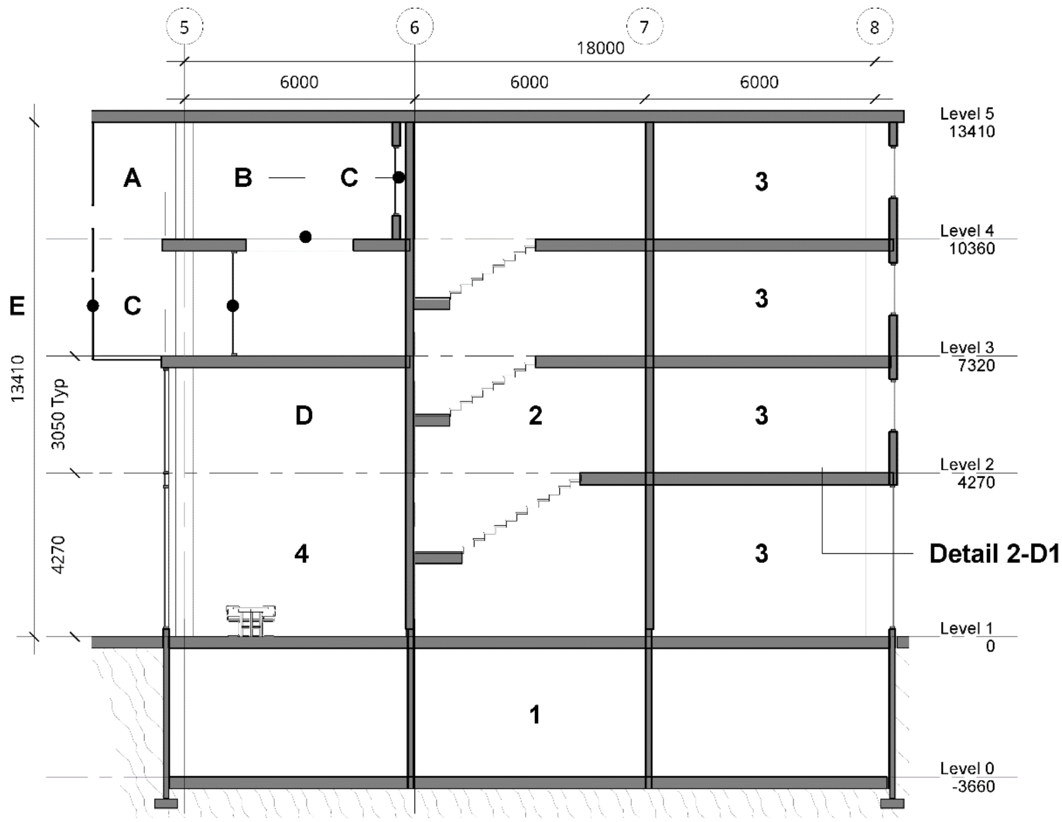


Figure 9 Group 2 proposed building section (not to scale)

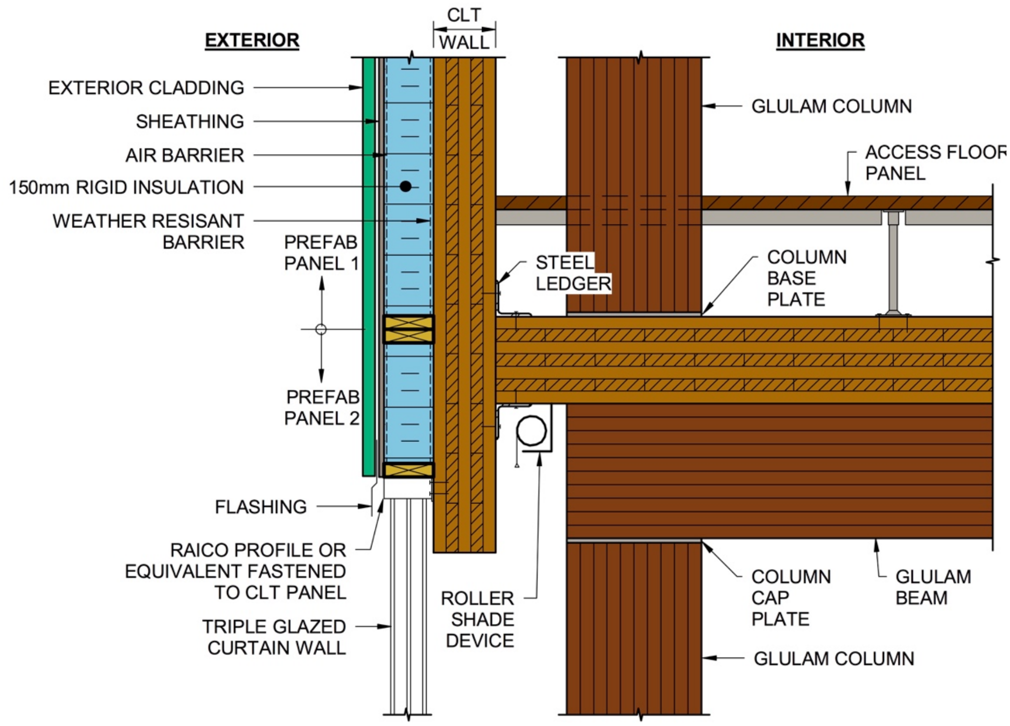


1. Underground parking
2. Exist stairs
3. Tenant spaces
4. Feature seating area

A. Performance / code. Enclosed semi-conditioned space (atrium intent)
B. Skylight-floor
C. Partition to semi-conditioned space
D. Code: double-level feature gallery
E. Semi-transparent feature screen

If shear walls are implemented between glazing units, instead of relying solely on the cores as a lateral resisting system then a prefabricated wood curtain wall/shear wall system can be used for efficiencies in construction costs (Figure 10 next page).

Figure 10 Prefabricated wood curtain wall / shear wall system (not to scale)



3.2.4 Details

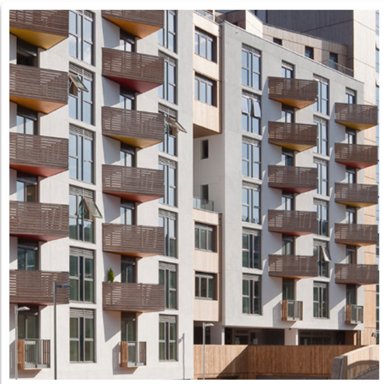
The following details were developed for this case study and are presented in Appendix C.2.

1. **Detail 1 – No-brainer, Built-up floor assembly to accommodate building services:** This system is not unusual today. Key differences are with market expectations (suspended ceilings are the norm) and owner education.
2. **Detail 2 – Medium-term, Prefabricated wood curtain/shear wall system:** The product types proposed are not uncommon today. Testing and standardised details of the wood panel and curtain wall would help but would require commitment and investment by product suppliers.

Fewer details were designed for this case study. The majority of the project team’s time was spent reconciling and optimizing the envelope, environmental performance and structural systems as a holistic and efficient mass timber solution.

3.3 Case Study 3 – Social housing in the City of Surrey

An eight-storey seniors' residence with common areas on the ground floor, and the possibility of future conversion to a care facility. The main challenges in this project related to the code implications of the proposed change of use, and the need for a shallow floor depth to comply with height restriction in the zoning bylaw.



The owner is a Non-Profit Housing Society which has secured a site in the City of Surrey on which to develop non-market housing for seniors with a ground floor amenity space. The permissible development height limit is 26.5m (87') to the top of the roof structure (excludes upstands and parapets) and the expected solution is a 7 storey concrete building.

There will be a mix of 1 and 2 bedroom units. There is also a 3-bed suite on each floor that may be for visitors, short-term care or for "live-on-site" care support workers. The amenity space will accommodate a dining area with a kitchen, lounge, staff offices and spaces for various healthcare services. The amenity space must have a floor to floor height that is at least 1m (3') more than the typical residential units. Floor to ceiling heights in the residential units must be at least 2.4m (8') throughout.

The owner is prepared to investigate a structural wood solution for the following reasons:

- The poor bearing strength of the site soils means that additional foundations may be required for a concrete building
- Most of the units will have balconies and the owner thinks that a wood building will offer greater thermal comfort and energy efficiency
- The owner has heard that by using a wood floor system there may be a way to squeeze in an extra floor within the overall height limit (i.e. build 8 storeys altogether)

In the future, this building may transition from an independent living facility into becoming able to provide assisted living services and support for those with memory loss. This means that residents do not have to move once they need a little more mental and physical care. What are the implications of such a change of use? Is it possible to accommodate?

While there is no specific energy efficiency requirement beyond code, the owner wishes to ensure the building is as comfortable and energy efficient as possible. Three sides of the building will have access to views and the overall wall to window ratio of these three facades will be in the order of 70 per cent. The fourth side abuts the property line with a low-rise commercial building next door.

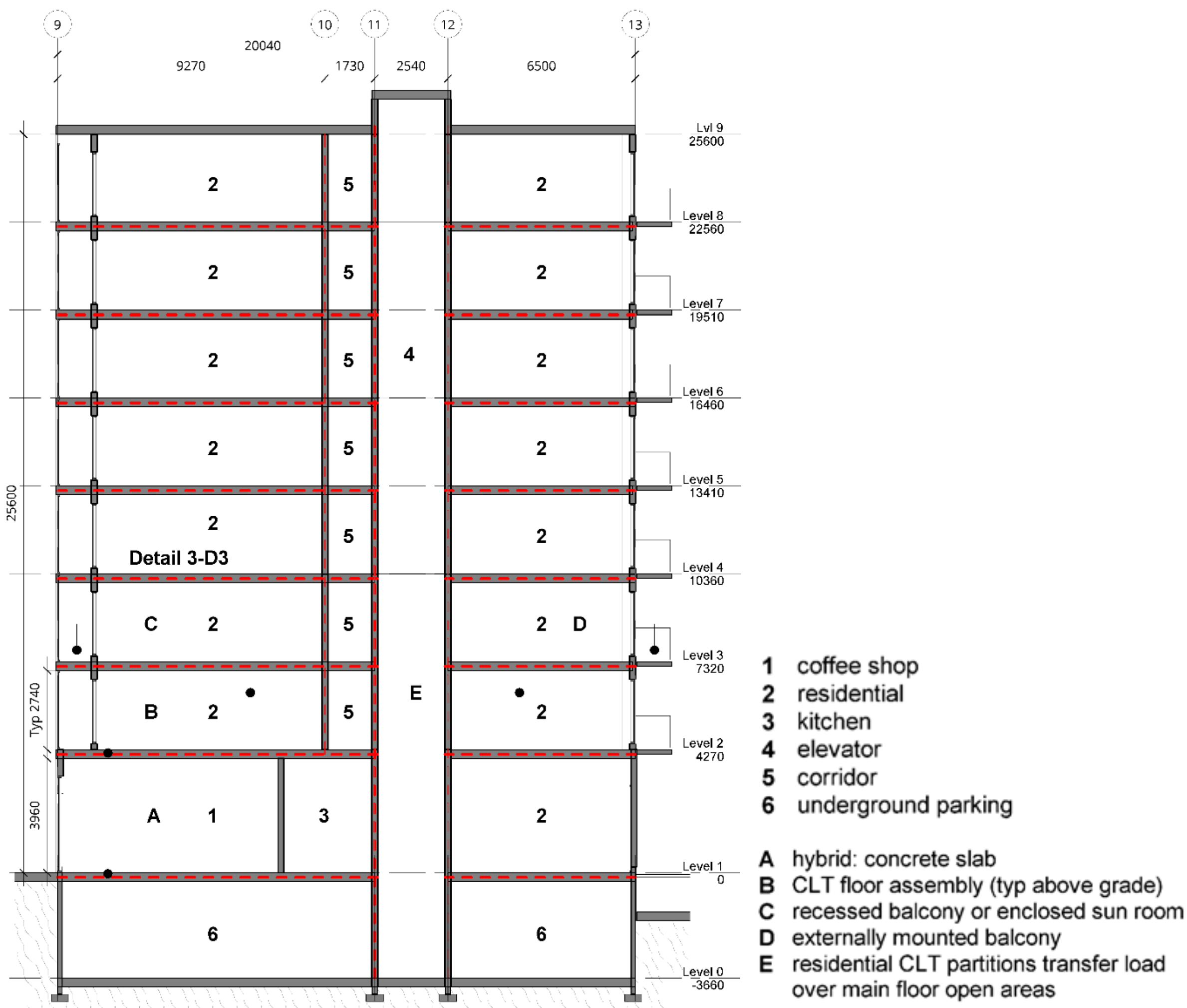
To achieve a total of 8 storeys means that the floor assembly must be extremely efficient. Is this doable? Given the loading issues resulting from poor soils, can the elevator core be constructed out of wood?

3.3.1 Concept and context

3.3.1.1 Tall structures - Building Code and approval pathways

The group discussion exposed market norms that often impede the adoption of mass timber. The owner in this project is considering a wood structure because of the potential benefits a lighter structure might offer in the face of challenging soil conditions. However, there is a significant increase in BC Building Code requirements when stepping from 6 storeys up to 8. With this project, the economic benefit of going to 8 stories may not be cost effective against reduced foundations, because the additional code requirements offset any savings in the foundation systems if a higher number of stories are being pursued. The experts reviewed the proposed eight storey schematic design and noted the fire rating requirements (Figure 11).

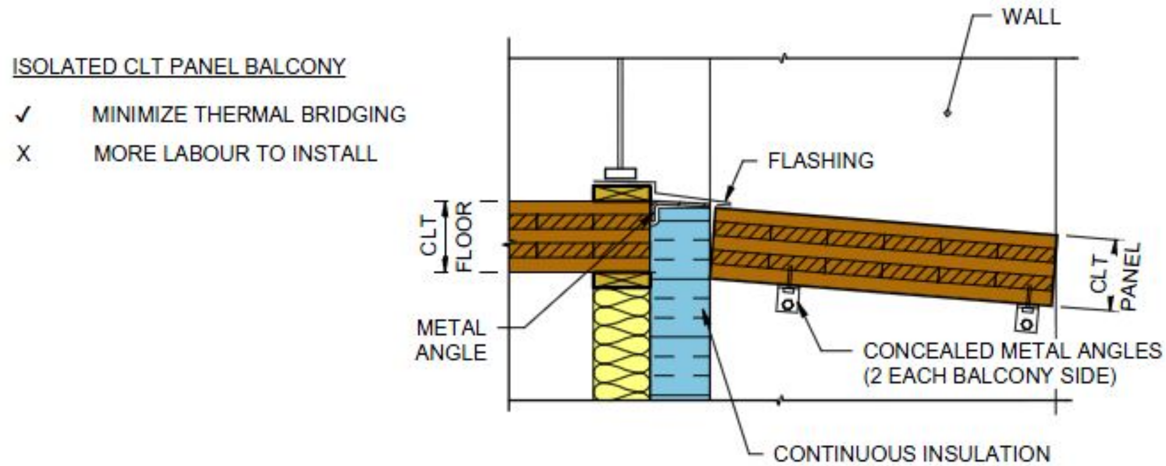
Figure 11 Revised schematic section showing an 8 storey configuration with fire rating requirements (not to scale)



3.3.1.2 Balconies and projections in mass timber – Market influences

Several problems were identified with the layout of the baseline design. For example, each residential unit each had a recessed balcony – a typical assembly in housing in British Columbia. This can be difficult to achieve with mass timber, especially taking thermal bridging and durability into account. This issue highlights the fact that market norms in housing and condo that are not only incompatible with the use of mass timber, but also with the general move towards better energy efficiency. A proposed alternative balcony detail was developed using CLT (Figure 12).

Figure 12 Balcony detail option for Group 3 case study (not to scale)



3.3.1.3 Planning for future change of use - Building Code and approval pathways

When considering the possibility of changing the senior's housing project to an assisted-living facility in the future, the project team noted that the B.C. Building Code still has gaps compared to codes in other jurisdictions. This often leads to conservative designs or requires a series of Alternative Solutions, which can increase time and cost uncertainty that often rules out the use of wood.

3.3.2 System selection

3.3.2.1 Hybrid wood construction – Market awareness and education

The experts began by determining the best structural systems and material given the proposed use. The advantages of hybrid construction (where mass timber is used in conjunction with light wood frame where appropriate) were discussed in the context of life safety, constructability and durability. The experts noted that consideration should be centred on a material's inherent advantages and characteristics:

- Mass timber can be exploited to modularize or prefabricate aspects of the project. For example, using parallel load bearing party walls between units could provide the advantage of prefabricated, drop-in residential units.

- Considering energy and durability concerns, the wood balconies could also be eliminated, replacing them with thermally isolated steel balconies or enclosed “sun rooms”.
- Wood’s ability to be easily machined provide opportunities to reduce on-site work, potentially increasing both quality and construction speed. For example, the recessed balconies could be routered into CLT floor plates, complete with the necessary slope, in the factory.
- The variety of options for connections (typically prefabricated metal) and the need for fewer trades could prove ideal for budget and schedule conscious owners.

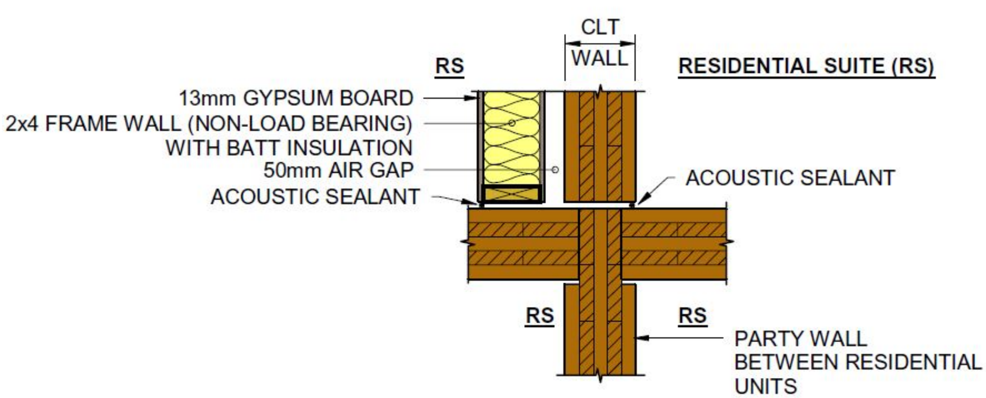
3.3.3 Project optimization

3.3.3.1 Tactical benefits of wood construction – Market awareness and education

Discussion was centred around the fact that market demands and owner expectations that are not always optimized for wood. The team started by outlining the advantages of building with wood, adjusting existing practices and expectations to maximise these benefits. For example, designers may wish to “celebrate” wood by exposing it as a finished surface, which can conflict with the fire code or pose durability concerns. The team then proposed a more flexible approach that would leverage the benefits of mass timber, such as prefabrication (quality and speed of construction), even if it means encapsulating the wood behind drywall for fire protection and maintenance reasons. For the project case study, the case study experts offered the following optimizations:

1. **Acoustics:** The floor assembly was designed to deal with the typical foot fall issue while the joints at the party walls included mineral wool and acoustical sealant. The party walls themselves included an insulated and framed wall on one side, and untested system that may provide superior unit-to-unit acoustics performance (Figure 13).

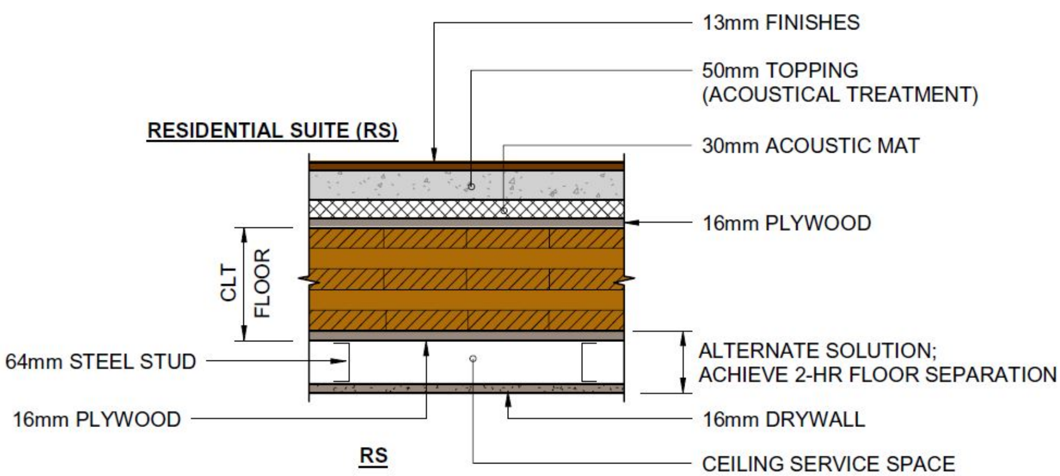
Figure 13 Acoustic designs for residential suites not to scale)



2. **Fire Protection:** Given the residential use and the proposed future conversion to an assisted-care facility, drywall encapsulation will likely be required.
3. **Balconies:** The experts designed multiple solutions to address issues of durability, as well as stringent energy code requirements. Significant discussions exposed this issue as technically simple but requiring changes to expectations from builders and real estate stakeholders.

1. **Servicing:** A significant consideration for this project involves the approach to mechanical and electrical systems. By considering what services need to be centralised (e.g. Sprinklers), and what is better served individually (e.g. in-suite HRVs), the experts minimized the depth of the service chase in the corridor, allowing for flexibility with the CLT floor assembly.
2. **Floor assembly:** The design of the floor structure (Figure 14) was adapted from an assembly from the CLT Handbook[23] and provided a means to manage fire protection, servicing and acoustics, in as thin a floor structure as possible. In addition, notching the structural walls (partitions between units) may be required to deal with crushing forces.

Figure 14 CLT floor assembly detail between suites (not to scale)



3.3.4 Details

The following details were developed for this case study and are presented in Appendix C.2.

1. **Detail 1 – No-brainer, Load Bearing Wall Options for Stacked CLT:** These options for load-bearing stacked CLT are based on well-known practices and have been used in some form on projects in British Columbia. Note that the acoustic mat considers products from Europe that may not be widely available in Canada.
2. **Detail 2 - No-brainer, CLT Party Wall Options:** Mass timber partition wall options are not unprecedented (one wall is untested for acoustic performance). However, the second option does demonstrate the utilization of prefabricated CLT assemblies in residential suites for faster construction.
3. **Detail 3 - No-brainer, CLT Floor Assembly Between Residential Suites**: The mass timber floor assembly acts as both a fire separation as well as a service space and requires acoustical performance for residential use. This is modified from an assembly from the CLT Handbook.[24]
4. **Detail 5 – No-brainer, Balcony detail options:** The balcony concepts are relatively common globally, but not necessarily in North America. One assembly maximises the machinability of mass timer panels – also easily possible today.

3.4 Case Study 4 – Commercial building with supermarket in the City of Vancouver

A four-storey commercial building with a supermarket on the ground floor and offices above. The main challenge in this project was the need to transfer loads from the smaller column grid of the upper floor offices to the larger grid required by the supermarket.

An on-line high-end grocery company is proposing to build its headquarters in East Vancouver. For the neighbourhood to accept the proposal, the company is offering to build a state-of-the-art "bricks and mortar" supermarket to complement its virtual offerings which, at 3,700sm (40,000sf), will take up the entire ground floor.

The supermarket requires a clear ceiling height of 5m (16'): lighting systems may be suspended below this. Throughout the building the owner wants to eliminate as many columns as possible. The property backs onto a lane which just allows for two delivery trucks to back into a diagonal loading zone at the rear of the ground floor adjacent to the supermarket storage area. Mechanical equipment for the supermarket and offices will be integrated so that heat exchange can occur. The upper floors will comprise open plan office space and the facades will be designed to maximize natural daylight. Given the different uses anticipated, are the cores wood or concrete? What are the key fire separation issues?

The top floor of the building will comprise meeting and class rooms, a demonstration kitchen, rooftop cafe and outdoor entertainment space. The company intends to use this space for staff training and will also offer courses and events that will be open to the public. The project is located in the City of Vancouver and will be required to meet the rezoning requirements of the Zero Emissions Building Plan (so GHGI = 1.0, TEDI = 21).

3.4.1 Concept and context

3.4.1.1 The right material for the right purpose – Industry norms

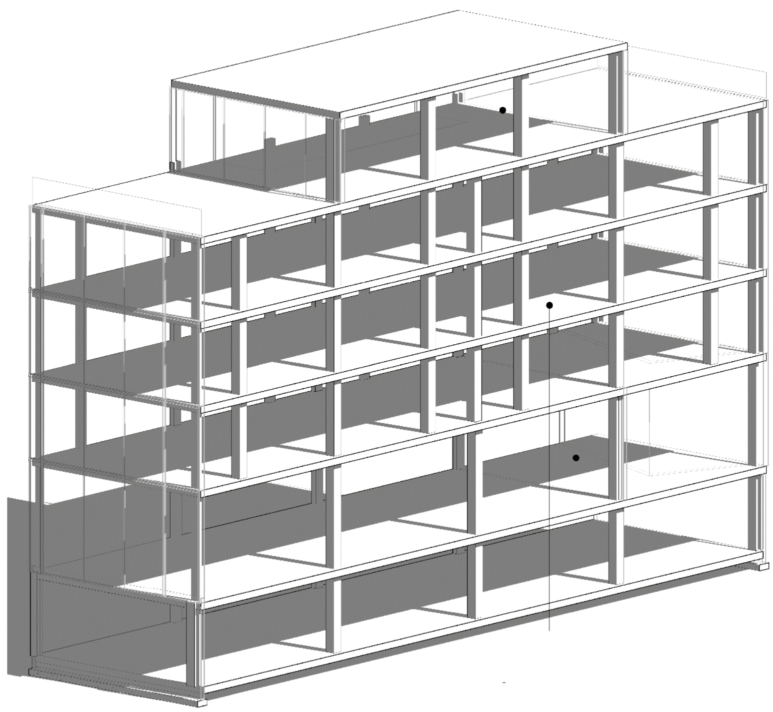
The challenge of this case study centres around the very different spatial needs between a commercial space and a retail space that requires a significant transfer system at the change of occupancy level. A complete wood framed structure could be very expensive with little or no obvious benefits. A straight substitution of wood for concrete or steel would likely result in larger dimensions for the beams and columns. However, by intentionally expressing the material and the scale of the structural members, this could be part of the desired solution. A timber design can provide different interior finishes to a steel or concrete building but to achieve this requires consideration early in the design process.

3.4.1.2 Lateral and transfer system – Market influences

As mentioned in other case studies, a paradigm shift away from full height and continuous glazing will lead to better envelope systems which will lend themselves to wood solutions. If the project is to be an all wood solution, the transfer system will require large timber beams, (potentially) expensive connection details and a reduction in the glazed area. However, commitment for the project to use wood need to be made at the conceptual stage, when these design challenges can be resolved elegantly.

The configuration of the column layout and the transfer between retail and office occupancies as proposed in the baseline scheme did not easily suit an all-wood solution. While technically possible, it requires considerably larger structural members (that could be exposed) as well as continuity of the load transfer through floor levels and a closer spacing between vertical members (Figure 15).

Figure 15 3D diagram as proposed by experts



3.4.1.3 Alternative Solution for top floor assembly use over commercial below - Building Code and approval pathways

The top storey of this building contains classrooms/meeting rooms which are classified as assembly spaces. Under the current BC Building Code, combustible materials (wood) are not permitted in assembly spaces above the second-floor level. In the City of Vancouver, this clause may be renegotiated, as it is mainly based on emotional rather than technical reasons. While an Alternative Solution may be reached with an AHJ, moving the classrooms down to the 2nd floor will avoid these discussions altogether and satisfy all building authorities.

Similarly, the allowable code limitation for a six-storey building footprint designed with combustible material is currently 3,000 m^2. This particular building footprint is 3,700 m^2 - above the current allowable limitations. A concession may be acquired from the AHJ but would require further design changes which could affect the project's cost or schedule.

3.4.2 System selection

3.4.2.1 Addressing thermal performance – Building requirements

To achieve minimum building energy performance requirements, the terrace area would be required to accommodate the prescribed insulation thickness (18” to 2’). Generally, this expansion in overall floor depth would be accommodated above the terrace floor level as so not to impede on the clear ceiling height of the room below; this would require a ramped entrance.

3.4.2.2 Addressing horizontal movement – Building requirements

The overall structure is over 100m long and therefore at least one movement joint should be provided within the supermarket along the centre of the long dimension of the building to control the horizontal movement. Adding a double line of columns in the centre of the building may allow for this movement.

3.4.2.3 Key differences between wood and concrete – Market awareness and education

This case study allowed the team to explore the differences between a building originally proposed in concrete and steel but now wanted in wood. The comparisons of various structural and construction approaches that the team explored are presented side by side in Figure 16 (next page). In contrast to the all-wood system to grade, a comparison with a concrete approach to the ground floor retail space. This hybrid solution allows for a simpler structural system and is likely more cost effective. The stair cores would need to be 2 hour fire rated above the basement level. This can be achieved with a combination of mass timber and drywall. Two stack joint connection options are illustrated in the Details for this case study (Appendix C.2).

3.4.3 Project optimization

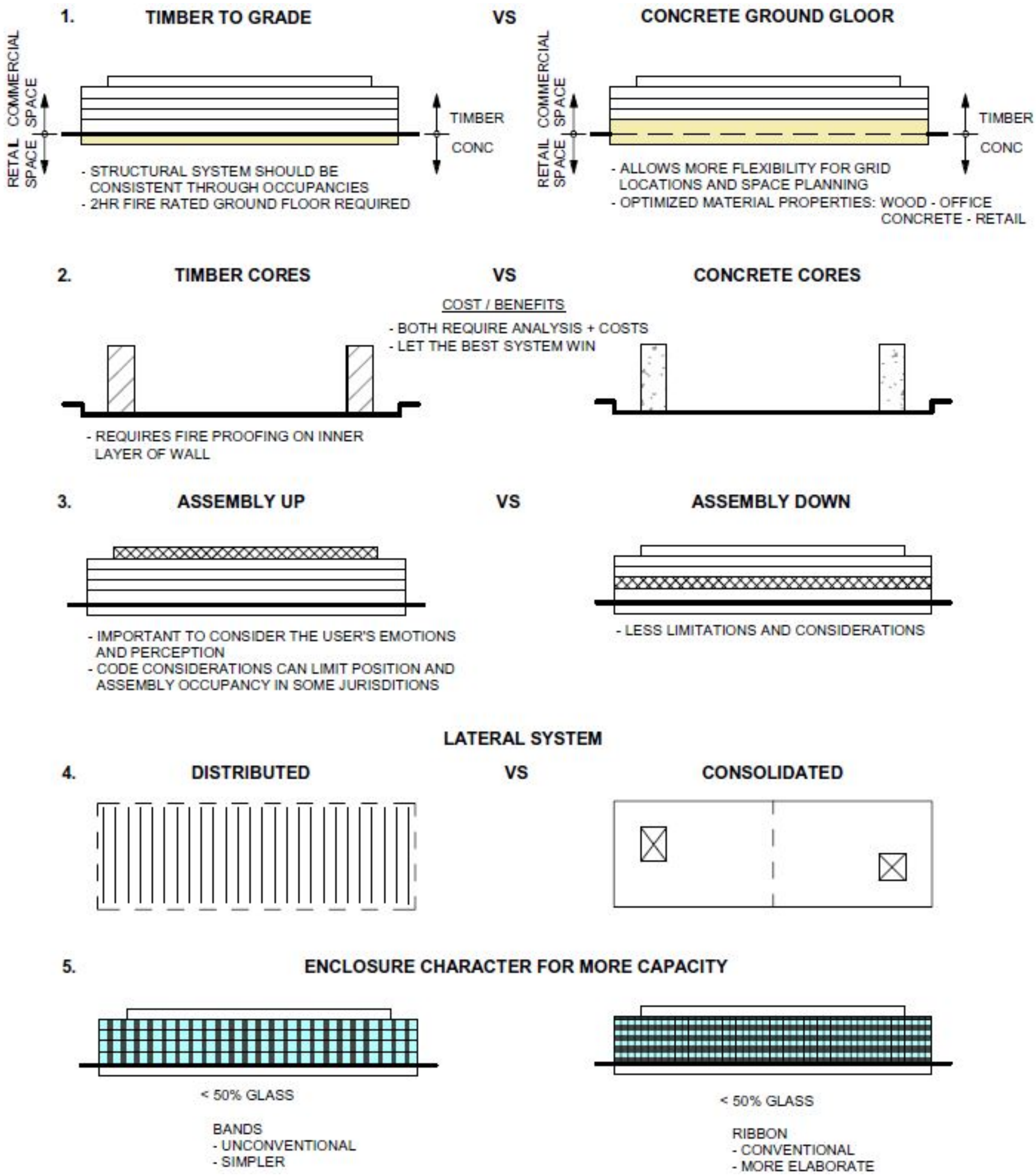
3.4.3.1 Structural layout adjustments – building characteristics

Optimization considerations for this case study quickly emerged around the grid layout to make it work for an all wood solution. The 9m x 9m column layout grid in the baseline schematic is common for supermarket designs but too large of a span to consider timber members given the eccentric load path considerations. The project team proposed that the grid should be altered to accommodate a 9m x 6m column layout and allow for continuous columns throughout the lower floors. The original grid on the office levels presented a 6m x 6m grid, which would create eccentric loadings.

3.4.3.2 Reconciling open plan flexibility – Building characteristics

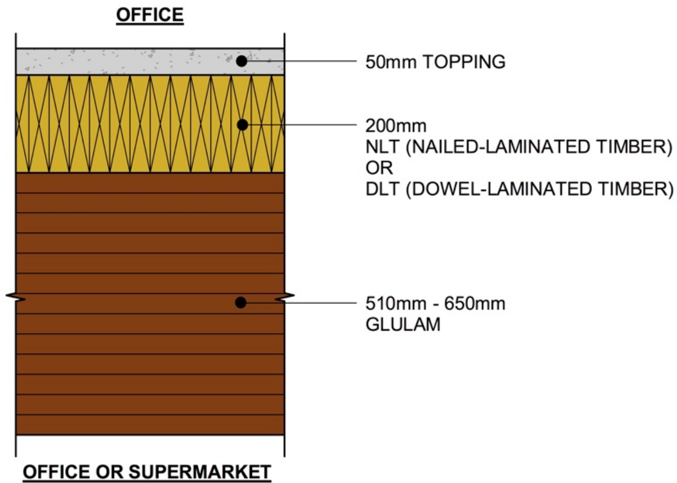
Incorporating a concrete structure at the level where the occupancy changes would simplify the structure and provide for the use of concrete cores, thereby freeing up the perimeter. However; shear walls could be utilized along the prefabricated curtain wall system. This will create a 50 per cent glazed area within the office working space (which is low in British Columbia’s current new office leasing market) but would allow the structure to avoid using the timber stair cores as major bracing units (see 5. Enclosure character for more capacity in Figure 16 next page).

Figure 16 System selection considerations and comparisons



Other structural systems were explored to assist in achieving the open plan office layout. One idea included hanging the upper floors from a roof level truss although it was likely to be less cost effective. A typical office floor assembly detail is illustrated in Figure 17.

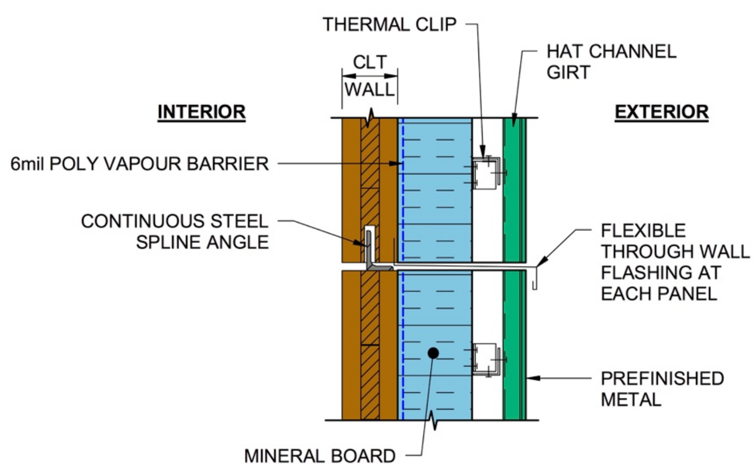
Figure 17 Typical office floor assembly (not to scale)



3.4.3.3 Blindside firewall – Building requirements

Similar to case study 1, this project has a zero lot-line party wall. There is an adjacent building located on the east side of the building and a two-hour fire separation will need to be considered. A single side installation on prefabricated structural CLT panels may be considered to provide the necessary fire resistance. The project team conferred with the team working on the mixed-use residential project (Case Study 1) and sketched an additional detail option (Figure 18), which comprises an optimized prefabricated system that can be installed from within the space and braced until the superstructure has been erected.

Figure 18 Exterior party firewall (not to scale)



3.4.4 Details

The following details were developed for this case study are presented in Appendix E.

1. **Detail 1 – Short-term, Curtain Wall located on gridline 1 and 5:** Proposing a pre-fabricated panel envelop system in combination with CLT shear panels.
2. **Detail 2 – Short-term, Exterior party Firewall:** Similar to the other options presented in Case Study #1, this detail is dependent on early collaboration with a builder to ensure the construction strategy and wall assembly design are practical.
3. **Detail 3 – No-brainer, CLT Stack joint connection options:** Simple, hybrid connection options.
4. **Detail 4: No-brainer, typical office floor assembly:** A floor assembly that provides a unique exposed wood ceiling for the ground floor supermarket and the require fire resistance for the office above.

3.5 Workshop summary

3.5.1 Technical and regulatory outcomes

Consistent across all of the group discussions was the sentiment that awareness and education on the business case, benefits and practicalities of building with wood – particularly for owners and authorities having jurisdiction – is lacking. It is neither functionally nor technically reasonable to assume that traditional market expectations that arise from familiarity with one building design approach can replicated with wood – and indeed that it is even necessary. The following points were noted:

1. **Industry stakeholder collaboration:** Mass timber projects benefit from earlier coordination with the building trades, such as integrating sprinkler trades earlier to ensure the critical life-safety system will work before the building begins construction. A long-term stretch goal would involve broader stakeholders, such as building authorities, insurance and legal, for structured solutions that normalize collaboration earlier in the design process.
2. **Knowledgeable consultant lead:** A consultant with experience working with wood will know that it is important to design for wood systems from the outset, which can still provide flexibility to switch to other systems should market pricing dictate. It is not so easy to go the other way – to reconfigure a concrete design for wood.
3. **Industry-led, public education:** Current real estate trends are not necessarily leading to good design. For example, there is still a desire for overly-glazed envelopes. To take advantage of wood's potential time and cost advantages, expectations need to evolve. A formal "Public Education" program would require time to develop but may be an important component of encouraging demand for innovations such as mass timber.
4. **Consistent regulatory pathways:** not all building authorities have the technical knowledge and/or experience with the regulatory processes necessary to exploit mass timber to its full advantage. Industry-level innovation coordination and knowledge sharing platforms will help to ensure that all industry stakeholders gain access to the latest ideas as quickly as possible.

3.5.2 Opportunities for broader application

While each of the four case studies developed solutions to address the innovation themes specific to each project's challenges, there were commonalities across all of the case studies which offered opportunities for broader application. Each summary point uses the "feasibility time to market" to describe whether the opportunity can be easily implemented now, or whether further development is required beyond individual practitioners.

3.5.2.1 Concept and context

Given that the owners were fictitious, the experts used their professional judgement and experience to establish a reasonable market-oriented context in which the solutions were prioritized based on "best value". Issues related to concept and context were primarily driven by:

- Site limitations
- Building design and material limitations and assumptions
- Procurement considerations
- Construction considerations
- Cost implications
- Code considerations
- Managing and understanding owner expectations

The following prioritized themes emerged relating to the concept and context of wood buildings:

1. **No brainer - understand Code limits:** Designers need to know what can realistically be achieved through existing pathways (e.g. Alternative Solutions). A project concept must be developed cognizant of these issues or it will either fail quickly or get bogged down by cost, regulatory or constructability challenges. Such failures and challenges may turn owners and building authorities away from attempting innovative wood solutions again in the future.
2. **Short-term – develop a holistic understanding of wood design**: All stakeholders need to develop an understanding of the material and structural characteristics and constraints of wood, and the broad design and construction strategies that takes these limitations into account while exploiting wood's advantages. In many cases, this often means adopting a mix of new and accepted practices (e.g. hybrid solutions).
3. **Medium-term - build awareness with owners:** Enveloping all of these issues is the need to educate owners about the unique characteristics of wood (economics, supply, etc.), the opportunities and advantages (prefab, modularization, etc.), and the resources and "pathways" available to support adoption (see Appendix B for more information).

3.5.2.2 System selection

During detailed design and analysis, the structural systems are further defined by factors such as material constraints, market constraints, project location, etc. This includes:

- Development of the structural system, such as load bearing structure, load transfer systems, gravitational and lateral systems, optimal spans and member size selection

- Occupancy and related code requirements, such as firewalls and building safety
- Total building performance, inclusive of the building envelope, energy efficiency and durability

These criteria are different for each design, location, material and owner. The experts noted many owners would approach an architect with a highly prescriptive brief without considering these factors. Therefore, in order for wood to be successful, consultants and builders must be willing to challenge these beliefs. Key to this objective will be helping owners establish the underlying performance objectives of a project as opposed to the traditional prescriptive approach. Setting clear measurable performance goals offers greater design flexibility and fully utilizes the project team's expertise. In every case study, adaptations to the baseline case study configuration were made to optimize the use of wood in the following areas:

1. **No-brainer – determine the overarching priorities:** The governing constraints to the project may be cost, speed, regulatory, sustainability requirements or skilled-trades availability – or a combination. The impacts of these factors need to be made clear to the owner as early as possible and will dictate the choice of structural system.
2. **Short-term – understand the owner's requirements:** The project requirements dictate the extent to which the design team can innovate.
3. **Short-term – Strategies for wood adoption:** a white paper for owners that outlines the basic parameters for designing a mass-wood building and all the associated benefits and compares mass timber to traditional concrete and/or steel alternatives could foster greater adoption of innovative wood projects. Owners may be encouraged to consider wood from the start, if they are confident that it is easy to "switch" to a different structural system if required.

3.5.2.3 Project optimization

Workshop experts were charged with developing optimal solutions (i.e. trade-offs) in terms of energy efficiency, constructability and cost effectiveness and, in some cases, better occupancy comfort, more flexible use or increased marketability. Fine-tuning designs to be the most efficient and developing alternative details that may be more cost effective and constructible – even if adjustments over accepted practice are only minor – will bolster market adoption of mass timber. The optimization process routinely occurs on an iterative basis in the design development stage based on the following:

1. **Short-term – Collaborative approach:** Case study optimizations highlight the value of input from both consultants and builders working closely together. The difficulty is ensuring that true collaboration extends into the procurement process and construction.
2. **Short-term – Impact of prerequisite decisions:** optimization comes after the system selection decisions have been made. Working within regulatory limitations limits, it is important to allow for as much flexibility as possible to respond to unfamiliar and/or unforeseen challenges, such as those encountered in the case studies.
3. **Medium-term – Front-end effort:** similar to real projects, the workshop baseline designs had been worked up to a certain level of resolution where the opportunities to optimize and balance the design had, to a certain extent, been limited. Two case studies required reconfiguration – something that a real project may not allow. To limit the need to "shoe horn" wood solutions into inappropriate building layouts, the owner must be educated on the costs and benefits of early involvement from the building team and the need to start with a wood design first.

3.5.2.4 Construction details

Not every case study got into construction solutions to the same degree of detail. Nevertheless, a number of details emerged that focus on no "brainers" or "state of the shelf" solutions that are usable today. It is important to state that the intent is not to imply these details replace the audiences' experience and judgment. Each detail needs to be considered in the context of the specific project and be modified to suit other situations. In addition, a few of the details may require Alternate Solutions.

3.5.3 Opportunities for further research and education

The workshop discussions raised a number of questions that could not be answered within the time allowed, but which – if solved - could help practitioners build a case for adoption to owners. These issues offer opportunities for further outreach by industry advocates, targeted education and/or research:

- What is really driving/restricting the use of wood in real world projects?
- What are the reasons for the premium on mass timber projects?
- Which in-demand building topologies should be focussed on to drive market adoption of wood?
- What are the tangible downstream benefits of wood for building occupants, that will encourage building owners and developers to use it?

The workshop discussions provide evidence that the adoption of innovative wood solutions reinforces a mega-trend of industry wide "modernization". Given the rapid pace of change, all stakeholders (and not just the building industry) could benefit from education in order to revise out-dated assumptions. This might be accomplished through a wood building procurement guide or white paper, together with workshops for developers and owners, detailing what wood can and cannot do.

3.5.4 Workshop effectiveness

The workshop participants were selected for their track records in design and construction innovation, their readiness to share ideas, and their willingness to go beyond accepted 'best practice' solutions without losing sight of what is achievable within the economic constraints of the British Columbia market. Unsurprisingly, this experienced and talented "faculty" provided a great deal of useful feedback that covered ranged from strategic industry initiatives, through product supply and building procurement to code issues and specific design solutions. Indeed, a great deal of value can be placed on providing a means for these industry leaders to collaborate on a regular basis.

It is important to note that while the workshop was generally well received by the participants (Appendix C.3), the evaluation forms also captured a number of suggestions for improvement if this workshop collaboration format becomes a regular event. The following provides a debrief on what we believe worked and what can be done differently if the workshop format is to become a means for resolving gaps and identifying opportunities for emerging building systems and wood innovation. The following chapter also discusses the role of the workshop format as a vehicle for industry collaboration to continue to resolve challenges on an ongoing basis.

3.5.4.1 Case study effectiveness

- The case studies were developed based on professional experience and input from industry interviews. We designed them to expose as many different levels of challenge (concept and context, system selection, optimization, details) as possible, yet we found that, for some, the range of opportunities were too broad, and it took a while for them to get focussed.
- Developing the case studies with sufficient information for the participants to tackle solutions involved striking a fine balance between providing enough information to orient the project team and too much, where they start to critique the "design". However, all of the case studies achieved the goal of highlighting the different levels of innovation and produced useful outputs.
- We expected that the emphasis of the workshop would be on dealing with details. However, most of the discussions were on how best to configure the buildings for wood so that the technical challenges were then achievable.
- Participants wanted to work on real projects. Finding a project team willing to share their project was difficult given issues of liability and IP protection. However, having now gone through the workshop, participants may be willing to share – at least within this group of close-knit peers.

3.5.4.2 Workshop logistics

- The workshop participants would have benefited from being able to familiarize themselves with the case studies ahead of time.
- The groups would have benefitted from having an owner present and, while construction professionals participated some felt it would have been valuable to have cost consulting advice.

3.5.5 Limitations of case studies and details: innovation as a principle

Within the workshop's constraints, the details within this report respond to the specific case study projects' assumptions, which include the owner's design brief, market supply issues (e.g. CLT), codes and standards, regional climate and cost effectiveness. Some topics, such as energy /carbon emissions, were recognized as critical factors but may not have been explicitly addressed given the lack of time. Based on these assumptions, the details cannot cover every possible project given the variability of climate, labour and material costs, etc. across British Columbia. Therefore, the case studies offer a methodology for disseminating an understanding of the underlying principles that support the adoption of new wood technologies and practices. As the building industry begins to utilize these innovations their usage will become normalized and they will be assimilated into standard practice.

Historically, the assimilation of new products and technologies has typically taken 10-15 years from the moment of introduction to the market, to the full understanding of that product's potential and its common use across a range of building occupancies and applications. In this context, the details that have emerged from the workshop can be seen as a tool to accelerate the assimilation process but may not represent fully optimized solutions for any given situation specifically.

CHAPTER 4 Recommendations

In this section, we review the lessons from the workshop in the broader context of advancing emerging building systems and wood innovation and offer recommendations for encouraging information sharing and collaboration outside the project team environment.

There is broad agreement among economists on the importance of innovation for long-term economic growth and competitiveness. According to the OECD, long-term growth depends upon "building and maintaining an environment that is conducive to innovation and the application of new technologies."[25] As the scale and diversity of new ideas expected to impact the construction industry grows, there will be pressure to integrate building design and construction resources in line with the industry trend towards greater efficiency through collaboration. This chapter reviews the role of the workshop format as a vehicle for industry collaboration so that the emerging issues and challenges associated with the adoption of innovative wood solutions can be addressed on an ongoing basis. Based on our research of best practices in innovation management in British Columbia and other jurisdictions, we also suggest some additional elements that might be incorporated to make the process even more effective.

The recommendations in this chapter are also derived from consultation with the workshop participants. During the workshop, we conducted a one-hour facilitated discussion to probe concepts and perceptions related to innovation management. Based on their first-hand experience of the workshop, we wanted to hear how participants felt it might fit into the range of innovation support programs and services that exist already and about what role industry advocates (such as governments and NGOs) should play to best support the innovation process.

It is important to stress that encouraging leaders to collaborate to solve technical and regulatory challenges and to share their knowledge[26] should not be seen as a one-off exercise. Innovation requires a sustained, formalized process for development and diffusion to work effectively. Therefore, a proposed framework and information platform is addressed in a separate report to government and industry decision makers.

Finally, for any or all of the recommendations, leadership from government in the form of policies and innovation support for public sector projects can play a key role in helping to build capacity, grow emerging markets and ensure that external issues (such as the shift towards zero emission buildings) are adequately addressed.

Objective	Recommendation
1. **Precedent for the workshop format**	Leverage government interest in advancing innovation in buildings to advance the concept of an innovation peer group or "faculty" of experts. To reassure users of the information that the data has been properly validated, a list of the faculty could be provided on the website where the solutions are published (although there would not be attribution to specific information, detail, etc.).
2. **Position innovation as an investment, not an expense**	Building awareness of the value of corporate investments in innovation within the construction industry will be key to engaging more members of the mainstream industry. Incentives and/or financial support programs designed specifically for the construction industry may be necessary. This is not an easy fix.

Objective	Recommendation
3. **Build a culture of information sharing**	Targeted information and support is needed to help businesses of all sizes understand the value of and participate in information sharing and collaboration.
4. **The workshop as a platform for collaboration**	The workshop was an effective means for leading practitioners to collaborate and share information. It is important to encourage knowledge sharing among practitioners, so long as by doing so, the author's competitive advantage or Intellectual Property rights are not infringed upon.
5. **Financial considerations**	There is value in repeating the workshop for another group of practitioners using much, if not all, of the existing materials.
6. **Organize information effectively**	For innovation diffusion to happen, information about new technical or regulatory solutions must be organized in a way that allows practitioners to engage with it in a timely way based on their project needs, experience and expertise.
7. **Open discussion environment**	Retain an experienced workshop facilitator with subject matter expertise and ensure that the note takers at each table are allowed to focus on documenting the work. Project owners and developers should participate at the workshop.
8. **Real projects**	Real projects as case studies, though difficult to secure, would provide the difficult constraints and challenging trade-offs that encourage innovative, practical solutions.
9. **Peer to peer learning**	Broaden the application of the workshop format to any practitioner willing to share information.
10. **Utilize Alternative Solutions**	While an Alternative Solution cannot be published and put to use in situations outside that which it was developed to address, a high-level list of Alternative Solutions that have been accepted in generic form, along with a mechanism for identifying common applications, could help both practitioners and policy makers address barriers to innovative design.
11. **Ensure access for small businesses**	When developing innovation resources, consideration should be given to the limited capacity of small businesses to invest in innovation. Published case studies should be balanced in their scope and present project challenges, so that real-life lessons can be learnt. Ensure that construction expertise is available during the workshop and as an integral element of a "faculty" of experts.
12. **Innovation organization**	An organized and curated innovation management platform could help to streamline and target the information flow to be of most use to practitioners.
13. **Develop a component catalogue**	Develop a library of standard, pre-fabricated components and assemblies
14. **Assign responsibility for addressing innovation challenges**	Given that there is no organization that is mandated to advance innovation in construction in British Columbia, key provincial agencies (e.g. Building Safety and Standards Branch, BC Housing and Forestry Innovation Investment), NGOs and researchers may consider collaborating to address the challenges identified in this report.
15. **Consider mass timber assemblies in BC Building Code**	Develop and incorporate regulations for the design and construction of mass timber structures into the BC Building Code.

APPENDIX A Additional information - barriers and opportunities to innovative wood design

The following information provides additional support to Chapter 2.

A.1 Concept and context

A.1.1 Industry norms – Example: Construction Scotland Innovation Centre

The focus of the Construction Scotland Innovation Centre (CSIC) is to connect industry and researchers to increase innovation and get research into industry. Developed by industry for industry, CSIC provides businesses with a one-stop-shop for all aspects of innovation funding and support. The vision is to create a networked community of industry, academic and public-sector talent, channelled towards providing necessary, effective and appropriate innovation support to industry in order to deliver a paradigm shift in the sector's approach to innovation and drive transformational change within the industry.

CSIC supports all construction related businesses across Scotland from architects to product manufacturers to facilities management. They will work with businesses to connect them to the expertise and services the business requires. Innovation themes include Infrastructure, Design and Performance, Advanced Construction, Energy and ICT and the Environment. For each theme, CSIC offers:

- An entry point to the innovation support landscape
- To match business needs with academic and public-sector expertise
- Access to potential funding
- Access to prototyping and testing facilities
- Facilitation of training and education
- Collaboration, networking, partnering and knowledge sharing

A.1.2 Authorities Having Jurisdiction - Existing regulatory pathways

A detailed evaluation of the pathways available to practitioners in British Columbia is necessary. There are a number of options and approaches available to industry today for resolving technical and/or regulatory barriers to the use of new products and practices. The following review assesses whether any of these solutions' "pathways" could serve as an innovation platform (or part thereof). It is expected that these pathways will continue to serve important functions, but the findings could be incorporated into a platform that centralizes and organizes the data so that it is searchable based on a number of criteria and is included in search results based on relevant / complementary topics.

A.1.2.1 Alternative Solutions process (formerly "equivalencies")

OVERVIEW	
Solution lead	Code consultant and building owner
Timeline	Short-medium (depending on application complexity)
Description	An Alternative Solution is an application to an Authority having Jurisdiction (AHJ) for review of a solution not prescribed explicitly in the BC Building Code. The Alternative Solution achieves the intent of the building code and requires exact code reference. The Alternative Solution takes the form of a signed and sealed code report that is almost always developed and submitted by a code consultant. Others involved may include the architect and applicable sub-consultants. The results of the alternative solution are specific to the project and historically are not shared publicly.
STRENGTHS	1. Direct AHJ review and approval. 2. Process is established (declared in previous editions of BCBC and/or has been used for many years). 3. Conforms with a professional consultant's typical assurance (legal, liability covered by schedules). 4. Solution's performance (needs to achieve "what") is objectively known (typically quantitative: "1 hour").
WEAKNESSES	1. Limited to time of building permit application. 2. Different AHJs require varying submission requirements and review process. 3. If rejected, AHJ decision is final and some may not allow multiple AS applications. 4. An application is fixed to defined solution performance minimums and must not modify the Code's intent. Application is also tied to 5 year BCBC update cycles and a lot can change in that time. 5. Complex AS applications often involve many submission/reviewing consultants. 6. Information is specific to the project and copyright protected.
OPPORTUNITIES TO ADVANCE INNOVATION	1. Often involves reviewing consultants: perhaps this reviewing process could have a standard panel or faculty of experts? 2. Streamline across various AHJ's into a standard procedure. 3. Create new AS process to account for pilot design types. 4. To develop a means to share information outside of the project – in general terms

Typical process

The following example is extracted from the City of Vancouver's information about Alternative Solutions.[27]

1. Register for an online.
2. Log into your account. Confirm the address and location of bylaw variances. Provide a brief project description. Make a separate application for each alternative solution (unless the solutions address related concerns).
3. Provide the following with your application:
    a. A document reference

   b. Summary of requested deviation
   c. Summary of proposed solution with support documents
   d. Payment information
4. Electronic application documentation may be provided with appropriate Digital Seal technology in accordance with the regulations of AIBC and APEGBC. Paper applications with ink seal may be submitted directly following the online application.
5. The system will provide you with a summary of fees and an invoice for your application.
6. Pay the application fees using the online system. Related alternative solutions may be applied for together for a reduced fee, subject to the approval of the chief building official.
7. Your application will be reviewed by building policy engineers in the Office of the Chief Building Official. An engineer may contact you for more detail by email or phone.
8. Track the status of your application online. If your application is approved, a building policy engineer will apply a Notarius seal to indicate approval and forward it to you for your reference.

Initial reviews take about four to six weeks but can take longer depending on the complexity of your proposal and whether we need any additional information or feedback. Further reviews will vary in length based on how extensive the revisions were.

A.1.2.2 BC Building Code appeals

OVERVIEW	
Solution lead	Consultant (code or related to code reference), building owner
Timeline	Short
Description	An application may be made by the code consultant or architect (lead), owner or contractor to the BC Building Code Appeals board for review of an AHJ's interpretation of the Code (typically a dispute from a building permit application or failed inspection). The appeals process is intended to capture disputes ranging from small owner-initiated renovations to large, professional developments. The BC Building Code Appeals Panel reviews the first judgement in conformance to accepted interpretation of the code and cannot modify the code in any way. NOT to be confused with the BC Building Code Interpretation Committee (which is not for time-sensitive code interpretations for site conditions). Rulings are available on the website.
STRENGTHS	1. Direct review of AHJ decisions by Building Code Appeals Board (similar to a "higher" court). 2. Independent from government (decisions are purely to review for conformance with the intent of the building regulations and not to judge AHJ's). 3. Solution's performance (need to achieve "what") is objectively known (typically quantitative: "1 hour").
WEAKNESSES	1. No ruling can modify the BCBC in any form. This process is only for BCBC intent clarification. 2. Decisions take 3-8 weeks and occur on a set review schedule.

	3. Decisions are final and binding and can only be overruled if a judicial court determines that the basic principles of administrative law have not been followed. 4. The list of approved decisions is organized by date only with no facility to filter or search. It would be better to organize the list by divisions of building code.
OPPORTUNITIES TO ADVANCE INNOVATION	1. Dynamic BCBC revision review (e.g. via open standard/living documents)

Typical process

The following process is extracted from the BC Building Code Appeals Panel's website.

The appeal must involve a disagreement between an authority having jurisdiction (a building official) and an owner or his/her agent (a designer, builder, etc.) over interpretation or application of the code. The appeal must be made by the building owner or someone retained by the owner under contract or subcontract in respect of the design, construction, alteration, repair or demolition of the building.

It is best to apply by the end of the month to minimize wait times. Decisions take 3-8 weeks. Only in extenuating circumstances is an appeal conducted in the form of a hearing where parties attend.

Prepare an application: Submission packages must meet the following requirements:

- A completed application form (PDF) – the applicant completes Section 1 and the building official completes Section 2
- Written details of the dispute
- Sufficient data to support the appeal (e.g. drawings and reports)

Applications can be either electronic or paper – paper copies must include six copies of the above items. Successful decisions are posted to the BC Building Code Appeals website in the order that they are approved.

A.1.2.3 Ministerial Orders and Site-Specific Regulations

OVERVIEW	
Solution lead	Binding to the Legal Description of the property.
Timeline	Long (custom government policy)
Description	The new Building Act will offer a pathway for innovative buildings. Under Section 8 of the Building Act, an individual (such as a builder or developer) will be able to submit a proposal for an innovative building to the Province for review. The Province will review the proposal to assess if the proposed building can provide an acceptable level of safety and performance. If the proposal is approved, the Province will enact a site-specific building regulation to authorize construction. The cost of the review will be paid by the proponent under the Act's fee and cost-recovery model. This process builds on a series of earlier successful experiences to create "custom" versions of the BC Building Code bound to a Legal Description (Property). The provincial government utilizes a Ministerial Order to issue a unique Building Code (known as a Site-

	specific Regulation) that must be backed up by consultation and testing by experts for all modifications in the Order. The reviewing / approving process is led by the Provincial Ministry responsible for Building Code, and related departments such as the fire commission. The team should include: • Project design team • Subject matter expert code consultant • Subject matter expert consultants (structural, architect, etc.) • 3rd party reviewing parties with expert authority (fire department, etc.) • Beneficial to include: subject matter expert contractor The solution is publicly available.
STRENGTHS	1. Allow "Site Specific Regulations" (SSR) modification of the Building Act/ BCBC. 2. Very versatile, by allowing the BC Building and Safety Regulations Branch to approach innovation case by case (by project).
WEAKNESSES	1. Policy level revisions: building code regulators and AHJ must have concerns alleviated. 2. Typically, MO still must be grounded in the objective performance of the code. 3. Limited to individual site and project (bound to legal description). 4. Requires extensive consultation and/or testing, with highly regarded, 3rd party firms. 5. Usually requires over-design for "first implementation". 6. May be time consuming and expensive. 7. The administrative process may need streamlining in order to scale up if demand increases.
OPPORTUNITIES TO ADVANCE INNOVATION	1. Following the model of a Ministerial Order by project/legal description, it would be helpful to be able to develop Orders for concepts so long as they are definable and repeatable. Such Orders could be dynamic documents that get folded into the next code cycle.

Typical process

UBC Brock Commons, an 18-storey timber student residence, required 20 expert reviewers and an estimated cost of $250,000 to complete to feasibility report prior to engagement with the Ministry. UBC and leading firms with excellent reputations were retained on the project. The MO process took eight months.

1. Jointly funded report to back-up MO application.
2. Experts produced the report, with an extensive list of 3rd party consultants to back-up the application.
3. Much of the report was based on existing, implemented practices.
4. The report must demonstrate new practices/design/technology achieves "equivalency".

A.1.2.4 Testing agencies

OVERVIEW	
Solution lead	Testing agency is the owner of the testing results
Timeline	Medium-Long
Description	Testing to industry/authority-acceptable standards by an approved testing agency. The testing is typically to establish standards, with repeatable methodology. Test can be as simple confirming slip resistance of floor tiles, to confirming performance of custom curtain wall assemblies at 1:1 scale. The AHJ is the reviewing/approving organization. Depending on the scope, related departments such as the fire department may be involved. The team involved may include: • Project design team, • 3rd party testing and reviewing agency (typically hired by project owner), • Depending on scope: subject matter expert consultants (code, structural, architect, etc.), • Depending on scope: contractor (e.g. shop drawing coordination).
STRENGTHS	1. Provides laboratory/scientific data that confirms the "design" as tested achieve the standard in question. 2. Protects consultants and AHJ by verifying "custom" design will perform to standards (“sleep at night” criteria). 3. Access to subject matter experts who can assist with developing solutions for compliance to standards.
WEAKNESSES	1. IP liability - lab tested assemblies must not be modified or have any materials substituted otherwise the assembly is considered "untested". 2. New testing – it may take time depending on the complexity or variance from tested designs that fulfil standards. 3. Cost of testing. 4. Still bound by standards, which are often updated or revised at great time spans and effort.
OPPORTUNITIES TO ADVANCE INNOVATION	1. Priority list of issues to be tested (message board style again). 2. Open standards or objective-based living documents? 3. Develop a centralized list of the testing centres serving BC’s construction industry.

A.1.2.5 Engineering judgment analysis

OVERVIEW	
Solution Owner	Consultant issuing the judgment
Timeline	Short
Description:	The following information is based on Hilti EJ of proprietary, tested systems.[28] Engineering judgments are extrapolation of approved/tested systems that conform to Standards. Typically, modifications or substitutions are proposed to the engineer who judges whether the system will perform similar to the tested system. The reviewing/approving organization is usually the Authority having Jurisdiction (AHJ) and/or the code consultant.

	The team involved may include: • Contractor (typical applicant) • Project coordinating professional • Optional: code consultant
STRENGTHS	1. Compliance by extrapolation - provides non-conforming, but "near compliant", variations to listed solution that do conform to standards. 2. Liability - typically has sealed assurance from an expert to support the solution.
WEAKNESSES	1. Typically, judgements must be "near compliant"; otherwise the AHJ will require formal testing to standards.
OPPORTUNITIES TO ADVANCE INNOVATION	1. Establish a priority list of issues to be tested for practitioners to add to (message board style).

Typical process

The following is based on Hilti's EJ submission process.

Fill in application and submit to Hilti email address, with the following:

- On-site situation (type of penetration, assembly being penetrated, etc.)
- Designed or intended tested fire protection system (including intended FRR)
- Modification suggested, or request for modification per the on-site situation.
- Application is electronically submitted.
- Coordination with US Engineer, including with Hilti's Canadian Review Engineer.
- EJ is written and sealed, and then submitted to Contractor for submission to Coordinating Consultant (Arch) and AHJ.

A.1.2.6 Academic R&D

OVERVIEW	
Solution Owner	IP typically agreed upon contractually.
Timeline	Long
Description:	Research and Development of technology and processes combining resources and expertise between industry and academia. The reviewing/approving organization is usually the Authority having Jurisdiction (AHJ) and/or the code consultant. The team involved may include: • Project design team, • Subject matter expert code consultant, • Subject matter expert consultants (structural, architect, etc.), • 3rd party reviewing parties with expert authority (fire department, AHJs), • Bonus: subject matter expert contractor

STRENGTHS	1. The R&D project has access to university-grade R&D resources (labs, professors, students, etc.). 2. Time/resource/risk sharing for R&D. 3. Leverages the university's network (beyond typical private firms).
WEAKNESSES	1. Working within academic timeframes and priorities.
OPPORTUNITIES TO ADVANCE INNOVATION	1. Currently there is no centralized list of R&D "assets" for construction such as testing centres, laboratories, equipment, expertise etc. in Canada. 2. An easily searchable list of current and/or recently completed projects and test results.

Typical process

R&D forms the scientific, evidence bases for design solutions. Therefore, the time and resources required to "commercialise" R&D outputs vary. Examples of existing "commercialisation" organizations within universities in British Columbia include UBC's UILO[29] and BCIT's ARLO.[30]

A.1.3 Time to market descriptions

A framework was developed by the workshop participants to prioritise the solutions for their case studies (Figure 19) to organize, evaluate and disseminate solutions for "no brainer" to "short-term innovations" that have already been implemented by early adopters through existing pathways, and to catalogue other issues for future attention by the industry. Several observers from the R&D and commercialisation field were invited to take part in the workshop to provide perspective on the challenges and opportunities present by real-world innovation.

Figure 19 Descriptions and examples of innovation time to market

	No brainer	Short term	Medium term	Long term "blue sky"
Definition	In use but not broadly adopted.	Evolving typology.	New concept.	Theoretical.
Example	Wood elevator shafts. CLT balconies.	Large scale Passive House.	Large scale / complex modular / digital fabrication.	30+ storey tall timber buildings.
BC market acceptance	Several local examples already accepted by some AHJs.	Few local examples, acceptance may be considered by AHJs.	No local examples, AHJs require stringent practitioner due diligence to accept.	No local examples, not acceptable with local AHJs.
Project impact	Known but not widely disseminated, requires little/no change to typical project workflows.	Known but not widely disseminated or is contentious, requires variations to typical project workflows, such as Alternate Solutions.	Not widely known, requires significant variation to typical project workflows, such as pre-design due diligence reports.	Not known, cannot be utilised in current projects.

	No brainer	Short term	Medium term	Long term "blue sky"
Building industry application	Requires little/no adaption to be accepted by industry.	Requires adaption through "structured" pathways (Alternate Solution) or specialised products to be accepted.	Requires significant adaption through pathways that allow code "customization" for custom solutions to be accepted.	No existing pathways or products/systems will allow industry adoption.
Regulations and Standards	Generally, conforms to current standards.	Requires specialised judgement (code consultant) or products (testing) to conform to current standards.	Requires new code interpretations or new (to BC) products to conform to current standards.	Requires significant revision to current standards or the development of new products/systems.

A.1.4 Market influences – Detailed discussions

The complexities of market influence were discussed in detail across many interviews and during the workshop.

A.1.4.1 Internal factors

Businesses that serve British Columbia's construction industry range in size from sole proprietors and SMEs to large trans-national corporations. They provide all manner of products and services, yielding a highly variable group of adopters. Inevitably, innovation is not for everyone. Availability of resources and support, ability to upgrade (or acquire new) competencies versus revenue generating activities, and the ability to "prove" competence with innovative solutions are all based on the characteristics of the proposing firm. The firms that are innovation leaders tend to choose to do so based on the corporate culture established by the principals. The size of the firm or its capacity for vertical integration tends not to be such a clear indicator of the likelihood for a firm to be innovative. Some of the largest firms, even multi-disciplinary ones, may be bound by internal procedures, whereas SMEs can be nimbler and more flexible. The recruitment process for the workshop experts sought participation from a wide range of leading firms in terms of size and discipline supported by researchers and NGOs.

Sharing information is perceived as being fraught with risk related to the loss of intellectual property (IP), and therefore can adversely affect competitiveness. Most companies protect their IP fiercely and they are wary of sharing information – particularly if it relates to negative experiences and failures. However, we heard from some leading practitioners and, as illustrated by the extent of participation in the workshop, there are those that share little concern for IP protection. They appear happy to share ideas as they believe that:

- It is extremely difficult to patent or otherwise protect a building design, assembly or construction methodology,
- There is only a brief window of time when an innovation is unique before it is absorbed into the mainstream market, and/or
- That any competent architect or engineer can replicate their solutions, and that their competitive advantage lies in their ability to be innovative rather than in specific solutions.

Nevertheless, it is important to ensure that experts always feel properly protected from risk of challenge resulting from the potentially improper use of their solutions.

A.1.4.2 External factors

In British Columbia, the development landscape, polices and regulations drive a maximization of liveable space, mixed and stacked occupancies, walkable and liveable neighbourhoods, and high-performance building envelopes. Specifically, within urban centres such as Vancouver, there are frequently set-back requirements and zero-lot line conditions that affect building form. In addition, housing affordability is a key priority, making the exploration of innovative solutions for non-market housing an important case study. This typically requires solutions that either shorten construction schedules or drive down the cost of materials and labour. The workshop case studies were designed to reflect realistic market conditions and constraints expected in British Columbia.

Mass wood construction exposes issues that can sometimes be seen as more cultural than empirical. Some designers and builders strive to work with wood whenever possible, whereas others are predisposed against it. The bases for these prejudices may or may not be grounded in fact or science.

Best practices, procurement, project delivery, and the method and means of construction all have far-reaching consequences for innovation. As a result, the presence of construction expertise was vital to the success of the experts' workshop, where cultural norms could be scrutinized when considering the barriers and opportunities with new wood technologies and practices.

Cultural fixtures: method and means

Weather protection at Limnologen, Sweden. Image source: Perkins + Will Research Journal 2014 / VOL 06.02

The most controversial (perhaps because of costliness) is with weather protection of structures during construction. Faced with similar climates to British Columbia, the Scandinavians routinely protect their wood structures with tents or temporary roofs, while in British Columbia typically do not. Some local projects have included a contingency sum for weather protection, but rarely provided that protection pre-emptively.

Numerous contractors, owners and design teams have ended up regretting this omission: the Richmond Oval, CIRS and the MEC Head Office all suffered water damage during construction, with significant costs and schedule delays.

These cultural norms can negatively impact the uptake of mass wood construction across the industry. However, justifying the extra cost, typically several hundred thousand dollars, will be extremely difficult until mass wood is truly cost competitive with concrete.

A.2 System selection

A.2.1 Building typologies

While institutions (e.g. universities such as UBC, SFU and UNBC) are often the first to explore and adopt new technologies and have a long track record of investing in some of the most innovative buildings in Canada), lessons may not be easily transferable to the market because of differing financial and regulatory constraints. By comparison, market multi-family residential and mixed-use (residential / commercial) projects make up the majority of new buildings in British Columbia. These are more commonly undertaken within the tight timeframes and budgets prescribed by the development community. Given the popularity of these building typologies and the constraints that are imposed on the design and construction processes, there are significant opportunities for innovations in wood technologies and practices to play a role in improving quality, affordability and performance. Input from interviews regarding typologies were included into the workshop case studies where possible.

A.2.2 Market awareness and education

Interviews and discussions provided numerous examples of situations where the entire design and construction team wanted to use a wood structural system but were overruled by the owner based on concerns that arose primarily due to lack of familiarity with the material and therefore a heightened perception of risk. A few of the most common misperceptions of mass timber that were gathered from interviews with practitioners were incorporated into the workshop case studies.

A.2.3 Market forces: Uncertainty of product availability and pricing

Currently, British Columbia is experiencing a highly inflationary and/or volatile market for construction materials, causing considerable pressure on pricing. British Columbia currently has two large scale manufacturers of mass wood panel products: Structurlam in Penticton, and StructureCraft in Abbotsford. Capacity cannot always be matched to demand, so prices and delivery times offered at the schematic design stage may not be achieved at the time of tender. The information these experienced design/fabricate/build firms can provide on cost and schedule is product specific, and its accuracy over time is currently a function of the supply and demand cycle. With limited availability of local CLT, prudent structural engineers design their buildings such that the specified CLT panels may be replaced by other product alternatives such as nail laminated timber (NLT) or dowel laminated timber (DLT) should local supply not be available at the quoted cost or within the required time frame.

A.3 Optimization

There is no question that governments, communities and the general public clearly understand the impacts of buildings as major consumers of natural resources, emitters of greenhouse gas emissions and generators of waste. Neighbours of construction projects can be vocal in their objections to the noise, mess and traffic congestion. At the same time, companies are looking to lease or buy healthy, digitally smart workplaces and housing developers are differentiating their new projects based on green features and access to amenities. All of these factors are being brought to bear in the development of new building projects and encouraging professionals to be more predisposed towards innovation.

A.4 Details

The professionals interviewed noted that they do utilise a wide range of technical resources and will call their peers from time to time for advice. Indeed, there was a general comment that the overwhelming amount of unfiltered information was often difficult to deal with, time consuming and often fails to deliver a useful outcome. Interviewees mentioned there are few databases and libraries that are able to:

- Adequately communicate the contents of their dataset,
- Demonstrate that the data is valid, and
- Filter and sort the content in ways that are intuitive to design and construction professionals (e.g. by climate zone, building typology, applicable jurisdiction, etc.).

In effect, there are many sources used, but no central platform where innovation for the building industry is managed. The interviewees and workshop participants also raised the need for data resources to provide "information about the information". Busy professionals need to know whether a database is worth searching and then be able to navigate to the right information quickly.

APPENDIX B Information sources about emerging building systems and wood innovation

While no central "platform" exists, there are several useful resources that are applicable to British Columbia, all of which have some important, albeit quite specialized, information.

Figure 20 presents a selection of local and international resources that were mentioned in interviews or identified through the project research.

Figure 20 Selection of information sources for innovative wood building design and construction

Organization	Description	Programs, services and resources
LOCAL RESOURCES		
BC Housing Research and Education Centre	British Columbia's public housing agency and a primary research funder and aggregator of information related to energy efficient and affordable housing.	• Best practice guides for residential construction relating to building science, envelope design and home builder training (via "Builder Insights"). • "How-to" videos. • Develops guides in-house and funds technical and socio-economic research.
BC Hydro New Construction Program	British Columbia's electrical utility offers an energy efficiency incentive program for new construction for building owners, developers and the design industry.	• Design assistance services that include building energy modelling for commercial and high-rise residential projects. • Research reports and studies related to energy efficiency. • Technical guides, calculators and case studies.
FPInnovations	Canada's leading research provider in wood technologies and markets.	• Deep technical and market research related to forestry products. • Due-diligence research. • Feasibility analysis, needs analysis and support. • Hardware and software solutions. • Design and technical assistance. • Prototyping and piloting that may not be feasible for individual firms. • Direct consulting services. • Measurement and verification. • Building instrumentation and monitoring.
Wood Innovates BC	A curated online portal designed to inspire and connect designers to wood suppliers.	• A repository for research and technical papers. • Showcases the latest projects and technologies. • Profiles the latest expertise, wood design resources, events and workshops, to encourage exchange on technological developments, research, building and manufacturing efficiencies and innovations.

Organization	Description	Programs, services and resources
Wood *WORKS!* BC	Wood WORKS! BC is an industry led program of the Canadian Wood Council intended to increase the use of wood in residential, non-residential and tall building projects.	• Technical support is offered for free at the project level at both the design and construction stage. • Wood WORKS! BC offers education, resources and project assistance related to the design of non-residential and multi-family wood buildings. • Practitioners particularly appreciate the technical case studies that include details and costing information.
INTERNATIONAL RESOURCES		
Architizer (US-based)	A simple, intuitive yet powerful search interface that connects designers to products.	• Architizer is one example (there are several) of a two-sided content aggregation platform that lets architects upload their work in order to win work as well as professional feedback from their peers. • Showcases case study projects, new products and technologies. • Provides a substantial product directory that includes but is not limited to wood.
Building Research Establishment (UK)	BRE is a global leader in research in building science. Hosts Constructing Excellence which supports construction innovation in the UK and manages an industry benchmarking and KPI program.	• Scientific reports and testing results. • Suite of industry KPI and performance benchmarking tools. • Canadian firms refer to BRE technical reports and case studies.
Holzforschung Austria	An industry-association led, membership-based wood research centre.	• Technical research papers, construction best practice case studies, codes and standards. • Online education (webinars, presentations, etc.). • Accredited (internationally through ISO standards) for all relevant testing, inspection and certification.
Passipedia (Germany)	A wiki-based research library initiated by the International Passive House Institute.	• A comprehensive technical peer-reviewed catalogue related to the design and construction of Passive House projects.
Puuinfo (Finland)	Government and forestry industry-funded wood innovation management provider.	• Technical research papers, construction best practice case studies, codes and standards. • Particular focus on tall wood and pre-fabrication. • Online education (webinars, slides, etc.). • Enjoys an international following.

Organization	Description	Programs, services and resources
RIBA Journal (UK)	The professional magazine of the Royal Institute of British Architects. The printed version has over 28,000 subscribers around the world.	• Curated research, articles, interviews, inspirational case studies, market intelligence, technical and regulatory reports, practice guides and commentary on professional liability issues. • The National Building Specification (NBS) is a subsidiary of the RIBA. NBS recently launched in Canada.
ThinkWood (US)	A portal designed to contextualize innovative wood technologies and practices.	• Aggregator of technical, regulatory research, best practice applications, case studies related to design, building science and construction. • Users like this site for its “smart” search capabilities and a “quickstart” function, allowing users to browse categories of information. Latest additions are located on the home page.
Wood Works US	Offers education, resources and project assistance related to the design of non-residential and multi-family wood buildings.	• Library of resources to enable wood adoption, including leading edge innovations that may appear "risky". • Free technical assistance for projects. • Users appreciated the technical information in the form of CAD and Revit files but only available for standard details.

APPENDIX C Workshop materials

C.1 Baseline workshop drawings set

The following packages of drawings were provided to participants at the start of the workshop.

Case Study 1: Mixed-use residential in Vancouver

Plans	G1-P1
	G1-P2
Sections	G1-S1
Detail underlays	G1-D1

Case Study 2: Multi-tenant office in Victoria

Plans	G2-P1
	G2-P2
Sections and detail underlays	G2-D1
	G2-D2
Elevations	G2-E1
	G2-E1

Case Study 3: Seniors housing in Surrey

Plans	G3-P1
Sections	G3-S1
Detail underlays	G3-D1

Case Study 4: Commercial mixed use with supermarket in Vancouver

Plans	G4-P1
Plans and sections	G4-S1
Sections and detail underlays	G4-S2
Sections	G4-S3

C.2 Workshop designs drawing set

The following drawings were added or revised by participants ad refined after the workshop by Associated Engineering.

Case Study 1: Mixed-use residential in Vancouver

Plans	1-1
	1-2
	1-3

C.3 Workshop documentation

The following backgrounder and agenda were sent out to participants ahead of the workshop.

C.3.1 Backgrounder

Emerging building systems and wood innovation

Tuesday April 17th, 2018 8.30am – 4.30pm, lunch and snacks provided

Vancouver Regional Construction Association, 3636 East 4th Avenue, Vancouver

The workshop is intended to gather experts to resolve persistent barriers to the adoption of innovative wood technologies and accelerate best practices. It forms part of a 9-month research project that tests the potential for an online innovation management platform that will give architects, engineers and builders access to accurate, relevant, validated information.

The workshop allows us to explore how to bridge across industry silos and foster a culture of collaboration while testing a process for streamlining the resolution of emerging issues faced when designing wood buildings in BC. The format allows us to gather insights into the concept of establishing a "faculty" of experts – that are respected by mainstream industry - that could be retained on an ongoing basis to review and, where necessary, develop information prior to sharing via the platform. The project deliverable is a report to Forestry Innovation Investment Ltd. (FII) that reviews best practice models for innovation management, tests processes for creating and validating information (this workshop is a key element) and proposes the key features and functions of the innovation management platform (completion Summer 2018).

This research is important because BC is developing a world-class reputation for the design and construction of innovative wood buildings. Vital to ongoing success is to create a healthy innovation ecosystem whereby technical and regulatory solutions can be proactively identified, solved and shared in a low-risk, efficient and effective way. Building design and construction leaders lack a coordinated system for managing innovation and, in the face of an unprecedented pace of change, this shortcoming may start to impact competitiveness.

For innovators to continue to be effective, accepted solutions need to be diffused quickly to the market. They benefit from an evolving market that can accept and deploy new products and processes. At the same time, these experts are the most qualified to solve problems encountered by late adopters who, in turn, have a greater confidence in unfamiliar solutions if they have access to validated solutions developed by the peers they respect and trust the most.
This event has been approved for 6.5 AIBC LCUs.

C.3.2 Agenda

8.00 – 8.30	**Registration and breakfast**
8.30 – 9.00	**Welcome and setting the scene** • Workshop logistics and objectives • Code of conduct – Chatham House Rule

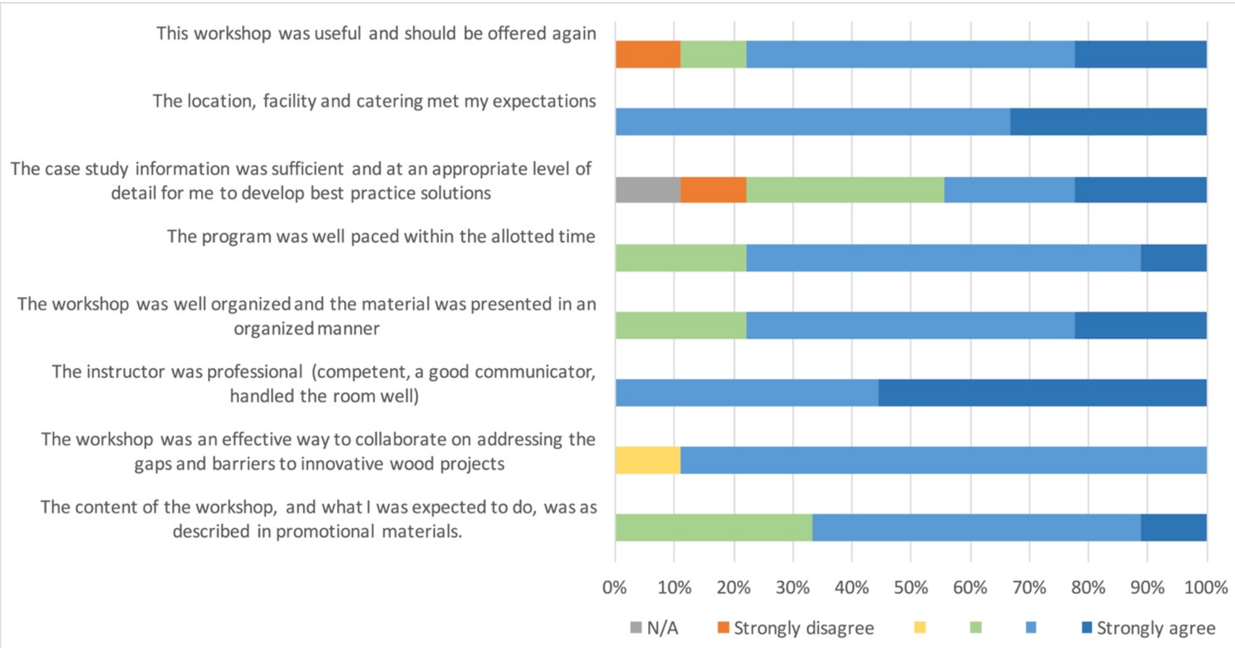
9.00 – 9.30	**Exercise 1**
	• Group introductions
	• Review your Case Study project
	• Review proposed details to resolve:
	    o Are they the right ones?
	    o Is there anything missing?
	• Identify, rank and prioritize the issues to be solved:
	    o Today: Can be solved today
	    o Need more time: Solvable but needs additional resources and/or time
	    o Blue sky: Requires R&D (Parking lot)
	• Questions?

9.30 – 10.45	**Exercise 1 - resolution** • Get to work on issues that can be solved today first • Prepare proposed solutions so information can be shared with the room. • Summarize the issues that require more time or additional research (and why they cannot be solved today)
10.45 – 11.45	**Debrief** • Each group presents solutions • Questions?
11.45 – 12.15	**Working lunch**
12.15 – 1.15	**Innovation management platform:** Introducing the concept, scope and objectives Facilitated discussion
1.15 – 3.00	**Exercise 2** • Introduction to the Case Study project • Questions? • Get to work!
3.00 – 4.00	**Debrief** • Summarize designs proposed • Discuss barriers and challenges • Allocation of responsibilities to follow up
4.00 – 4.30	**Workshop wrap-up and next steps** Remember to complete the workshop evaluation!

C.3.3 Workshop participant evaluations

The workshop evaluations are summarized in Figure 21. The survey questions are provided below.

Figure 21 Summary of workshop evaluations



Q1. What was the most important outcome from the workshop?

- There was a consistency of issues around Code that needs to be fed into the Code development system.
- Discussion about whether solutions info is really applicable to others
- There really is no "best practice" for this topic. Every project is unique and requires professional input
- Details and detail design
- Our industry is "one off" - implementing innovative solutions in wood (or other) is not like manufacturing.
- Best Practice is once solutions are widely adopted/adapted. Innovation is in the early integrated approach
- Networking, collaborative approach to the issues / working together

Q2. Do you have any concerns about the workshop as a way to collaborate and share solutions? If so, what are they?

- No, collaboration was good
- Possible competition

Q3. Please provide your suggestions to help us improve this workshop

- Owner education
- Take actual buildings that have been built and examine alternatives
- Better base buildings
- It would have been helpful if the facilitator at each table would have been more forceful + define outcomes better & keep coming back to them

Q4. What more should be done for a workshop like this to become a legitimate means for addressing the gaps and barriers to innovative wood projects?

- I think these are needed not for the technology leaders, but more for the 2nd wave, with a few leaders. That said, compensation for the leaders who do pass technology on needs to be improved ~noting typical billing rates of $200/h x 6h.
- Include developers

Q5. Were there any important issues that were not addressed today?

- Wood costs and commitment of our society to sustainability
- List of key items required *further work*

Q6. Any other comments or suggestions for how to develop and share information about innovative solutions?

- Summarize the limitations we see in the Code to allow clear recommendations to province.

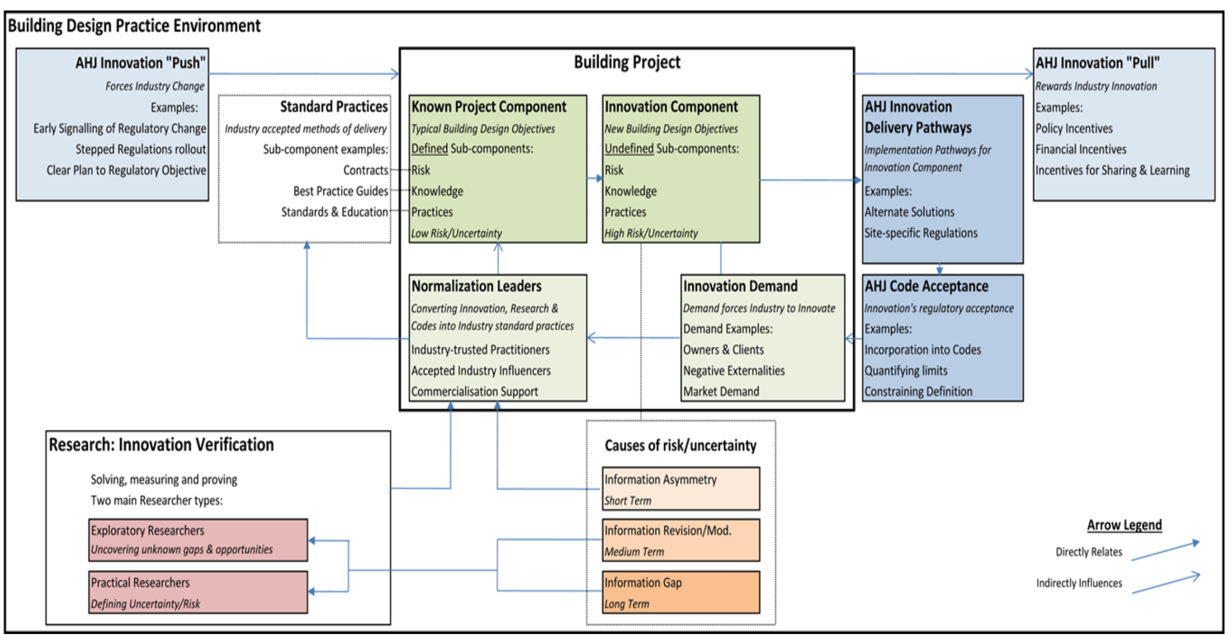
APPENDIX D Detailed recommendations

In this section, we review the lessons from the workshop in the broader context of advancing innovation in the wood design and construction in order to offer recommendations for encouraging information sharing and collaboration outside the project team environment.

There is broad agreement among economists on the importance of innovation for economic growth and competitiveness. According to the OECD, long-term growth depends upon “building and maintaining an environment that is conducive to innovation and the application of new technologies.”[31] As the scale and diversity of innovation that is expected to impact the construction industry grows in step with evolving awareness of the role of wood in addressing climate, resource and productivity challenges, there will be pressure to integrate building design and construction resources in line with the industry trend towards greater efficiency through collaboration.

The following recommendations are derived from consultation with the workshop participants. During the workshop, we conducted a one-hour facilitated discussion to probe concepts and perceptions related to innovation management and information sharing. Based on their first-hand experience of the workshop, we wanted to hear how the participants felt it might fit into the range of research, education and innovation support programs that exist already and about what role industry advocates should play in supporting the innovation process (Figure 22).

Figure 22 Innovation process map



D.1 Precedent for the workshop format

The idea of formalizing this process into a “platform” for encouraging industry leaders to collaborate on new approaches to building design and construction outside of a specific project relationship may be new but there are two peer review processes that offer important models for how to convene and manage a peer group or "faculty" of experts. The BC Building Envelope Council's Building Research Committee, which is convened twice a year by BC Housing[32], is well established and with the roll-out of the new British Columbia Building Act there will also be a regulatory pathway for innovative buildings via Site-specific Regulations which will include a peer review process as well. The workshop offered an opportunity to test the viability of convening a body of experts that is trusted by the industry to review gaps and opportunities, verify the usability of information, and to explore new innovations.

The workshop participants were drawn from a small pool of experts who know each other and have worked together in the past. That said, there is usually some reluctance with offering advice for free versus facilitating knowledge sharing and bouncing off and improving ideas. Intellectual Property in the construction industry is a blurred line: individual products have clear IP attached to them. Wall assemblies, connections and other building families of components can be easily observed and copied during or after construction. Regardless, there is a background process of design development that cannot be easily replicated.

Recommendation: leverage government interest in advancing innovation in buildings to advance the concept of an innovation peer group or "faculty" of experts.

Recommendation: to reassure users of the information that the data has been properly validated, a list of the faculty could be provided on the website where the solutions are published (although there would not be attribution to specific information, detail, etc.).

D.2 Innovation as an investment, not an expense

Within a typical project team environment, design consultants, builders and industry stakeholders work closely together in the service of the owner or developer. The learning and experimentation that goes on during the project design and construction are usually budgeted for and the costs associated with any innovation (research, mock-ups, testing, etc.) are expensed to the project. A key benefit to the project team is the knowledge they acquire along the way. The fact that innovation is "expensed" to a project may be a cause for the disparity between how much industry stakeholders believe is spent on innovation and how little is reported in national statistics.[33] As market expectations evolve, and prices continue to rise, owners may become less willing to shoulder the cost of "learning on the job".

The successful adoption of innovative technologies is predicated upon a much greater degree of information sharing and collaboration, most of which happens outside the confines of a particular project. Interviews with leading practitioners, suggest that the companies that have successfully fostered a culture of innovation are making strategic (i.e. non-project specific) investments in R&D and education. Indeed, we heard that some leading businesses (large and small) are investing between 2 and 5 per cent of pre-tax profits in research projects, building skills and corporate innovation management.

Recommendation: building awareness of the value of corporate investments in innovation within the construction industry will be key to engaging more members of the mainstream industry. Incentives and/or financial support programs designed specifically for the construction industry may be necessary. This is not an easy fix.

D.3 Build a culture of information sharing

Whether it is peer-to- peer within specific disciplines (e.g. structural engineers from different firms), across different disciplines or at different stages in the supply chain, a significant amount of collaboration and industry coordination will be necessary to create knowledge networks and disseminate new ideas.

Non-project specific industry collaboration is usually undertaken in the context of R&D and is common in other sectors, sometimes with a high degree of organization and funding (e.g. the Canadian Oil Sands Innovation Alliance (COSIA)[34]). However, collaboration within the building industry is much more ad hoc, primarily because of the risk of competition (real or perceived). When it comes to information sharing, there is a wariness and scepticism within the construction industry related to IP protection and a perceived loss of competitive advantage that must be addressed.

Recommendation: information and support are needed to help businesses of all sizes understand the value of and participate in information sharing and collaboration.

D.4 The workshop as a platform for collaboration

In anticipation of the workshop, we interviewed several providers of innovation management programs and the point was made that it is extremely important to encourage knowledge sharing among practitioners, so long as by doing so, an author's competitive advantage or IP rights are not infringed upon. Knowledge diffusion potentially increases value through several means:

- **Network effect:** Occurs when the value of a good or service improves as more users engage with it. The scale and scope of Building Information Modelling (BIM) adoption is an example. Anecdotal statements from interviews and a review of other markets (such as the UK where a BIM mandate is in effect for public projects over £50m[35]) provide evidence that all members of the building industry need to adopt BIM and share best practices to yield maximum benefits across all adopters.
- **Economies of scale:** Increasing production of a product, such as CLT, decreases the average cost of production, yielding lower prices for owners. Many practitioners noted that despite local production of CLT panels, it is often cheaper to procure panels from Europe. Sharing CLT details and best practices could increase the number of CLT projects enough to yield economies of scale for local suppliers. This will also increase the competitiveness of mass timber against other forms of construction.
- **Economies of scope:** Knowledge sharing decreases the average and marginal costs of innovation in the long run. For example, sharing lessons learned and reducing duplication of effort among practitioners serves to spread adoption costs across many firms, reducing the cost for individual firms, potentially increasing the value of adopting innovation.
- **Competition and collaboration:** Both competition and collaboration resulting from diffusing knowledge (communicating to industry peers) can be a driver of supporting innovations that serve to increase demand and practicality than possible if the knowledge was kept secret. For

example, with competition, sharing sustainability strategies have yielded innovative products and practices beneficial to the entire industry; with collaboration, cooperation between metal connector and timber suppliers have supported greater adoption of unique timber structures.

- **Public communication:** Another form of communication is knowledge diffusion to an outer orbit of interested parties, such as the public, AHJs or related professions. These stakeholders may represent key drivers of innovation diffusion, who also need to be convinced and persuaded to adopt an innovation. When members of these groups adopt, it tends to signal to others that the innovation is valid and valuable.
- **Market positioning:** Knowledge diffusion also serves to advertise and signal the originator's inimitable competitive advantage as a leading-edge practitioner, opening up new opportunities.

Recommendation: The workshop was an effective means for leading practitioners to collaborate and share information. It is important to encourage knowledge sharing among practitioners, so long as by doing so, an author's competitive advantage or IP rights are not infringed upon.

D.5 Financial considerations

Feedback from the workshop participants suggests that the format and approach was, by and large, a success. So, we can conclude that, with the adjustments discussed below, the workshop offers a viable mechanism for reviewing, resolving and validating gaps and opportunities.

To sustain the attention and involvement of a group of busy experts to meet, discuss and resolve technical and regulatory challenges over the long term requires financial support. The experts need to be compensated for their time and the workshop requires organization, facilitation and documentation.

There was a considerable amount of time invested in preparing the case study materials for the workshop. To replicate the workshop as delivered would be relatively affordable if the case studies, as designed, are re-used. Certainly, the level of refinement of the case studies as a result of the first workshop will be small.

There may even be a willingness among mainstream practitioners to pay to participate if some of the leading experts were in the room. For 24 participants to work on the 4 previously prepared case studies, the costs associated with putting on the workshop and preparing the results for publication may range from around $15,000 to $30,000 or between $600 and $1,200 per person (Figure 23 next page).

The appetite of project owners to submit a real project to a group of experts for a day (or part thereof) and if/how much they might pay to do so has not been tested.

Recommendation: there is value in repeating the workshop for another group of practitioners using much, if not all, of the existing materials.

Figure 23 Budget to reconvene the workshop as delivered

Case study preparation	$0 - $5,000
Low – replicate current case studies without any changes	
High – refine current case studies	
Facilitator	$1,200 - $1,500
4 Documentation / note takers	$2,000 - $4,000
Low – students	
High – professional (i.e. AIBC, P.ENG) table top facilitators	
Catering	$750 - $1,200
Low - lunch only	
High - breakfast, lunch and snacks	
Venue	$0 - $500
Low – donated space	
High – rented meeting room	
Printing	$0 - $200
Low – materials provided digitally	
High – large format printed package for each case study	
Solution preparation and publication	$10,000 - $15,000
Low – sketches developed at the workshop are transferred to CAN/BIM	
High – workshop details designed and shared in a summary report	

D.6 Organize information effectively

The method and means of sharing the information flowing out of the workshop effectively was a central point of discussion with practitioners. While disseminating information regarding the benefits of wood is important, we heard that practitioners tend to assess information based on the needs of their scope of work, experience and expertise. For example, in the workshop, the architects and engineers developed the details for complex situations (such as the fire rated zero lot line wall) and then sought advice on how to build it from one side (i.e. blind") from the contractors and on whether the details fulfil the intent of the code from the code consultant. Information must therefore be structured to flow through these various phases and levels.

At the same time, there was considerable discussion about the need for information that suited other significant adopters, in particular owners and developers, so the practitioners can effectively make the case to build with wood. Therefore, the method of sharing the information must also cover these information layers and scope adjacencies that make solutions complete and implementable in practice Figure 24 next page).

Recommendation: For innovation diffusion to happen, information about new technical or regulatory solutions must be organized in a way that allows practitioners to engage with it in a timely way based on their project needs, experience and expertise.

Figure 24 Technology / process information layers

First principles	What it is	Academic research reports Images Webinars Articles in technical journals Interviews Conference presentations
	Who it's for	Engineer, architect, builder, researcher, etc.
Best practices	When and where it should be used	Case studies Technical guides Codes and standards Calculators Testing procedures and results
Nuts and bolts	How it should be applied	Spreadsheets & formulae How-to videos Design details (CAD / BIM) Specifications Software and applications
Context / adjacencies	What it should be applied with	Referral system: "If you looked at that, then you might want to know about this".

D.7 Open discussion environment

A genuine open exchange of ideas can only occur when participants feel comfortable, respected and the risk of challenge is removed. The following rules of facilitation were followed in the workshop:

- All workshop participants have a chance to speak, expressing their own ideas and feelings freely, and to pursue and finish out their thoughts, and hear others' ideas and feelings stated openly.
- Participants can safely test out ideas that are not yet fully formed.
- Participants can receive and respond to respectful but honest and constructive feedback. Feedback could be positive, negative, or merely clarifying or correcting factual questions or errors, but is in all cases delivered respectfully.
- A variety of points of view are put forward and discussed.
- The discussion is not dominated by any one person.
- Arguments (often spirited) are based on the content of ideas and opinions, not on personalities.
- Even in disagreement, there's an understanding that the group is working together to resolve a dispute, solve a problem, create a plan, make a decision, find principles all can agree on, or come to a conclusion from which it can move on to further discussion.

Facilitating a group of technical experts requires experience not only in facilitation but also in the subject matter. For our workshop, note takers were at each table, each of whom were knowledgeable in building design (either architectural or structural), supported by the lead facilitator. Nevertheless, some of the note takers found themselves taking on a number of different roles, including role-playing the owner and facilitating spirited debates. In the future, it would be advisable for each table to have a dedicated facilitator and note taker to ensure the problem-solving exercise is seamless. Ideally, the facilitator would be a professional owner (institutional owner or developer) with the authority to make decisions on behalf of the project.

Finally, as this was the first workshop of its kind, we felt it was important to impose the Chatham House rule, whereby participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed.[36]

Recommendation: retain an experienced workshop facilitator with subject matter expertise and ensure the note takers at each table are allowed to focus on documenting the work.

Recommendation: project owners and developers should participate at the workshop.

D.8 Real projects

Innovation in building design and construction is primarily a result of a series of specific circumstances best represented within actual projects. There is no question that real projects would provide the difficult constraints and challenging trade-offs that encourage innovative, practical solutions. However, given that our workshop was the first of its kind and the value to practitioners was not yet clear, it was not possible to find four real-life innovative projects at or near the same stage of development, with the owners and designers willing to open up their process to scrutiny. Even if such projects were available, every owner, designer and construction company will have a different level of interest in exploring innovative solutions. Therefore, to articulate the issues to best effect, we prepared schematic designs of "almost real" case study projects that were distilled from professional experience, actual examples and/or information gathered by interviews.

The four case study projects were constructed to resemble reality as close as possible – two even included some myths about mass timber design that needed to be busted. As more projects are investigated through the lens of advancing innovation, a more complete understanding will be developed of what type of project might lend itself to the adoption of new ideas and which is better served by the deployment of tried and tested solutions.

There was also consensus that using completed projects would also have been beneficial in order to examine alternatives. The presence of the owner or developer would not only expedite decision making, but also offer an opportunity to educate them about the potential advantages (and trade-offs) wood offers.

Recommendation: real projects as case studies, though difficult to secure, would provide the difficult constraints and challenging trade-offs that encourage innovative, practical solutions.

D.9 Accelerate peer to peer learning

The workshop brought together peers who were willing to share their ideas - even with their competitors. However, it was noted that the workshop would have benefited not just the technology leaders, but also the second wave, or fast followers. Our interviews with practitioners suggest that consulting with peers who have experience on mass-wood projects is an important first step in the exercise of information gathering and confidence building. Only then do they look for detailed technical information from sources such as the CLT Handbook or Build Tall with Wood.

By definition, the innovators in any industry can only represent a small proportion of the total, and there will always be a spectrum of adopters: from natural trailblazers and early adopters, to those who will only follow a well-trodden path. Accelerating the mainstreaming of new ideas requires not only a more comprehensive and concerted emphasis on information sharing across this spectrum, but also the removal of the legislative barriers, the perception of heightened risk, and the real or imagined cost premiums associated with innovation.

Recommendation: broaden the application of the workshop format to any practitioner willing to share information.

D.10 Utilize Alternative Solutions

Workshop participants discussed some Alternative Solutions that have been reused so often, they should be adopted into the Building Code and there could be some room for guidance for Alternative Solutions. Providing a database of Alternative Solution details is likely not feasible since:

- Alternative Solution approval sits with the authority having jurisdiction. There have been cases when the Alternative Solutions have been approved and used several times over but there is no guidance / list on generally accepted alternative solutions.
- There is a difference between Site-specific Regulations (SSR) and Local Authority Variations.[37] Site Specific Regulations are provincial alternative solutions which are specific to the project site and cannot be used again for another project. Local Authority Variation is requested by a local authority body and if enacted, will be applicable to the local jurisdiction making the request.
- The idea was floated that, in the future, it might be possible for an individual to have their own building code written rather than proceeding with an SSR or Local Authority Variation route. The idea here is to accommodate professionals who have demonstrated expertise in aspects of construction that are not yet permitted under the Building Code, (e.g. tall wood design).

Recommendation: while an Alternative Solution cannot be published and put to use in situations outside that which it was developed to address, a high-level list of Alternative Solutions that have been accepted in generic form, along with a mechanism for identifying common applications, could help both practitioners and policy makers address barriers to innovative design.

D.11 Ensure access for small businesses

Many small businesses have limited economic and human capacity to invest in R&D, or the time to get involved with non-billable activities, whether it is developing new technical details, navigating the regulatory environment for new ideas or problem solving on site. That said, many of the innovators in wood design are themselves small businesses that have chosen their market leadership position as a key differentiation strategy. Nevertheless, A convergence of information (e.g. posted on a centralized website) would be ideal, even though it may be hard to keep current. There are challenges of consistency with some issues, such as fire rating of party walls – partly driven by the potential for different interpretations by AHJs - and generic best practice examples may prove valuable.

When sharing information about technical solutions, it was noted that published case study projects are often presented in a good light. Case studies should also present project challenges, for example: “These are the challenges we faced, and this is how we solved them”.

While a contractor’s source of information may usually be to pick up the phone to a friendly engineering or to study the competition, the trend towards greater integration of the construction supply chain may facilitate information sharing. Certainly, the inclusion of construction professionals at the workshop provided invaluable insights into constructability, scheduling and cost.

Recommendation: when developing innovation resources, consideration should be given to the limited capacity of small businesses to invest in innovation.

Recommendation: published case studies should be balanced in their scope and present project challenges, so that real-life lessons can be learnt.

Recommendation: ensure that construction expertise is available during the workshop and as an integral element of a faculty of experts.

D.12 Innovation organization

Innovation in the building industry and specifically the wood industry largely occurs organically. Adoption could be streamlined and accelerated if some level of organization was applied to encourage and focus the information sharing process. The incentive for innovation often comes when firms seek to obtain a competitive edge. However, the advantage is usually only short-lived and market leaders need to be constantly evolving to stay ahead.

Recommendation: an organized and curated innovation management platform could help to streamline and target the information flow to be of most use to practitioners.

D.13 Develop a component catalogue

In today’s construction industry, more and more components are pre-defined, which is where standardization can happen. There may be an opportunity to create a platform for summarizing the standard components in a library and facilitate knowledge sharing. Instead of assisting with standard details, it may be more worthwhile for innovation advocates and researchers to investigate how to systemize and assist with prototyping.

Recommendation: develop a library of standard, pre-fabricated components and assemblies.

D.14 Assign responsibility for addressing innovation challenges

Given that there is no organization that is mandated to advance innovation in construction in British Columbia, a number of organizations may consider collaborating to take responsibility for addressing the challenges identified in this report (Figure 25). However, a coordinating agency would need to be established to coordinate efforts.

Figure 25 Organizations that may take on responsibility for addressing construction innovation in British Columbia

Responsibility	Organizations
No brainers / best practices	• **Provincial agencies:** (e.g. BC Housing, Forestry Innovation Investment, BC Hydro) • **NGOs:** (e.g. Wood WORKS! BC, industry associations)
Short term solutions	• **Provincial agencies:** (Building Safety and Standards Branch, BC Housing Research Centre) • **Testing centres:** (e.g. some engineering and code consulting firms, FPInnovations, BCIT, National Research Council) • **NGOs:** (e.g. ZEBx, Innovate Wood BC, Passive House Canada, CAGBC)
Long term solutions	• **Applied research centres:** (e.g. FPInnovations, BCIT, universities)
Blue sky	• **Academia**

Recommendation: given that there is no organization that is mandated to advance innovation in construction in British Columbia, key provincial agencies (e.g. Building Safety and Standards Branch, BC Housing and Forestry Innovation Investment), NGOs and researchers may consider collaborating to address the challenges identified in this report.

D.15 Consider mass timber assemblies in BC Building Code

While the workshop yielded examples of practical and usable detail designs, the building code continues to be restrictive with emerging solutions that were brought up during the workshop. Although, the BC Building Act has language that may unlock some flexibility in the future, in the interim, workshop participants and interviewees considered guides, such as the CLT Handbook, to be useful. However, they noted that the guides often do not address regulatory issues in sufficient detail to make implementation simple for many practitioners. Currently, the BC Building Code does not speak to wood systems specifically. This means that every mass timber project has to make an argument to an AHJ on a case-by-case basis. A building code interpretation for wood (e.g. a “Mass Timber Code”) could help address specific challenges with the greater adoption of wood.

Recommendation: develop and incorporate regulations for the design and construction of mass timber structures into the BC Building Code.

APPENDIX E Firms with expertise in innovative wood design and construction

The following list of firms serving the large format residential and non-residential market in British Columbia. provided a starting point for participants in the interview process and the workshop.

More information is available from the Architectural Institute of BC (AIBC), Engineers and Geoscientists of BC (EGBC) and the four regional construction associations (Greater Vancouver, Vancouver Island, Southern Interior and Northern Regional).

Architects	Engineers and Building Scientists
Acton Ostry Architects	Associated Engineering (B.C) ltd
CEI-HDR	Aqua-coast Engineering Ltd.
Cornerstone Architecture	C.Y. Loh Associates Ltd
Francl Architecture	CWMM Consulting Engineers Ltd
GBL Architecture	GHL Consultants Ltd, Building Codes & Fire Science
HCMA	Equilibrium Engineering
Hemsworth Architecture	Evolution Building Science
Integra Architecture	Fast + Epp Engineering
Iredale Architecture and Planning	Herold Engineering Limited
Johnston Davidson Architecture + Planning Inc.	Morrison Hershfield
Local Practice	RDH Building Science Ltd
Michael Green Architecture	RJC Engineering
McFarland Marceau Architects	RWDI
NSDA	Thomas Leung Structural Engineering Inc.
Office of McFarlane Biggar	Wicke Herfst Maver Consulting Inc.
Patkau Architects	
Perkins & Will	
Proscenium Architecture + Interiors Inc.	
Ryder Architecture	
Stantec Architecture	
Urban Arts	
VIA Architecture	
ZGF Cotter Architects Inc.	

Researchers	Builders and Specialist Contractors
BCIT High Performance Building lab	Adera Development Corp.
FPInnovations	Alliance Truss Ltd.
UNBC Wood Innovation Research Lab	Axiom Builders
UBC Centre for Advanced Wood Products (CAWP)	BC Passive House
UBC Department of Civil Engineering	Bird Construction
UBC School of Architecture and Landscape Architecture (SALA)	Chandos
UBC Sustainability Initiative	Greyback Construction
	Kinetic Construction
	Ledcor Construction
	Omicron
	Performance Construction
	Peak Construction Group
	Seagate Structures
	StructureCraft
	UrbanOne Builders

APPENDIX F References and notes

1 Ryan Zizzo, Zizzo Strategy Inc. Joanna Kyriazis, Zizzo Strategy Inc. Helen Goodland, Brantwood Consulting, "Embodied Carbon of Buildings and Infrastructure", 2017. www.naturallywood.com/resources/embodied-carbon-buildings-and-infrastructure

2 As set out in the BC Energy Step Code www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/energy-efficiency/energy-step-code

3 Conversation with Rob Bernhardt, CEO of Passive House Canada, October 2017.

4 For example, while 100 five-and six-storey wood-frame buildings have been completed in British Columbia since 2009 (Wood *WORKS!* BC), it is still a small proportion of the province's total multi-family market which saw over 140,000 new multi-family units built in the same period (BC Housing, "2016 BC Residential Building Statistics and Trends Report", http://www.bchousing.org/publications/BC-Residential-Building-Stats-Report-2016.pdf).

5 Goodland, H. Lindberg, C. Shorthouse, P. "Construction Innovation Project: Building BC's Vision" for the BC Construction Association and BC Housing, 2016. www.bccassn.com/media/bcca-report-construction-innovation-2016.pdf

6 WOODCUBE Building in Hamburg. www.iba-hamburg.de/en/themes-projects/the-building-exhibition-within-the-building-exhibition/smart-material-houses/woodcube/projekt/woodcube.html

7 Note these reports do not directly address proprietary systems, or market consideration (supply and demand); focus is own industry level innovation and adoption.

8 McKinsey & Company, "Beating the low-productivity trap: How to transform construction operations", July 2016 www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/beating-the-low-productivity-trap-how-to-transform-construction-operations

9 Ryan Zizzo, Zizzo Strategy Inc. Joanna Kyriazis, Zizzo Strategy Inc. Helen Goodland, Brantwood Consulting, "Embodied Carbon of Buildings and Infrastructure", 2017. www.naturallywood.com/resources/embodied-carbon-buildings-and-infrastructure

10 As set out in the BC Energy Step Code www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/energy-efficiency/energy-step-code

11 Conversation with Rob Bernhardt, CEO of Passive House Canada, October 2017.

12 For example, while 100 five-and six-storey wood-frame buildings have been completed in British Columbia since 2009 (Wood *WORKS!* BC), it is still a small proportion of the province's total multi-family market which saw over 140,000 new multi-family units built in the same period (BC Housing, "2016 BC Residential Building Statistics and Trends Report", http://www.bchousing.org/publications/BC-Residential-Building-Stats-Report-2016.pdf).

13 Statistics Canada. Table 27-10-0024-01 Business enterprise expenditure on research and development characteristics, by geography and industry (x 1,000,000). www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2710002401

14 ibid.

15 Goodland, H. Lindberg, C. Shorthouse, P. "Construction Innovation Project: Building BC's Vision" for the BC Construction Association and BC Housing, 2016. www.bccassn.com/media/bcca-report-construction-innovation-2016.pdf

16 This definition of innovation appears in Goodland, H. Lindberg, C. Shorthouse, P. "Construction Innovation Project: Building BC's Vision" for the BC Construction Association and BC Housing, 2016. www.bccassn.com/media/bcca-report-construction-innovation-2016.pdf

17 E. M. Rogers, *Diffusion of Innovations*. 3rd edition. 1983. The Free Press https://teddykw2.files.wordpress.com/.../everett-m-rogers-diffusion-of-innovations.pdf

18 Goodland, H. Lindberg, C. Shorthouse, P. "Construction Innovation Project: Building BC's Vision" for the BC Construction Association and BC Housing, 2016. www.bccassn.com/media/bcca-report-construction-innovation-2016.pdf

19 McKinsey & Company, "Beating the low-productivity trap: How to transform construction operations", July 2016 www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/beating-the-low-productivity-trap-how-to-transform-construction-operations

20 NRC's six areas of technical expertise are detailed at www.nrc-cnrc.gc.ca/eng/solutions/advisory/index.html and comprise:

- Aerodynamics of bluff bodies
- Codes Canada
- Canadian Construction Materials Centre
- IA-Quest: indoor air quality emission simulation tool
- Infrastructure expertise and technology assessment

- soundPATHS – A web application to predict the sound transmission between rooms

21 https://vancouver.ca/green-vancouver/zero-emissions-buildings.aspx

22 Cambie Corridor Plan https://vancouver.ca/home-property-development/cambie-corridor-plan.aspx

23 The Canadian version of the CLT Handbook is available for free download from FPInnovations, https://fpinnovations.ca/Pages/CltForm.aspx

24 Ibid.

25 OECD, Workforce Skills and Innovation: an overview of major themes in literature, 2011. Available at: https://search.oecd.org/innovation/inno/46970941.pdf

26 Note these reports do not directly address proprietary systems, or market consideration (supply and demand); focus is own industry level innovation and adoption.

27 https://vancouver.ca/home-property-development/alternative-solutions.aspx

28 The information was sourced from a presentation to Iredale Architecture by Hilti in April 2017. More information about Hilti's Canadian "Engineering Judgment Requests" may be found at: http://www.hilti.ca/content/hilti/W1/CA/en/engineering/design-centers/firestop/engineering-judgments.html

29 https://uilo.ubc.ca

30 www.bcit.ca/appliedresearch/techtransfer

31 OECD, "Workforce Skills and Innovation: an overview of major themes in literature", 2011. Available at: https://search.oecd.org/innovation/inno/46970941.pdf

32 http://bcbec.com/research-education

33 According to StatsCan, construction was the lowest R&D investor of all major industries in 2015. Industrial spending on construction R&D was $79m (down from $101m in 2012), which comprises only 0.5 per cent of the $15.5bn total spent by industry across all sectors and compares with an average sector spend of $2.8bn. When R&D expenditures for architectural and engineering services of $354m are added then the total share of industry R&D spending climbs to 3 per cent. Comparing the dollar spent on R&D per GDP dollar generated across major industry sectors, construction ranks the lowest.

34 www.cosia.ca

[35] More information about the Digital Built Britian initiative including the BIM mandate can be found at: www.gov.uk/guidance/creating-a-digital-built-britain-what-you-need-to-know

36 The Chatham House Rule reads as follows: "When a meeting, or part thereof, is held under the Chatham House Rule, participants are free to use the information received, but neither the identity nor the affiliation of the speaker(s), nor that of any other participant, may be revealed." www.chathamhouse.org/chatham-house-rule

37 www2.gov.bc.ca/gov/content/industry/construction-industry/building-codes-standards/building-act/consistency/local-authority-variations