



# Design Options for Three- and Four-Storey Wood School Buildings in British Columbia

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# 1 Introduction

## 1.1 Background

As land values continue to rise, particularly in higher-density urban environments, schools with smaller footprints will become increasingly more necessary to satisfy enrollment demands. There are currently a number of planned new school projects throughout British Columbia that anticipate requiring either three-or four-storey buildings, and it is forecasted that the demand for school buildings of this size will continue to rise.

Though timber construction would offer a viable structural material option for these buildings, the British Columbia Building Code (BCBC 2018) currently limits schools comprised of timber construction to a maximum of two storeys, while also imposing limits on the overall floor area. Given these constraints, to date there has not been much effort put into the development of viable structural options that would accommodate larger and taller schools constructed primarily with timber materials.

With the above factors in mind, the purpose of this study is to illustrate the range of possible timber construction approaches for school buildings that are up to four storeys in height. Given this emphasis on four-storey construction, this study focuses on the main classroom blocks within a school building, as these portions of the building are the ones that are the most likely to take advantage of an increased number of storeys. While other portions of school buildings, such as gymnasiums, shops, and multi-purpose areas are also strong candidates for wood construction systems, since there are already numerous examples of this type of construction these areas are not emphasized in this report.

## 1.2 Related Studies

This study is closely related to the report *Outline Approach to Building Code Compliance – Vancouver Timber Schools* prepared by GHL Consultants for Wood *WORKS!* dated March 2019, which explores the building code related considerations of timber construction approaches for school buildings that are up to four storeys in height. As such, the reader is referred to the GHL report for further information regarding building code compliance (with a particular emphasis on fire protection) for timber school buildings.

There are also a number of available resources that, while they do not explicitly explore the concept of three- and four-storey school building approaches, do provide good background information pertaining to the use of wood in Canadian school buildings; these resources include

- + *Wood Use in British Columbia Schools* prepared by Stantec & Fast + Epp for Forestry Innovation Investment dated November 2018
- + *2012 Reference Guide: Wood Use in Low-Rise Educational Buildings – Ontario* published by the Canadian Wood Council and Ontario Wood *WORKS!*
- + *Case Study: Crawford Bay Elementary-Secondary School and Richmond Christian School* published by the Canadian Wood Council and Wood *WORKS!* BC
- + *Putting Wood to Work in BC: A User's Guide* published by the Canadian Wood Council and Wood *WORKS!* BC

## 2 School Design Principles

### 2.1 Overview

Presently, the learning program is in transition. Flexibility and future-proofing the progressive education model are a foremost objective. A dynamic shift is occurring within the education community from a teacher-led learning approach to a student-led learning approach. There is an increased focus on differentiated teaching – which targets individual student’s learning styles. A new student-centered learning paradigm must be supported by a well-thought-out learning environment. These environments must be safe and comfortable while also engaging the diverse learning styles and needs of students.

The 21st Century Learning model functions on the premise that education through creative and flexible spaces would empower school culture to evolve and transform supportive teaching and learning. Learning environments should be flexible, adaptable, and agile in their ability to support varied modes of learning. The challenge for the designer is to identify creative ways to meet the needs for flexibility and adaptability into the building, within the constraints of the structural requirements.

With the ever-pressing concerns of climate change and sustainability, architects and engineers have the responsibility to explore new techniques to mitigate the problem we are facing. Designers are increasingly looking at wood as an alternative to large scale construction. The use of timber as the primary material in school design not only provides an environment built to push the boundaries of sustainability, but in particular situations, could have the ability to improve the wellbeing of students and teachers through biophilia. The biophilia hypothesis describes the genetic predispositions for humans to seek nature. Biophilia expresses the idea that humans evolved around nature, and to have interactions and connections to nature and natural materials within the built environment enhances human health and wellbeing.

The ability to showcase the innovation of wood structures in a learning environment serves as inspiration to the progressive strides we are taking to encourage children to challenge the status quo, further pushing the envelope on the ever-changing education system that accentuates student-based learning.

### 2.2 Prototypical School Layout

The prototypical school layout examined in this study is based on the concept of 21st Century learning. The ground floor consists of a gym, trades wing, arts wing, administration wing, classroom and lab wing, and additional student spaces. Schematic architectural drawings for the prototypical school layout are provided in Appendix A. The focus of this study will center on the classroom and lab wing, which are standardized and consists of four quadrants. Each quadrant contains two groups of classrooms and two groups of lab spaces.

The vision for this layout focuses on the idea that classrooms should be flexible and connected, have access to daylight, and most importantly, support the needs of students and educators. Flexibility and connectivity of this plan relies on large bays free of columns and solid partitions. Students are encouraged to collaborate and explore between classrooms in order to promote varied styles of teaching and learning.

The ability to access daylight in all classrooms is also an important consideration to the design of the prototypical school. Strategic placement of openings in conjunction with the central atrium space provides opportunities for daylight into the core of the building.

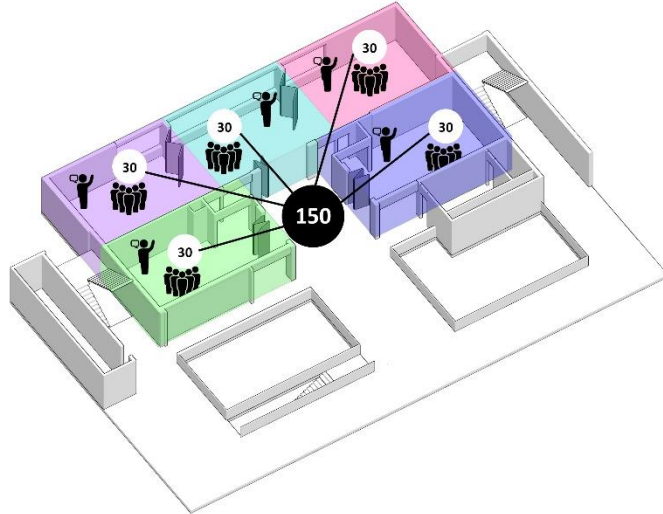


Prototypical School Layout: Typical Classroom and Lab Wing

## 2.3 Classroom Block, and Science Lab Block

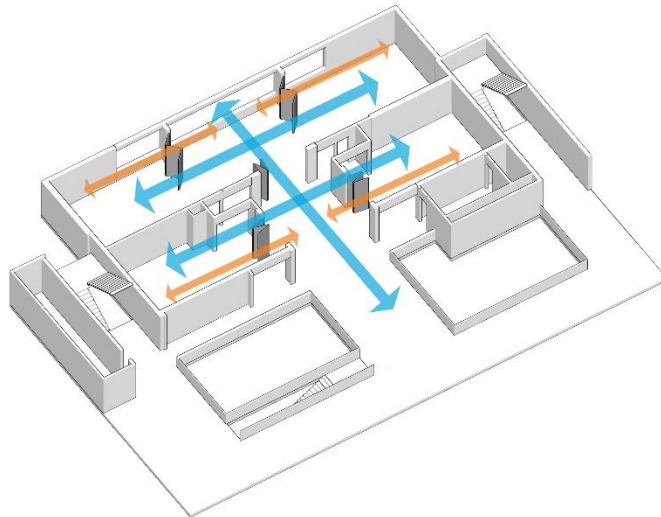
The key to a successful design rests on the ability of the building to create opportunities for collaboration. Principle learning spaces are divided into “learning communities”. Each community consists of no more than 150 students, with each classroom supporting a maximum of 30 students. These learning communities create smaller social units, thereby reducing the possibility of alienation and isolation. Learning communities incorporate teacher centered collaboration rooms to support group planning for cross curriculum and learner-focused approaches. This concept is replicated within the science lab block, in which each lab community also consists of a shared lab prep area. These science labs function similarly to general classroom spaces in terms of size and mode of education delivery and are therefore incorporated into the learning community concept.



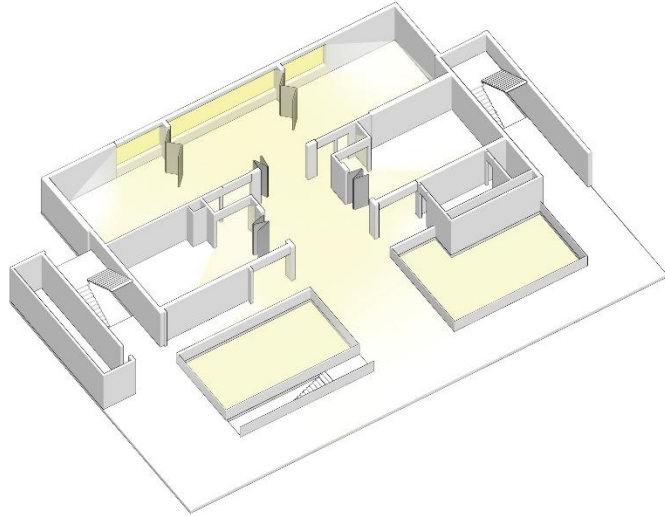


Distribution of Students per Classroom within a Learning Community

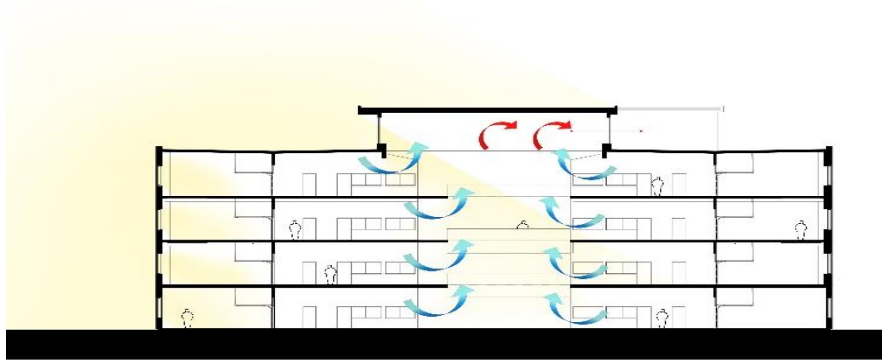
Transparency within learning communities is created through removable walls to support collaboration and a sense of community, while simultaneously enhancing the special quality of the shared spaces. The open spaces created by the atrium contribute to the interconnective quality of the learning environment. Additionally, the atrium functions to filter natural daylight through the core of the building. This not only reduces the need for artificial lighting but also enhances the health of the occupants.



Collaboration Opportunities within Learning Communities

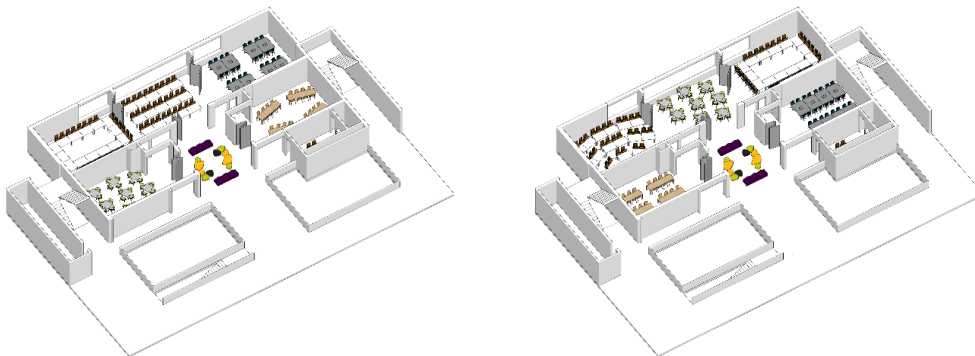


Daylight Harvesting Achieved Through Strategic Opening Placements



Section Showing Daylighting and Natural Ventilation Strategies

Flexibility within the classroom spaces allows teachers to create unique curriculums that traditional classrooms spaces would not have been able to accommodate. Columns and fixed partitions limit the possibility to space layout. With the use of well-designed timber construction, the distribution of structural elements could be shifted to the outer edges of the classroom spaces. Furniture layouts can then be adjusted based on the curriculum.



Potential Furniture Reconfigurations within Open Span Classrooms

## 2.4 Workshops, Tech Education, and Arts

While the focus of this study is on the classroom and lab wing, the trades and arts wing are comprised of high-volume spaces that are one storey but at double height. These spaces also typically require long span roof structures due to the equipment requirements and use. These criteria lend themselves well to the use of wood as a structural system.



Glulam Post-and-Beam Construction Featured in Wilson School of Design, KPU, Credit: Andrew Latreille  
Architect: KPMB Architects and Public Architecture + Communication | Engineer: Fast + Epp

## 2.5 Gymnasium

The requirements of gymnasiums are very similar to that of workshops. Gymnasiums are teaching spaces that also utilize long span structures with double height spaces. As mentioned in the previous section, wood is a strong candidate for these long span voluminous spaces.



Glulam Post-and-Beam Construction Featured in Richmond Christian School Gymnasium, Richmond BC, Credit: Florian Mauer  
Architect: Landform Architecture + Design Build | Engineer: Fast + Epp

## 3 Wood Framing Systems

### 3.1 Light Wood Framing

Light wood-framed construction is quite common throughout British Columbia for low rise buildings, especially for single-family homes and as multi-unit residential buildings up to six storeys in height. This construction type is well suited for these types of buildings due to the large numbers of walls typically present in the buildings, which allow for well distributed load paths for both vertical and lateral loading.



Typical Light Wood-Framed Construction, CREDIT: Wood WORKS/ BC

Light wood framing generally consists of relatively small lumber components (i.e. studs and joists) comprised of either conventional lumber or engineered lumber members. These members are arranged in regular spacing for both floors and walls, which are then generally sheathed with either plywood or OSB that provide the required in-plane lateral resistance for diaphragms or shear walls.

#### 3.1.1 CONVENTIONAL LUMBER

In Canada, conventional lumber generally consists of Spruce-Pine-Fir (SPF), Douglas Fir-Larch (DF-L), or Hemlock-Fir (Hem-Fir) dimensional lumber members. Although Hem-Fir is more available on the West Coast, SPF is the most commonly used species.



Dimensional Lumber, CREDIT: Craig Carmichael Photography, NaturallyWood.com

Available members sizes for conventional lumber can be somewhat limited: although 2x4 through 2x12 are commonly listed as available, 2x12 members often come with a cost premium as much larger trees are required to create these members. Additionally, conventional lumber members are usually limited in length to a maximum of 6m long, with availability of some of the smaller dimensioned elements (i.e. 2x4 or 2x6) becoming somewhat limited for members exceeding 4.8m in length.

Moisture content (MC) is also a factor worth considering for conventional lumber construction, especially in floor framing systems. Conventional lumber generally has an MC of about 16% when it first arrives on site. As the lumber dries out in its final installed condition, the MC drops to around 6-8%; this change in MC can result in significant shrinkage in the framing. If not properly accounted for in the construction detailing, shrinkage can result in a number of building performance issues, including:

- + Differential movement/settlement, particularly in structures with framing systems comprised of varying materials;
- + Overall building height movement in multi-storey buildings; and
- + Serviceability concerns such as floor creaking.

### 3.1.2 ENGINEERED LUMBER

Engineering lumber, such as Laminated Strand Lumber (LSL), Laminated Veneer Lumber (LVL), or Parallam (PSL), is a more controlled product compared to conventional lumber. Composite products such as I-joists, composed of Oriented Strand Board (OSB) and LVL to create wood I-sections, are also a common engineered lumber product used in light wood-frame construction.



LSL



LVL



PSL

Photos of Engineered Lumber Products, CREDIT: Fast + Epp

When compared to conventional lumber, engineered lumber offers greater flexibility in available member dimensions. LVL, LSL, and I-joists are commonly available in depths of up to 600mm. LVL and LSL members can also be fabricated to much greater member depths, although such custom fabrications would typically come at a cost premium. Engineered lumber is also readily available in a greater range of lengths than is available in conventional lumber. The available members sizes of engineered lumber products make them well suited for light wood-frame construction, even in conditions in which long spans or double-height walls are required.

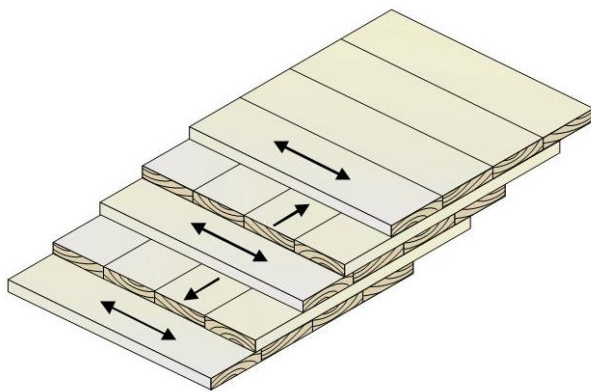
Additionally, the MC is much more regulated in engineered lumber products. The MC of engineered lumber products coming out of production is required to be 11% or less, which makes them more dimensionally stable in their final condition due to the smaller change in MC that will occur. Consequently, the shrinkage issues described for conventional lumber products will be reduced with engineered lumber.

## 3.2 Mass Timber Framing

Unlike light wood-framed construction, mass timber framing uses larger elements such as mass timber floor and roof panels, mass timber wall panels, and glulam posts and beams. These larger elements allow for the resistance of higher loads, as well as more inherent fire resistance rating through char of the elements.

### 3.2.1 CLT

Cross Laminated Timber (CLT) is a mass timber panelized product comprised of dimensional lumber elements on flat stacked in alternating directions and face glued together. This assemblage results in a mass timber panel with strength in two directions, the primary (or strong) direction, which aligns with the grain on the outer laminations, and the secondary (or weak) direction, which aligns with the internal cross laminations. These panels also exhibit significant in-plane strength and stiffness due to the cross laminations.



Composition and Photo of CLT, CREDIT: Fast + Epp

The out-of-plane strength (i.e. bending and shear resistance of floor and roof elements) of these panels in their primary direction is generally slightly less efficient by fiber volume than other mass timber panels since the cross laminations do not significantly contribute to the overall strength of the panel in that direction. This reduction in efficiency can result in CLT panel systems being somewhat deeper than other mass timber panel types when subject to the same loading and primary span criteria. That said, unlike other mass timber panel types, the cross laminations in CLT panels provide spanning capabilities in the secondary direction. It should be noted that this secondary axis behaviour is often limited to the width of the panels themselves (typically 3m or less).

Some of the main benefits of using CLT floor and roof panel framing systems include:

- + Availability of wider panel widths than other mass timber panel types, reducing erection time associated with lifting and placing the panels;
- + Ability to accommodate secondary axis spans, which can facilitate framing in narrow corridors or overhangs without the need for additional panel supports; and
- + Capability of achieving stiffer and stronger diaphragms when compared to plywood sheathed diaphragms.

CLT is also commonly used for both gravity and lateral load resisting walls, especially when intended to be architecturally exposed. The in-plane axial capacity of CLT panels tends to be quite high due to the panel acting as one solid member, much like concrete walls. CLT walls are well suited to tall walls around multi-

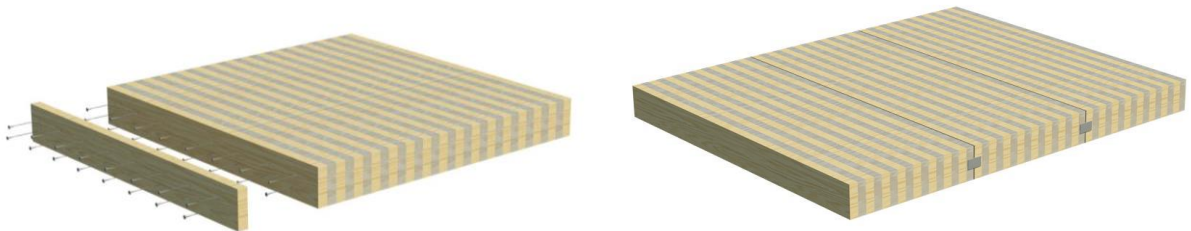
height spaces. It also provides the added benefit of relatively stiff shear walls. The panels themselves have very high in-plane shear strength and stiffness with the connections at the base of the panels typically governing the design. They can generally achieve much higher load capacities compared to stick framed plywood sheathed walls. However, since they are solid panels, consideration is required for placement of plumbing and electrical runs outside the wall.

Some of the main benefits of using CLT wall systems include:

- + Increased vertical and lateral strength and stiffness of the walls when compared to plywood sheathed light frame walls;
- + Reduced construction/dimensional tolerances resulting from shop fabrication of the panels; and
- + Reduced erection times when compared to conventional steel or cast-in-place concrete framing systems.

### 3.2.2 NLT, DLT, AND GLT

Nail Laminated Timber (NLT) and Dowel Laminated Timber (DLT) panels are similar from a structural perspective in that they are composed of dimensional lumber elements on edge mechanically fastened together with either regularly spaced nails in the case of NLT, or regularly spaced wood dowels in the case of DLT. Glued Laminated Timber (GLT) panels are another similar type of mass timber panel that are composed of glulam sections oriented on the flat, resulting of a series of individual laminations on edge that are glued together.



Composition of NLT, DLT and GLT similar, CREDIT: Fast + Epp

The result of all three of these types of assemblies is a one-way spanning panel element with minimal in-plane shear strength. Typically, both NLT and DLT are prefabricated in panels of up to 1200mm wide and GLT is prefabricated up to 600mm wide. That said, it is also possible to fabricate NLT panels in-situ.



NLT



DLT



GLT

Photos of Mass Timber Panels, CREDIT: Fast + Epp (NLT and GLT); StructureCraft (DLT)



NLT, DLT, and GLT represent an efficient use of wood fiber in the primary span direction, but unlike CLT panels they require additional framing for overhangs perpendicular to their primary span as well as any other conditions that could induce weak-axis bending. Additionally, these mass timber panels cannot resist in-plane shear forces (i.e., diaphragm forces or shear wall forces) without the addition of plywood sheathing.



NLT Roof Framing Featured in Samuel Brighthouse Elementary, Richmond BC, CREDIT: Fast + Epp  
Architect: Perkins + Will | Engineer: Fast + Epp

Some of the main benefits of using NLT, DLT, and GLT floor and roof panel framing systems include:

- + Availability of numerous different product suppliers and manufacturers;
- + Capability of achieving the most efficient use of wood fiber in one-way spanning systems, resulting in thinner panel depths;
- + Ability to reduce panel to panel connection requirements, since in-plane shear stresses are transferred entirely through the plywood diaphragms.

### 3.2.3 POST-AND-BEAM

Post-and-beam timber construction generally consists of glue laminated (glulam) beams and posts, although members can also consist of large dimensional lumber or engineered lumber beams and posts. Typically, the long spans required for schools necessitate larger members sizes than those that are readily available for engineered lumber products such as LVL or PSL, making glulam beams the most common choice for post-and-beam construction. On a similar note, large dimensional sawn lumber members can be difficult to source and are therefore not often used in modern construction (although they were more commonly used historically).



Glulam Post-and-Beam Construction Featured in Wilson School of Design, KPU, Credit: Andrew Latreille  
Architect: KPMB Architects and Public Architecture + Communication | Engineer: Fast + Epp

Post-and-beam construction is often combined with other mass timber framing systems as vertical supports for timber panels in locations where bearing walls are not desired due to architectural restraints. In such cases the beams are typically required to accommodate the long spans associated with large open classrooms, which can make the members relatively deep. Where deep members are used, early coordination with the mechanical and electrical disciplines is key to ensure that the required service runs can be accommodated either below the structural framing, or to ensure that penetrations can be accommodated through the beams.

The posts in these framing systems can consist of either engineered lumber or glulam, although glulam columns are more typically used. Readily available engineered lumber (i.e., PSL) columns do not meet the minimum dimensional requirements for heavy timber rating, and they would almost certainly not meet the char calculation requirements for fire protection. Since glulam columns are available in much larger dimensions, they are able to meet fire protection requirements without gypsum wrapping or some other additional fire protection system.

## 4 Gravity Design

### 4.1 Design Parameters

In order to assess the potential range of timber- framed gravity load resisting systems, these systems were applied to the prototypical classroom block discussed in Section 2 of this report and then analyzed under representative gravity loading in order to further study their feasibility.

An estimated uniform dead load was applied across the entire floor or roof of each framing option: the dead loads considered for the floors were 2.4kPa and 3.6kPa for the light wood framing and the mass timber options, respectively, and the dead loads considered for the roofs were 1.0kPa and 1.9kPa for the light wood framing and mass timber options, respectively. It is worth noting that although the different mass timber framing systems would likely require slightly different volumes (and therefore different self weights) for a given set of span conditions, this minor variation would not significantly impact the results of this study.

In addition to the dead load applied on the roof, a uniformly distributed snow load of 2.4kPa was considered assuming a building site located in Lower Mainland, BC, calculated as per the BCBC 2018. Although this snow load does not represent the worst case that could be encountered within the province (i.e., snow loading in northern BC and higher elevation regions in southern BC can be significantly higher), it provides a reasonable “average” condition for the purposes of this study.

As specified in BCBC 2018, the live loads considered for all floors were 2.4kPa for areas designated as classrooms (including laboratory and project spaces) and 4.8kPa for corridors, commons and exits.

### 4.2 Light Wood Framing

#### 4.2.1 FLOOR AND ROOF FRAMING

##### 4.2.1.1 System Overview

A typical light wood-framed system would consist of plywood-sheathed wood joists supported on either load bearing stud walls or on post-and-beam framing where required. The large spans required to accommodate the open learning spaces commonly desired in modern learning environments would likely dictate that engineered lumber with relatively deep member sizes would be required to accommodate the strength and serviceability (i.e., deflection and vibration) requirements for the floor and roof framing systems.



Engineered Lumber Joist Framing, CREDIT: Fast + Epp

Gypsum sheathing would typically be applied on the underside of the floor framing to provide a finished ceiling. The resulting cavity within the joist space is often used to conceal the required mechanical and electrical service runs.

#### 4.2.1.2 Architectural Implications

A light wood-frame system uses dimensional lumber and is an approach that is familiar to the trades. The framing members are smaller and therefore comprise of more parts to construct. Greater attention needs to be paid to the overall assemblies for fire ratings, acoustic separation and how the construction components come together as assemblies. As the component parts are made of smaller pieces, future renovations may be easier to accommodate, provided that the scale of such renovations is limited.

As light wood-frame systems require greater redundancies compared to mass timber structural systems, more shear walls and load bearing walls would be expected with this system. This requirement could potentially limit the transparency that is desired for both daylight and connection between learning spaces; however, it can be overcome with careful planning and design in an alternate concept.

Due to greater variances in light wood framing materials, expecting and planning for post construction movement is important. Dimensional lumber, even when kiln dried, has a greater tendency for differential shrinkage. When compared to other timber systems, this shrinkage could significantly affect the level of detailing required for exterior and interior finishes.

#### 4.2.1.3 Technical Considerations

Typical classroom spans, which can be in the range of 7 to 8m, dictate that at least some regions of the floor and roof framing system would require engineered lumber in order to make a light wood-framed approach feasible. Since it is uncommon for framing within a given building to alternate between conventional

dimensional lumber and engineered lumber framing, engineered lumber joist systems would be the likely choice for school buildings.

Applying these considerations to the prototypical school floor plan developed for this case study, the floor and roof joists would span across the classrooms in the north-south orientation to either the load bearing stud walls or engineered lumber beams, where required. For these spans, the joist depths would be expected to be 450mm to 550mm (nominal) across the entire floor plan to meet the strength and serviceability requirements when subject to classroom loading criteria.

In addition to the classroom spaces, the prototypical floor plan also includes a number of large open areas to provide collaborative learning spaces. To maintain a light wood framing approach in these locations, supporting beam lines would need to be provided in order to limit the joist spans to the 8 to 10m range previously mentioned. The spans of these beams would be limited to around 5m if readily- available engineered lumber beam sections are to be used, and if longer beam spans are required then more robust sections, such as deep glulam beams, would be required.

## 4.2.2 LOAD BEARING WALLS

### 4.2.2.1 System Overview

To accommodate four-storey construction (in which it is presumed that the load bearing walls would vertically align, or “stack” between stories) it is likely that relatively thick load bearing stud walls would be required, particularly in regions where the load bearing walls support the long joist spans described in Section 4.2.1 of this document.



Light Wood-Framed Load Bearing Wall, CREDIT: Fast + Epp

It is also worth noting that pre-fabricated light wood-framed walls are commonly used to provide tighter construction tolerances and reduce erection times. Prefabrication would also be advantageous when combining a light framed wall system with a mass timber floor system, as the mass timber panels cannot easily accommodate varying top-of-wall elevations.

It is worth noting that in addition to providing load bearing elements, light wood-framed stud walls can also be used as non-load bearing partition walls in combination with any of the other timber framing systems mentioned in this document. The use of light wood -framed partition walls in three-and four-storey schools is described in more detail in the GHL report cited in Section 1.2 of this document.

#### **4.2.2.2 Architectural Implications**

As noted above, light wood framing systems benefit from vertically aligned walls that extend through all levels of the building. Diligent planning of load bearing walls is required to limit the impedance of transparency and flexibility within the classroom communities. Since load bearing walls must remain as fixed elements, relocations of these elements are restrictive and therefore limit the flexibility of any future renovations.

#### **4.2.2.3 Technical Considerations**

In the case of a four-storey building with vertically aligned load bearing walls supporting the main classroom floor and roof spans, the wall framing within the top two levels of the structure could consist of 2x6 stud walls with studs spacing in the range of 300mm to 400mm. However, the lower two levels would likely require 2x8 stud walls, with the bottom level requiring stud spacing as close as 200mm. This tight stud spacing, while feasible, would constrain the placement of electrical and plumbing services within the load bearing walls.

It is worth noting that the use of engineered lumber would not significantly change the depth or spacing of the load bearing wall studs. However, engineered lumber would improve the dimensional stability of the wall framing, mitigating the risk of shrinkage in the wall framing. As previously mentioned, dimensional stability becomes an increasing concern as the number of storeys increases in a building.

### **4.3 Mass Timber Framing**

#### **4.3.1 FLAT PANEL FLOOR AND ROOF FRAMING**

##### **4.3.1.1 System Overview**

A flat mass timber panel framing system consists of mass timber panels spanning clear across large open spans supported on either load bearing walls or post-and-beam framing where required.



Point-Supported Flat Panel System at Brock Commons, UBC, CREDIT: Neil Taberner  
Architect: Acton Ostry Architects Inc. | Engineer: Fast + Epp

This framing approach allows for either architectural treatments or flat soffits that could either be left exposed to view. In cases where dropped ceilings are required for either acoustical treatments or to conceal services, the framing can provide a clear space in which the mechanical and electrical services could run unimpeded by structural framing.

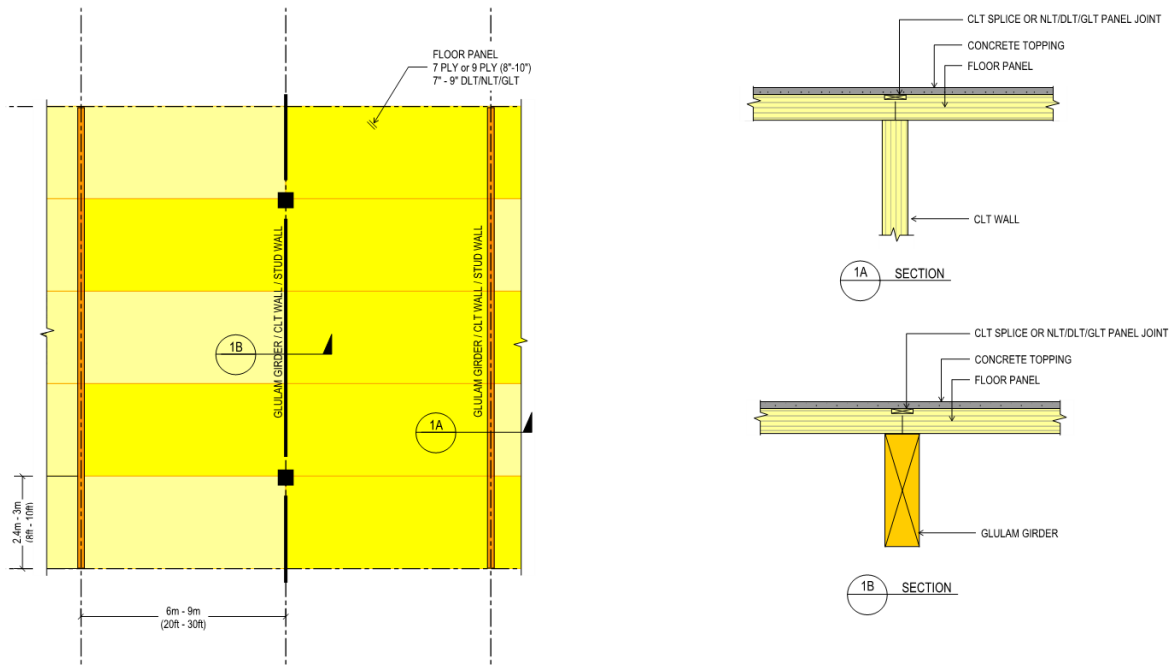
#### 4.3.1.2 Architectural Implications

A flat panel mass timber framing system accommodates the clear span spaces desired for flexible learning environments. With adequate panel thickness, mass timber structures are proven fire resistant, and could be exposed. The opportunity to minimize finished surfaces on walls and ceilings when using mass timber allows for the expression of wood surfaces, which can add warmth and create an inviting teaching environment.

When properly detailed, mass timber can provide an added level of acoustic separation due to its inherent density. While this density is good for acoustic separation, careful attention must be paid to ensure the environment is not overly reverberant. Acoustic absorption becomes even more of a design requirement when there are more exposed hard surfaces.

### 4.3.1.3 Technical Considerations

The mass timber panels used in a flat panel system could be any of the panel types mentioned in this document (i.e., CLT, NLT, DLT or GLT). In most situations, the panel design will be governed by the required stiffness and bending strength. For some configurations, particularly ones in which the panel configurations require large clear spans across classrooms or other common areas, the vibration performance of the panels can also be a driving factor in the serviceability design of the panels and should, therefore, be considered in the design.



Indicative Flat Panel Framing Layout and Details, CREDIT: Fast + Epp

For the school layout under consideration, the mass timber panels would span in the short direction across the classrooms and would be supported on either load bearing walls or glulam post-and-beam framing where required. For CLT panel framing, this configuration would require approximately 245mm deep (likely 7ply) panels; the CLT panel design in this case is governed by the stiffness needed to meet serviceability requirements. For NLT/HLT/GLT panel framing, this configuration would require approximately 235mm deep panels, the design of which would also be governed by serviceability requirements.

As mentioned in Section 3.2, the relatively low self-weight of mass timber over long spans compared to concrete will require consideration of the vibration performance of the system. Factors such as panel continuity (i.e. multiple-span panels as opposed to single span) and the anticipated partition walls and finishes should be considered in order to make the vibration analysis as realistic as possible.

In cases in which the soffits of the panels are left visually exposed (and, therefore, not provided with additional fire protection) the char resistance of the panels should be checked; refer to CSA O86-14 Annex B for guidance on char calculations. This check is especially critical for CLT panels due to the cross laminations as outlined in the O86 annex.



## 4.3.2 PANEL-ON-PURLINS FLOOR AND ROOF FRAMING

### 4.3.2.1 System Overview

A panel-on-purlin framing system would consist of a relatively thin mass timber panel supported on regularly spaced purlins. These purlins would then span across large open areas, with supports provided at the panel ends by either load bearing walls or post-and-beam framing where required.



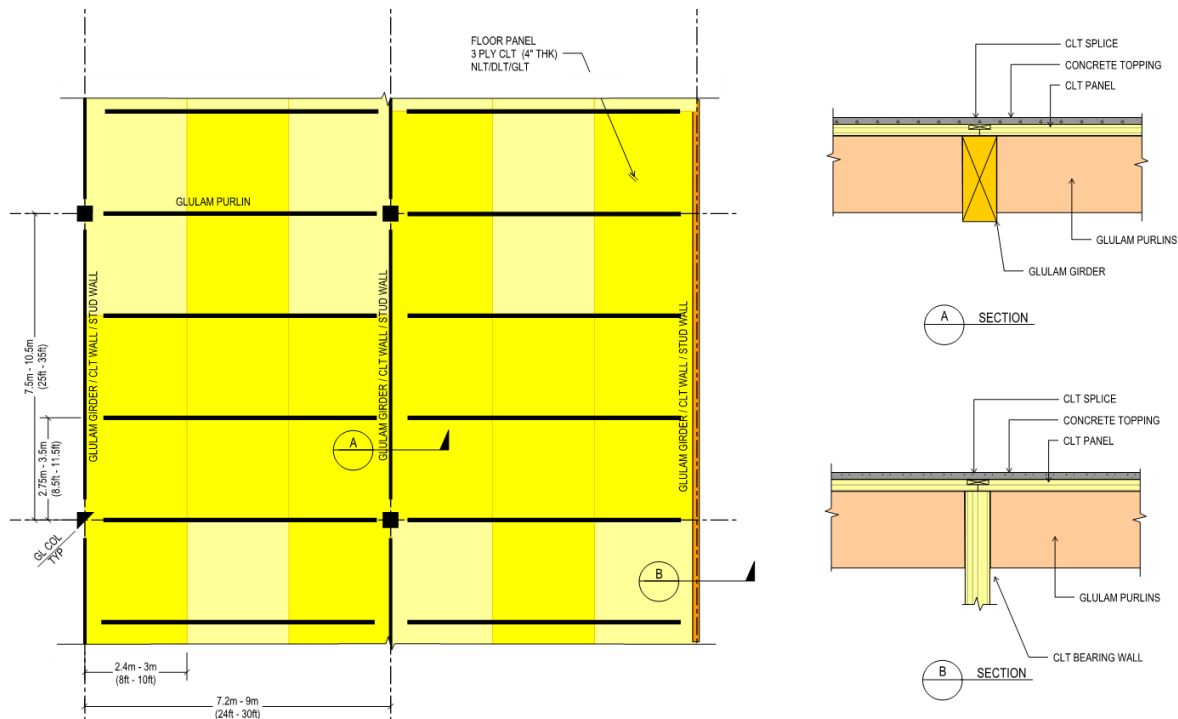
Panel on Purlin Framing Featured at UBC Centre for Interactive Research on Sustainability, CREDIT: Fast + Epp  
Architect: Perkins + Will | Engineer: Fast + Epp

This framing approach is generally quite efficient in terms of the total wood fiber used for the panels (and therefore cost) when compared to other panel systems. That said, the overall floor assembly depths can be significantly larger than flat panel mass timber framing, which can in turn increase the overall height of the building in order to achieve the desired floor to ceiling heights. The dropped purlins also make mechanical and electrical service runs more complex, as these systems would have to either run parallel to the purlins, beneath the purlins (which could necessitate a dropped ceiling) or penetrate the purlin framing in multiple locations.

### 4.3.2.2 Architectural Implications

The panel on purlin system could increase building envelope cost due to the increased floor to floor height. Careful planning and placement of demising walls must be considered to as interfaces between partitions and purlins could be difficult to detail. The nature of the panel on purlin systems can also prove to be a challenge for acoustical separation between teaching spaces.

Coordination between structural, mechanical and electrical systems becomes an important consideration in the early stages of the design process, as there may be unforeseen conflicts between system routing and the dropped purlins.



Indicative Panel-on-Purlins Framing Layout and Details, CREDIT: Fast + Epp

#### 4.3.2.3 Technical Considerations

The mass timber panels used in this framing approach would be selected based on the thinnest panel that can accommodate a reasonable purlin spacing; in the building configuration developed in this study, a purlin spacing somewhere between 2.5m and 3.5m would be optimal. If CLT panels are used, a 3-ply panel would suffice for spans of around 3m while still meeting the stiffness and fire design requirements. Fire design governs the design in this case based on a 1-hour fire, and the impact of the loss of the entire lamination, effectively leaving only a single lamination in each direction for the fire case. If NLT, DLT, or GLT panels are used, the thinnest available panel would suffice for the 3.5m span; for all of these panel types this depth would be approximately 80mm. For these panels the serviceability (stiffness) requirements govern the design. (Once the panel spans are set, the purlins would then be designed to accommodate the resulting spans and tributary widths.)

For the school layout under consideration, the purlins would span across the classrooms, resulting in a span of approximately 7 to 8m. In this arrangement, the purlin design is partially governed by serviceability (stiffness) requirements and partially governed by the char calculations required for fire design. A minimum purlin width of 175mm is required to meet a 1-hour fire rating and ensure that the purlins have sufficient residual strength to meet the demands of the fire load case. That said, it is worth noting that the fire implications on the purlin sizing only apply in conditions in which the purlins are left exposed (i.e., not protected by drywall sheathing). Once the required purlin width is determined, the purlin depth can then be selected based on the required stiffness; for this school layout purlin depths in the range of 500 to 600mm would be required.

### 4.3.3 GLULAM POST-AND-BEAM

#### 4.3.3.1 System Overview

Glulam post-and-beam framing would typically be used in lieu of load bearing walls to provide vertical support for the floor and roof framing systems in areas where either open spaces or future flexibility to reconfigure floor layouts are desired.



Glulam Post-and-Beam Construction Featured at Mountain Equipment Co-op Head Office, Vancouver, CREDIT: Ed White Photographics

Architect: Proscenium Architecture + Interiors Inc. | Engineer: Fast + Epp

As mentioned previously in this report, post-and-beam framing is often used in combination with other wood framing systems.

#### 4.3.3.2 Architectural Implications

Advantages of post-and-beam system are the lack of bearing walls which would otherwise limit the flexibility between communities, and within teaching spaces in a community. Flexible dividers are more readily accepted as a means to separate classrooms, but still allow for connectivity when required. The ability to create more transparency between spaces, which facilitates better safety and supervision, is achieved by long spanning post-and-beam structures. The reduced need for load bearing walls particularly along the exterior face of the building means that there are more opportunities for daylight harvesting.

#### 4.3.3.3 Technical Considerations

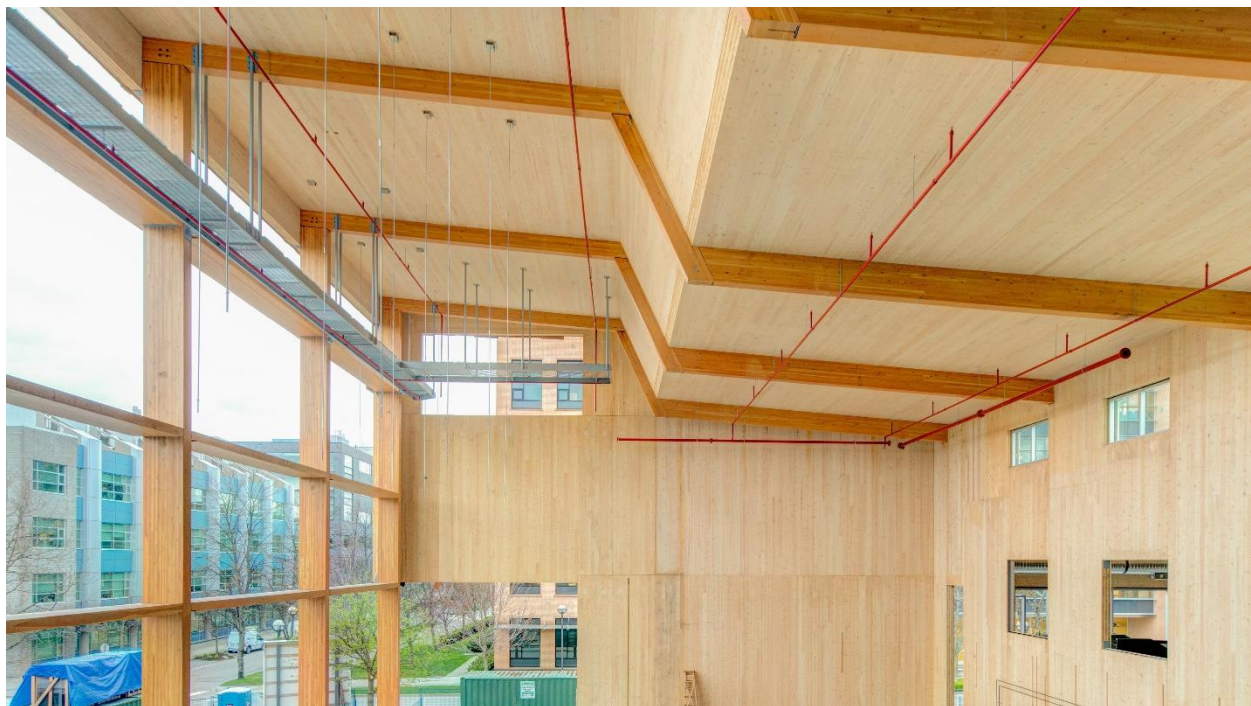
Similar to the purlin design procedure described in Section 4.3.2 of this report, the required width of the glulam beams as well as the required dimensions of the glulam posts can be dictated by char calculations in cases in which the timber elements do not include additional fire protection measures (i.e., gypsum cladding). That said, for a given depth the design of wider beams will be less significantly impacted by charring than thinner beams due to the reduced percentage of overall material lost to charring.

For the school layout under consideration, in locations where beam spans of around 7 to 8m are required to support the tributary widths of approximately 8m mentioned earlier in this report for the framing systems spanning across classrooms, beam depths of approximately 1000mm would be required. In this configuration the beam depth is governed by the required strength of the section. Given the significant depth of these beams, mechanical or electrical services may be required to penetrate through the beams. While such penetrations are feasible, in some cases reinforcement of the beams (i.e., shop-installed screws) may be required.

#### 4.3.4 CLT LOAD BEARING WALLS

##### 4.3.4.1 System Overview

CLT load bearing walls are stronger than light wood-framed stud walls of a similar overall thickness due to their solid composition. This increased strength is well suited to locations where thin load bearing walls are required as well as locations subject to significant out-of-plane loading (for example, double-height walls in stairwells, gyms, and shops/labs as well as tall exterior walls).



Double-Height CLT Wall Featured at UBC District Energy, CREDIT: Dirk Shoemaker  
Architect: Dialog | Engineer: Fast + Epp

Due to the solid composition of these wall panels, services are not typically integrated within the wall panels. Additionally, the solid mass of the walls can result in acoustic transmission issues, particularly in conditions in which both faces of the wall panels are left exposed. Given these constraints, a common approach is to provide furring on one face of the wall in order to accommodate acoustic insulation as well as provide a cavity in which service runs that feed the spaces on both sides of the wall can be accommodated.

#### 4.3.4.2 Architectural Implications

As discussed more fully in the CLT shear wall section of this report (section 5.3.1.2), the implications of mass timber are mainly focus on acoustics and the opportunity for exposed wood finishes. The density of the CLT panels create better acoustic separation between teaching spaces and allow for the wood to be exposed as a final architecture finish that is both durable and attractive.

#### 4.3.4.3 Technical Considerations

In the case of a four-storey building with vertically aligned load bearing walls supporting the main classroom floor and roof spans, CLT bearing walls can easily accommodate the imposed loading. Although 3ply panels may be sufficiently strong to resist the imposed axial loads, a practical minimum of 5ply panels are often used to facilitate connections with other framing elements. Additionally, with partition walls as thin as 3ply, acoustic performance can also become more of a limiting concern. For the school layout under consideration, approximately 140mm thick 5ply CLT panels throughout the building would suffice for load bearing walls.

When developing CLT wall panel layouts it is important to bear in mind that typical CLT panels are limited to width in the range of 2200mm to 3000mm, which results in the need for splice connections where wider wall elements are required. Conditions in which the wall panels are exposed on both sides may require recessed connectors that are plugged after installation in order to achieve the desired aesthetic, whereas panels that are only exposed on one side have the option of installing the required connectors on the concealed side only.

## 5 Lateral Design

### 5.1 Design Parameters

In order to assess the potential range of timber framed lateral load resisting systems, these systems were applied to the prototypical classroom block discussed in Section 2 of this report and then analyzed under representative gravity loading in order to further study their feasibility.

Seismic design loads were determined based on assuming a building site in Lower Mainland, BC (specifically Vancouver). Similar to the gravity design parameters described in Section 4.1 of this document, although it is recognized that the seismicity in this region is not the worst case that could be encountered within the province (i.e., seismicity along the coastal regions of the province can be significantly higher) it provides a reasonable “average” condition for the purposes of this study.

The site classification for seismic site response was assumed to be Site Class C, and the building was given a High Importance categorization, as defined in BCBC 2018 and required for school buildings. These parameters, along with the overall height of the building (which varies depending on the number of storeys under consideration), were used to determine the seismic forces applied to each lateral system included in this study.

### 5.2 Light Wood-Framed Shear Walls

#### 5.2.1 SYSTEM OVERVIEW

Although light wood-framed shear walls are typically used in combination with the light wood-framed gravity systems described in Section 4.2 of this document, they can also be combined with mass timber floor systems. These shear walls consist of plywood sheathing installed on either one or both faces of a wood stud wall. In typical light wood-framed construction, plywood sheathed shear walls would be combined with plywood sheathed floor and roof diaphragms.



Light Wood-Framed Plywood Sheathed Shear Wall, CREDIT: Fast + Epp

Light wood-framed plywood shear walls are designed using ductility and overstrength factors of  $R_d = 3.0$  and  $R_o = 1.7$ , respectively, as defined in CSA O86. Although this LFRS system offers relatively good ductility, there are limitations to the in-plane shear strength and stiffness that can be achieved by the system. Generally, the strength of the shear walls is limited by the nail spacing along the plywood panel edges. Where sheathing is placed on both faces of the wall (often referred to as double sheathed walls), the wall strength is effectively doubled. However, it should be noted that double sheathed can significantly constrain the ability to embed mechanical and electrical services within the wall cavities.

In order to accommodate the modern design principles described in Section 2 of this document, there would be a preference to minimize the amount of shear walls required. Consequently, the shear wall layouts considered in this study utilize double sheathed walls where required to facilitate the desired architectural layouts.

## 5.2.2 FOUR-STOREY BUILDINGS

### 5.2.2.1 Architectural Implications

The demands on a four-storey school with a plywood sheathed shear wall LFRS in a region of high seismicity would be very significant, to the extent that feasibility of such a system is questionable. In order to meet the seismic demands, nearly all the walls outlined in the prototypical school layout developed for this study would need to be taken as double sheathed shear walls. The image below illustrates the shear wall configuration

required for this system at the lowest level of the building (where the lateral demands are the greatest). In addition to the number of double sheathed shear walls required, partition walls that were intended to provide window openings to the central atrium would need to be replaced with solid shear walls (particularly at the lower levels of the building). Additionally, the diaphragm openings desired in the atrium space would need to be significantly reduced, particularly at the upper levels of the building.

The requirements imposed by the light wood-frame shear walls would limit the transparency between classrooms in communities, and between communities themselves, thereby limiting the opportunity for daylighting and, most importantly, flexibility. Limitations imposed by such systems would hinder the progressive nature of our current education model, making this system impractical functionally.

#### 5.2.2.2 Technical Considerations

As previously mentioned, due to the limited availability of shear wall elements within the prototypical classroom block a four-storey school would require double sheathed shear walls throughout the building. These walls would need to be heavily nailed on both faces in order to meet the imposed demands, thereby requiring built-up stud packs at the edges of each plywood panel. Additionally, the overturning forces in the shear walls would greatly exceed what can be achieved by commonly used continuous tie down anchor systems. Similarly, the compressive forces at the wall ends would exceed what could be achieved with stud framing packs at wall ends.

Given the significant design constraints noted above, the feasibility of such a system in a region of high seismicity is questionable. That said, such a system could be possible with the following approach:

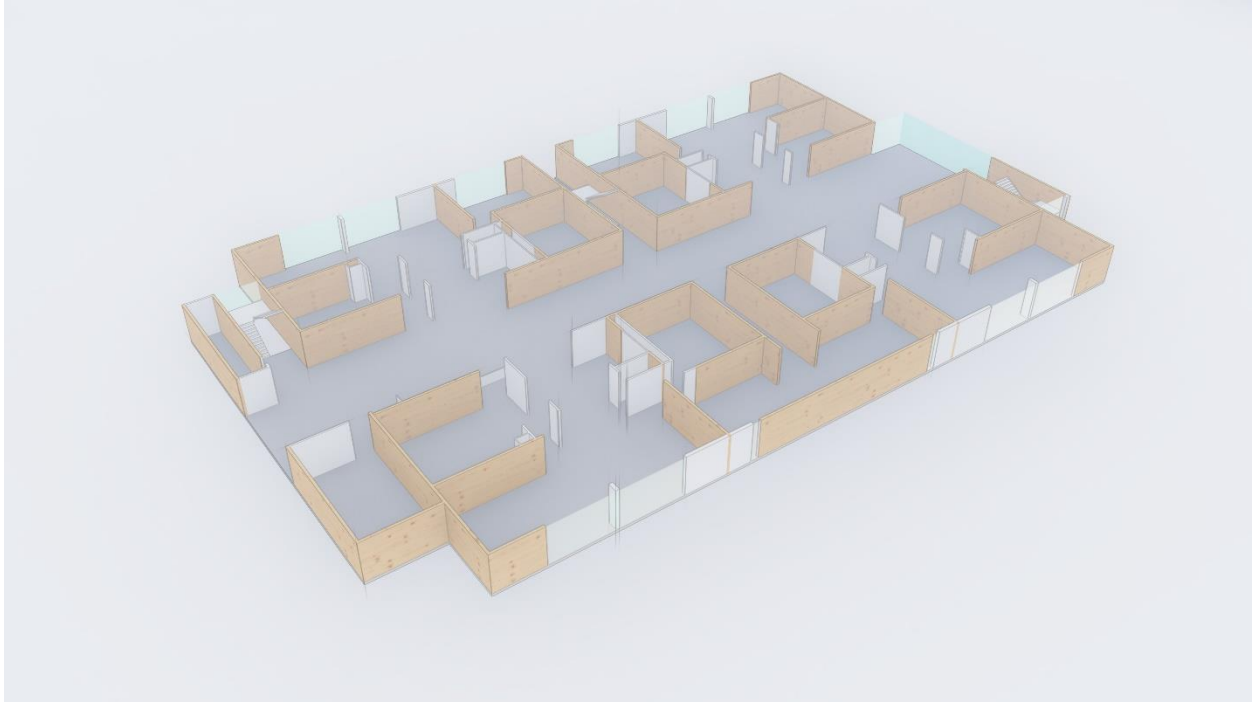
- + The shear wall framing would have to be sufficiently deep to accommodate the required internal framing;
- + The compression members at the ends of the shear walls would have to be sufficiently robust (i.e., likely not comprised of conventional stud framing) in order to resist the high overturning-induced compressive forces; and
- + Some form of specialty tie down system (i.e. either a custom designed system or a heavier version of a commonly used commercially available system) would be required.

### 5.2.3 THREE-STOREY BUILDINGS

#### 5.2.3.1 Architectural Implications

A three-storey school with a plywood sheathed shear wall LFRS in a region of high seismicity represents a more realistic upper limit of what is feasible with a conventional light wood-framed LFRS. The majority of the walls outlined in the prototypical school layout developed for this study would need to be taken as shear walls, with a large portion of the walls being double sheathed. The image below illustrates the shear wall configuration required for this system at the lowest level of the building (where the lateral demands are the greatest).





Shear Wall Configuration: Three-Storey Classroom Block with Plywood Sheathed Shear Walls and Plywood Sheathed Diaphragms

Similar to the constraints discussed for the four-storey building, the amount of required shear walls would limit the openness of the provided interior spaces. In some locations, the partition walls that were intended to provide window openings to the central atrium would need to be replaced with solid shear walls (particularly at the lower levels of the building). Additionally, the diaphragm openings desired in the atrium space would need to be significantly reduced, particularly at the upper levels of the building.

The requirements imposed by the light wood-frame shear walls in a three-storey scenario would present an improved layout compared to that of the four-storey LFRS, although it still limits the extent of transparency and daylighting desired in an ideal prototypical layout. Furthermore, capping the building at three storeys limits the projected student capacity of the school.

It is worth noting that a similar layout to that described above could be used for a four-storey building subject to relatively low lateral loading, such as schools that are not located in regions of high seismicity.

### 5.2.3.2 Technical Considerations

As previously mentioned, a three-storey school in a seismic zone represents a realistic upper limit of what can be achieved with a light framed approach. To resist the base shear loads associated with a design earthquake, the majority of the walls in the prototypical school layout developed for this study would need to be taken as shear in each direction walls, with approximately 40% of these walls requiring double sheathing. These shear walls would require continuous tie rod anchor systems along with robust compression members (likely large engineered lumber members at the wall ends) in order to resist the imposed overturning forces.

In this configuration the diaphragm at the upper storey would also be heavily loaded, consequently, the distribution of shear walls, including the distribution of single and double sheathed walls, would need to be evenly spaced throughout the system to avoid locally overstressing the diaphragm.

## 5.2.4 ADDITIONAL TECHNICAL CONSIDERATIONS

### 5.2.4.1 Overturning

Base overturning of multi-storey light wood-framed LFRS systems can also present a significant challenge. For example, in typical four-to six-storey multi-unit residential construction continuous tie down anchor systems are commonly required to resist the high overturning loads and also accommodate the anticipated shrinkage over the height of the building. These systems also require relatively heavy compression members at the ends of the shear wall segments. It is anticipated that similar anchor systems would be required for taller school buildings.

### 5.2.4.2 Diaphragms

Plywood diaphragms are typically comprised of a single layer of plywood sheathing installed on top of light wood-framed floors systems. Since it is generally not possible to sheath both sides of the floor and roof framing, the strength and stiffness that can be achieved is limited. Consequently, plywood diaphragms are commonly analyzed as flexible diaphragms, which generally requires more regular placement of LFRS elements (i.e., shear walls), which will limit the amount that the diaphragm can cantilever from the LFRS elements. While CSA O86 does not prescribe the maximum acceptable diaphragm cantilever, other design standards recommend a maximum cantilever of around 7.5m. That said, the strength and stiffness required for cantilevered diaphragms in taller buildings within regions of high seismicity will often govern the cantilever length that can be achieved.

## 5.3 CLT Shear Walls

### 5.3.1 SYSTEM OVERVIEW

Although CLT shear walls systems are typically used in combination with CLT floors, they can also be used with other mass timber panel systems.



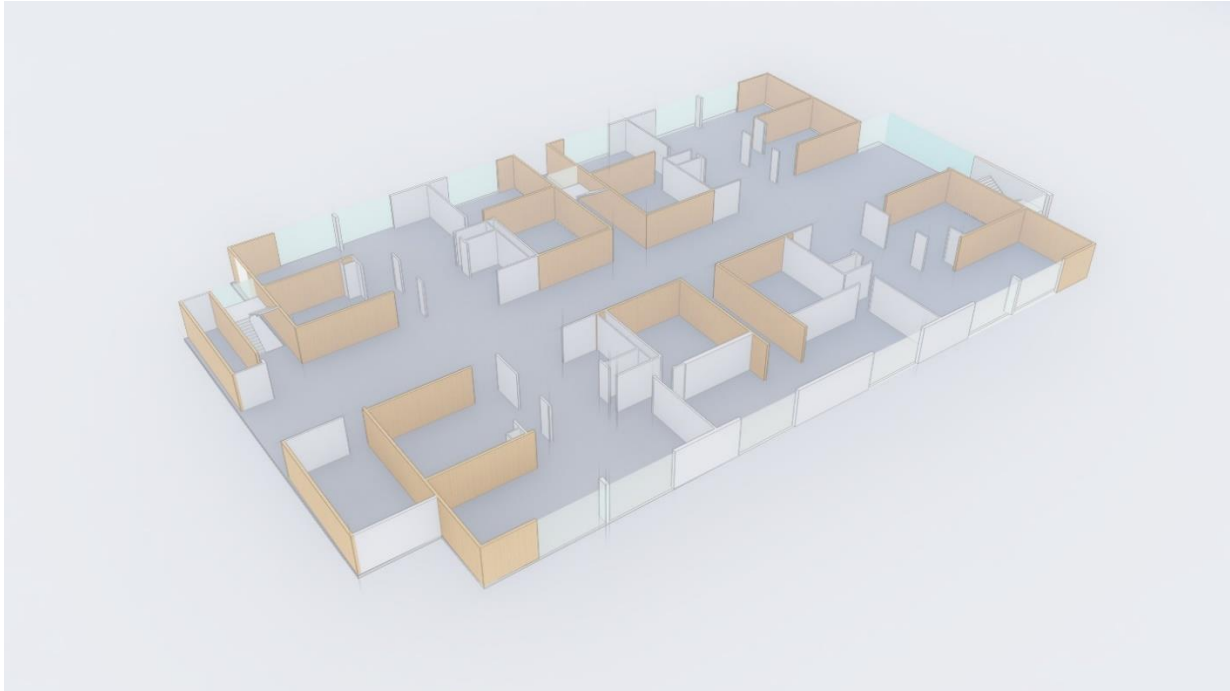
CLT Shear Wall, CREDIT: Fast + Epp

CLT shear walls permit a ductility and overstrength factors of  $R_d = 2.0$  and  $R_o = 1.5$ , respectively as defined in CSA O86. Although this type of LFRS offers lower ductility than light wood-framed shear walls, it can accommodate significantly higher lateral loads. As required by CSA O86, neither in-plane nor out-of-plane shear wall offsets are permitted between storeys for CLT shear wall systems, meaning that the shear walls are required to align between floors.

### 5.3.2 CLT SHEAR WALLS WITH CLT DIAPHRAGMS

#### 5.3.2.1 Architectural Implications

When considering the prototypical school layout developed for this study, the CLT shear wall with CLT diaphragm system LFRS offers the greatest flexibility to accommodate the desired (i.e., relatively open) architectural layout. The image below illustrates the shear wall configuration required for this system at the lowest level of the building (where the lateral demands are the greatest). The connectivity between classrooms is achieved with the CLT approach. Additionally, the opportunities for daylight harvesting from the atrium and exterior are less impeded by the CLT shear wall than seen in the plywood shear wall approach. This allows for the desired connection and flexibility to foster collaboration between students within the community.



Shear Wall Configuration: Four-Storey Classroom Block with CLT Shear Walls and CLT Diaphragms

With this system, the shear walls would be focused around the corridor walls and the partition walls between classrooms. The CLT diaphragms can accommodate this somewhat eccentric distribution of shear walls, thereby accommodating large window openings along the exterior walls. In fact, additional openings could be added based on the shear wall placements to allow for even more daylight harvesting. Additionally, the CLT diaphragms could also accommodate the full extent of the atrium diaphragm openings shown in the prototypical school layout.

#### 5.3.2.2 Technical Considerations

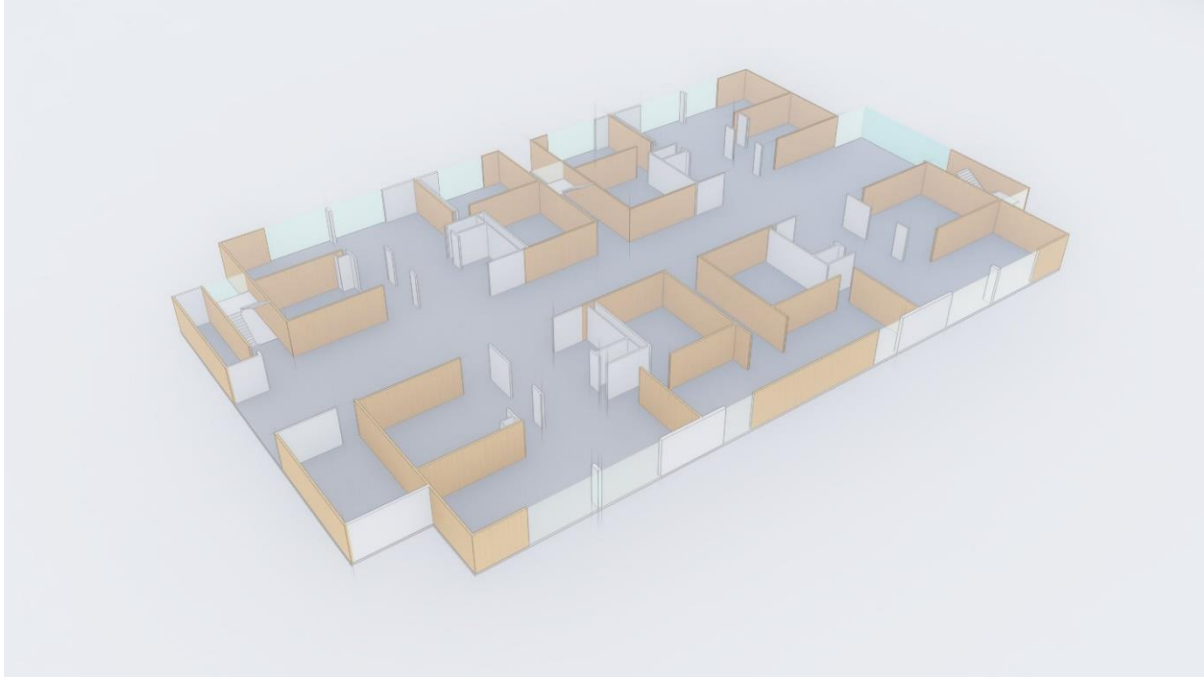
The limiting factor in the design of CLT shear walls for a four-storey school building would likely be the hold down design. Although relatively thin panels could be used in theory to accommodate the gravity and lateral loads forces in the panel, thicker panels are often required to accommodate the required connections.

As previously mentioned, since CLT diaphragms are relatively rigid they can accommodate larger spans between shear walls as well as larger diaphragm cantilevers (i.e., conditions where shear walls are not provided along the exterior of the building). When designing CLT diaphragms, particularly around significant openings and cantilevers, consideration needs to be given to the impact of these discontinuities on diaphragm deformation in the splines as well as in the panels. Large straps are typically required around the openings and at the diaphragm edges to transfer the diaphragm chord forces. Both the diaphragm and the associated connections need to be capacity-protected around the overall LFRS capacity.

### 5.3.3 CLT SHEAR WALLS WITH PLYWOOD DIAPHRAGMS

#### 5.3.3.1 Architectural Implications

Similar to the CLT diaphragm option discussed in Section 5.3.2 of this document, a CLT shear wall with plywood sheathed diaphragm LFRS could accommodate the desired (i.e., relatively open) architectural layout presented in the prototypical school layout developed for this study. That said, this system would require some shear walls along the exterior walls of the building, thereby limiting the size and extent of window openings. The image below illustrates the shear wall configuration required for this system at the lowest level of the building (where the lateral demands are the greatest).



Shear Wall Configuration: Four-Storey Classroom Block with CLT Shear Walls and Plywood Sheathed Diaphragms

With this system, the majority of the shear walls would still be focused around the corridor walls and the partition walls between classrooms. However, the exterior shear walls are required to eliminate the large diaphragm cantilever present in the CLT diaphragm system. Additionally, the diaphragm openings desired in the atrium space would need to be significantly reduced, particularly at the upper levels of the building.

Although the CLT shear walls and plywood diaphragm system works well with the architectural layout, it does have its limitations, particularly the reduction in the available atrium spaces. Unlike the CLT approach outlined in Section 5.3.2, this system does not allow for changes to the architectural features such as increasing the available window areas as outlined previously. Consequently, using plywood sheathed diaphragms with a CLT shear wall lateral system does start to limit the flexibility, connectivity and degree of transparency desired in each classroom neighbourhood.

#### 5.3.3.2 Technical Considerations

Plywood diaphragms with mass timber framing systems are typically comprised of plywood sheathing installed on NLT, DLT or GLT panels. As previously mentioned, plywood diaphragms are often analyzed as flexible

diaphragms, which generally requires more regular placement of LFRS elements (i.e., shear walls) and will limit the amount that the diaphragm can cantilever from the LFRS elements.

It is also worth noting that since diaphragms and their connections are required to be capacity protected around the LFRS, in some cases the configuration of the CLT shear walls could be constrained by the diaphragm resistance that can be achieved. In other words, even though CLT shear walls can offer much greater resistances than plywood sheathed light wood-framed shear walls, if the demand in the CLT shear walls is too great (which can be the case if relatively few shear walls are participating in the LFRS) then it can be difficult to achieve the required capacity in the plywood sheathed diaphragms.

#### 5.3.4 ADDITIONAL TECHNICAL CONSIDERATIONS

##### 5.3.4.1 Shear Wall Hold Down Connections

As stipulated in CSA 086, the energy dissipation mechanisms in CLT shear wall systems are limited to the spline connections between shear wall segments, the hold downs and the base shear connections. All the other connections need to be designed to meet capacity design requirements, including the diaphragms, the connections between the diaphragms and the LFRS, and the CLT panels within the shear walls.

For a four-storey system in a region of high seismicity, custom designed hold downs would typically be required since the resistance that could be achieved with commonly used proprietary hold down systems may not suffice. Such custom hold downs would likely need to be attached over a significant height of the wall, and they would likely consist of internal knife plates with tight fit pins in order to meet the high connection demands.

##### 5.3.4.2 Shear Wall Panel Connections

Typically, splines are provided either with plywood splines dapped in to one face of the CLT panels, or with notching and lapping the ends of adjacent panels. While plywood splines are typically more cost effective, lapped splines are often used in conditions where the CLT walls are exposed on both faces. In addition to the aesthetic benefit, lapped splines can achieve higher resistances than plywood splines; in a four-storey building such high-strength spline connections may be required, particularly in the lower levels of the building.

The base shear brackets, as well as floor to floor brackets are typically provided with steel angles either nailed or screwed to the base of the panel and anchored to the foundation at the base level. These angles are typically mounted to the face of the CLT panels but in conditions where the walls are exposed to view, the connections could be provided with internal knife plates and tight fit pins.

##### 5.3.4.3 Shear Wall Panel Thicknesses

As previously discussed, the limiting factor for the design of CLT shear walls are the connections, particularly the hold-downs and the base shear connections. The shear forces in the panels could generally be accommodated by relatively thin panels; however, the connections required to provide the load path into the wall panels often require thicker timber elements. For the four-storey building considered in this study, shear wall panels ranging from 175 to 200mm thick (5 ply or 7 ply) would be expected to be a practical minimum.

## 6 Example Framing System Concepts

### 6.1 Overview

In order to highlight some of the possible timber construction approaches for four-storey school building in British Columbia, the classroom block of the prototypical school layout described in Section 2 of this document will be examined in further detail. The selected framing system combinations presented in this section are the ones most likely to be utilized in the construction of a four-storey school due to their material efficiency, ability to respond to the architectural programming requirements, and economy.

The rendering below illustrates the typical classroom block developed for this study, and schematic architectural drawings of this block are provided in Appendix A.



Interior view showing the extent of mass timber construction in a 4 storey school

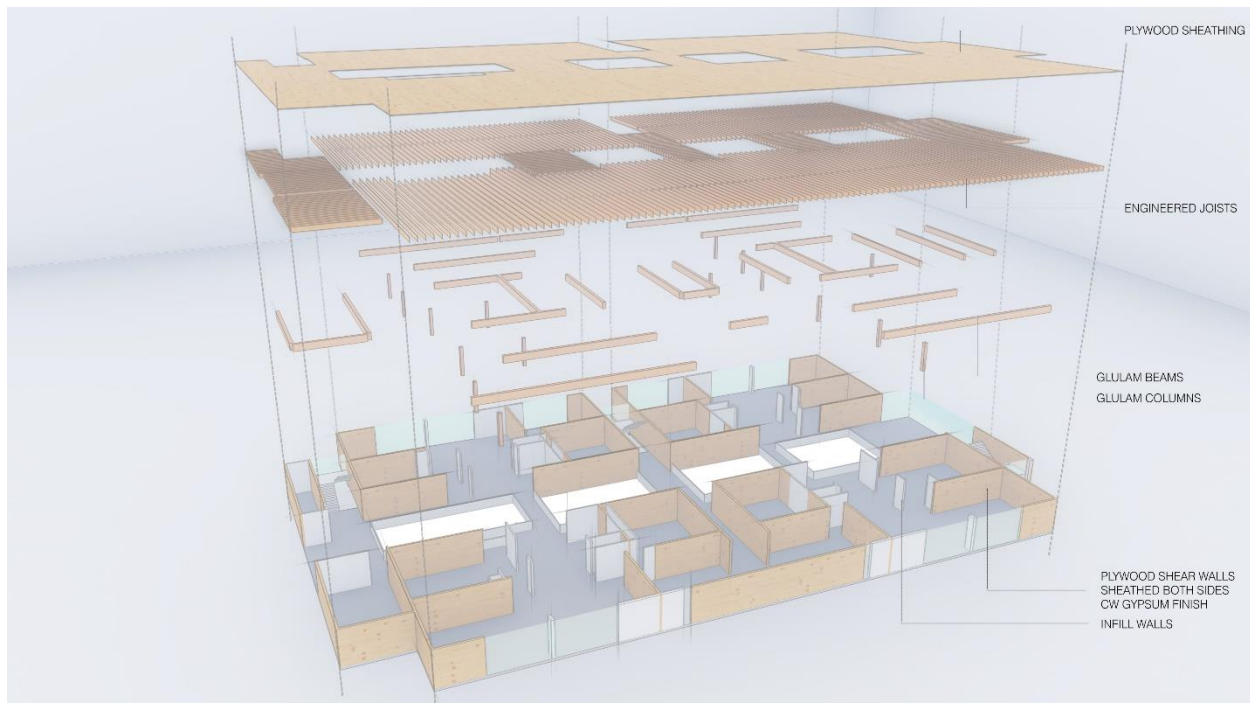
Using the various timber framing methodologies described earlier in this document, three different timber framed structural concepts were developed for this classroom block. These options, which are described in the following subsections, will be used to illustrate:

- + Possible combinations of the timber framing components in complete structural schemes;
- + The functional layout and architectural expression that can be achieved through the various framing systems; and
- + The relative cost of the potential framing systems.

## 6.2 Conceptual Options

### 6.2.1 OPTION A: LIGHT WOOD-FRAME STRUCTURE

Option A consists of the light wood framing system in combination with the light wood-framed shear wall LFRS described in Section 4.2 and Section 5.2.3 of this document, respectively. Schematic structural drawings for this concept are provided in Appendix B.



Axonometric Framing Diagram: Light Wood-Frame Structure

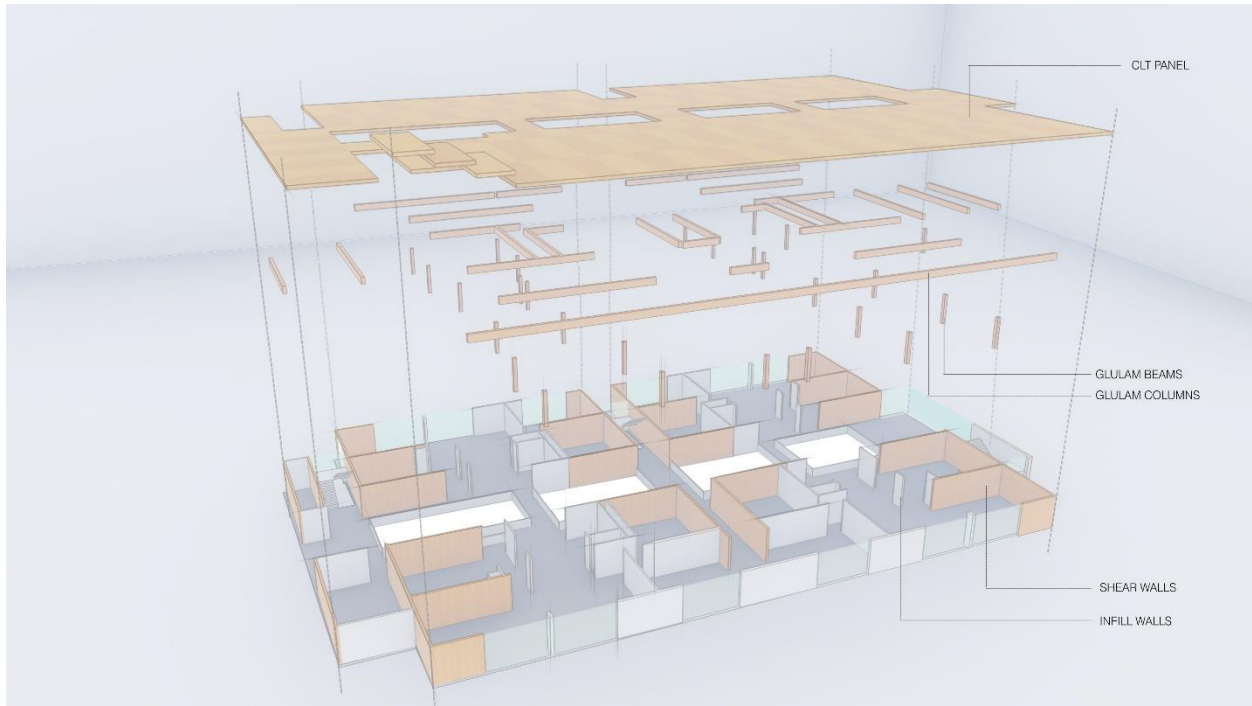
As mentioned earlier in this report, while the three-storey light wood-framed LFRS represents a realistic upper limit of what is feasible with a conventional light wood-framed LFRS in a region of high seismicity, the same design could likely be applied to a four-storey building not subject to high seismic loading. That said, for the purposes of this prototype comparison a four-storey building with the noted LFRS scheme is discussed.

In Option A, the light wood-framed LFRS has some inherent issues pertaining to acoustics and required fire resistance rating. Due to the susceptibility of this framing system to fire, the framing will require full coverage with fire resistant finishes (i.e., gypsum wall board). These finishes would conceal the wood members and limit the architectural expression of the material. Although the light wood framing system requires protection, the finishes allow for acoustic treatments as well as service runs to be incorporated into the framing cavity.

### 6.2.2 OPTION B: CLT STRUCTURE

Option B consists of the flat panel CLT floor and roof framing system in combination with the CLT shear wall and CLT diaphragm LFRS described in Section 4.3.1 and Section 5.3.2 of this document, respectively. Schematic structural drawings for this concept are provided in Appendix C.





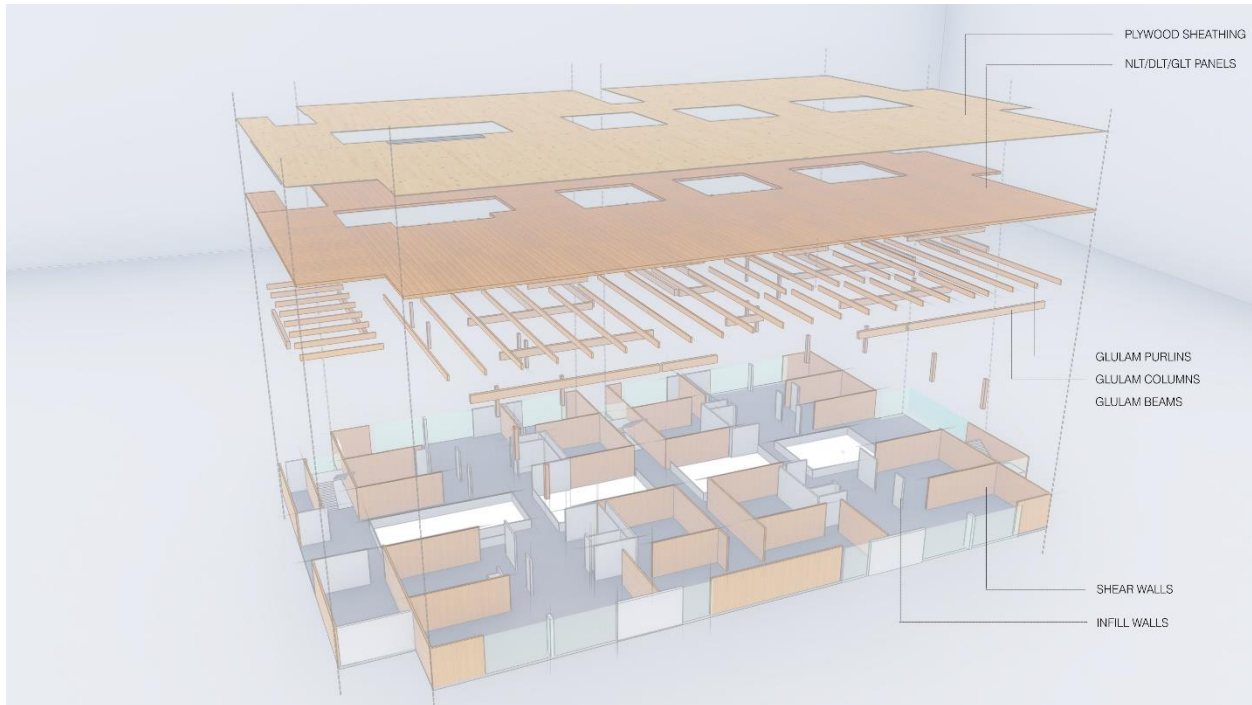
Axonometric Framing Diagram: CLT Structure

In Option B, the flat panel CLT floor and roof system in combination with CLT walls creates an opportunity for reduced interior finishes. Because of the inherent fire-resistant quality of CLT, these mass timber panels can remain exposed in majority of the building. Consequently, using a CLT system provides an opportunity to express wood as both a structural component and an architectural finish; this narrative of wood as a material that is both functional and aesthetically pleasing is put at the forefront in Option B, thereby solidifying its effectiveness as a material to consider in future school buildings.

From an acoustic perspective, CLT panels would likely perform better than light wood framing due to their density. That said, CLT structures can be susceptible to reverberation and impact-related acoustic transmission if not properly detailed. Consideration for acoustical treatment would potentially conceal portions of the CLT finish.

### 6.2.3 OPTION C: CLT SHEAR WALLS WITH NLT, DLT, OR GLT PANEL ON PURLIN FRAMING

Option C consists of the mass timber (either NLT, DLT, or GLT) floor and roof panel on purlin framing system in combination with the CLT shear wall and plywood sheathed diaphragm LFRS described in Section 4.3.2 and Section 5.3.3 of this document, respectively. Schematic structural drawings for this concept are provided in Appendix D.



Axonometric Framing Diagram: CLT Shear Walls with Panel on Purlin Framing

In Option C, the degree of expression of the timber framing that can be achieved is comparable to that in Option B. With NLT, DLT, or GLT framing systems, additional options for concealed/integral acoustical treatments are available compared to that of CLT. In certain cases, NLT, DLT, and GLT would require additional fire protection measures compared to CLT due to the lower wood volume of these products. All that said, Option C offers potential for reduced interior finishes just as in Option B, but perhaps to a lesser degree.

### 6.3 Further Study

In order to better compare and contrast the three schematic framing systems mentioned above, further study regarding the anticipated erection timelines and a relative cost comparison of the three systems are recommended for further study. It is anticipated that these additional considerations will be addressed in a future update of this report.

# APPENDIX A: Prototypical School Architectural Plans



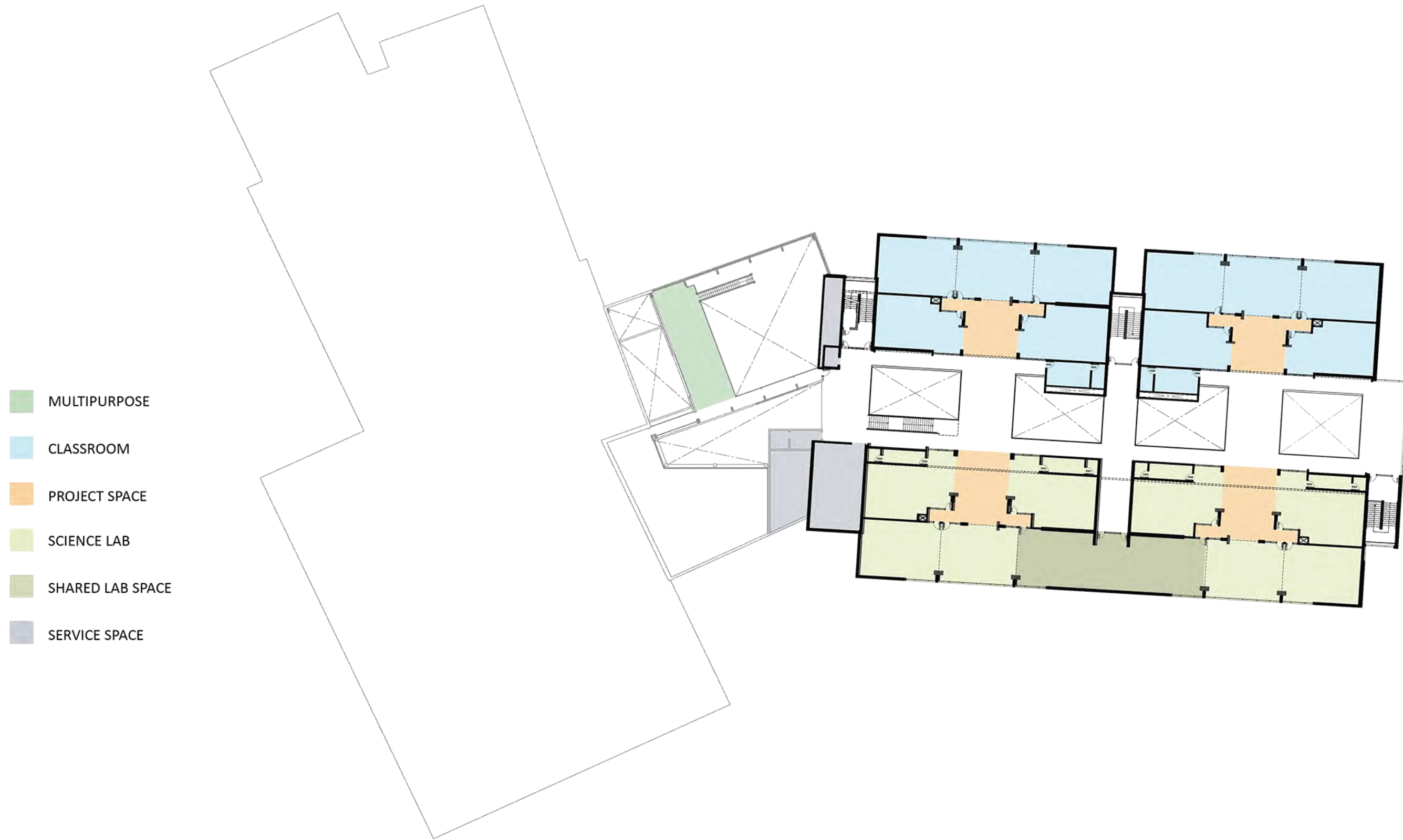
- GYM
- ARTS
- TRADES
- ADMIN
- MULTIPURPOSE
- NEIGHBOURHOOD LEARNING CENTRE
- CLASSROOM
- SERVICE SPACE

① LEVEL 1 FLOOR PLAN



- GYM
- MULTIPURPOSE
- CLASSROOM
- PROJECT SPACE
- SCIENCE LAB
- SHARED LAB SPACE
- SERVICE SPACE

① LEVEL 2 FLOOR PLAN



- MULTIPURPOSE
- CLASSROOM
- PROJECT SPACE
- SCIENCE LAB
- SHARED LAB SPACE
- SERVICE SPACE

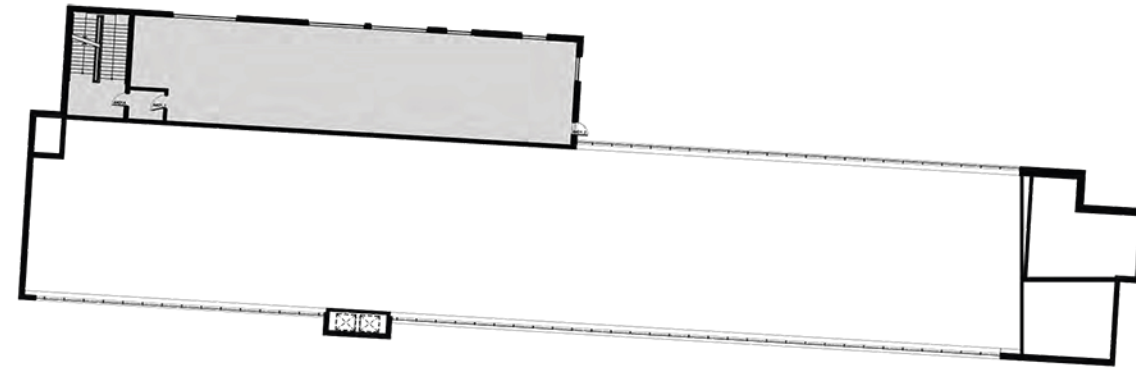
① LEVEL 3 FLOOR PLAN

- CLASSROOM
- PROJECT SPACE
- SCIENCE LAB
- SHARED LAB SPACE
- SERVICE SPACE



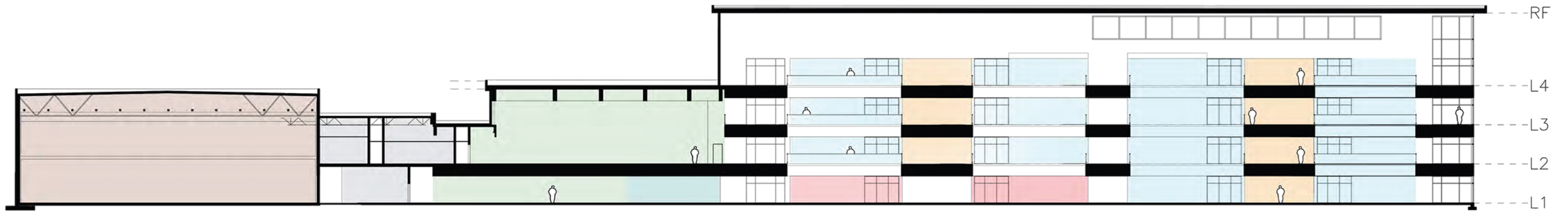
① LEVEL 4 FLOOR PLAN

■ SERVICE SPACE



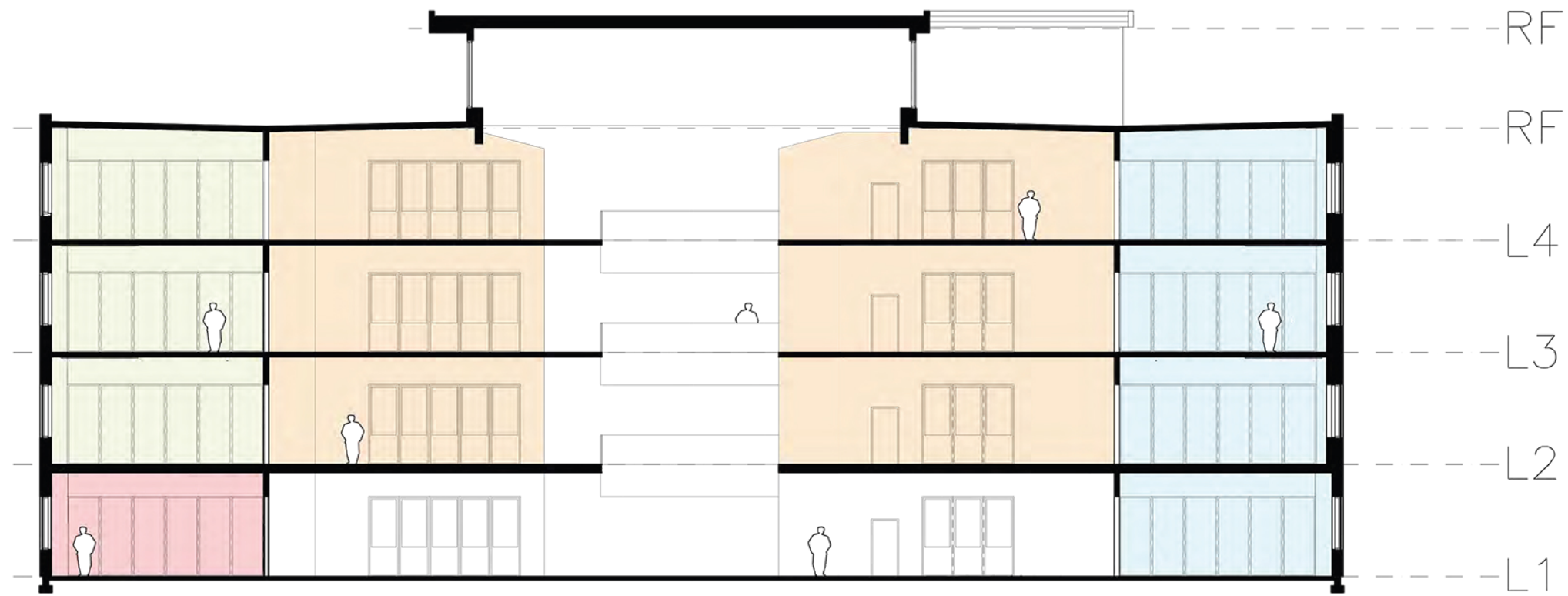
① MECHANICAL PENTHOUSE





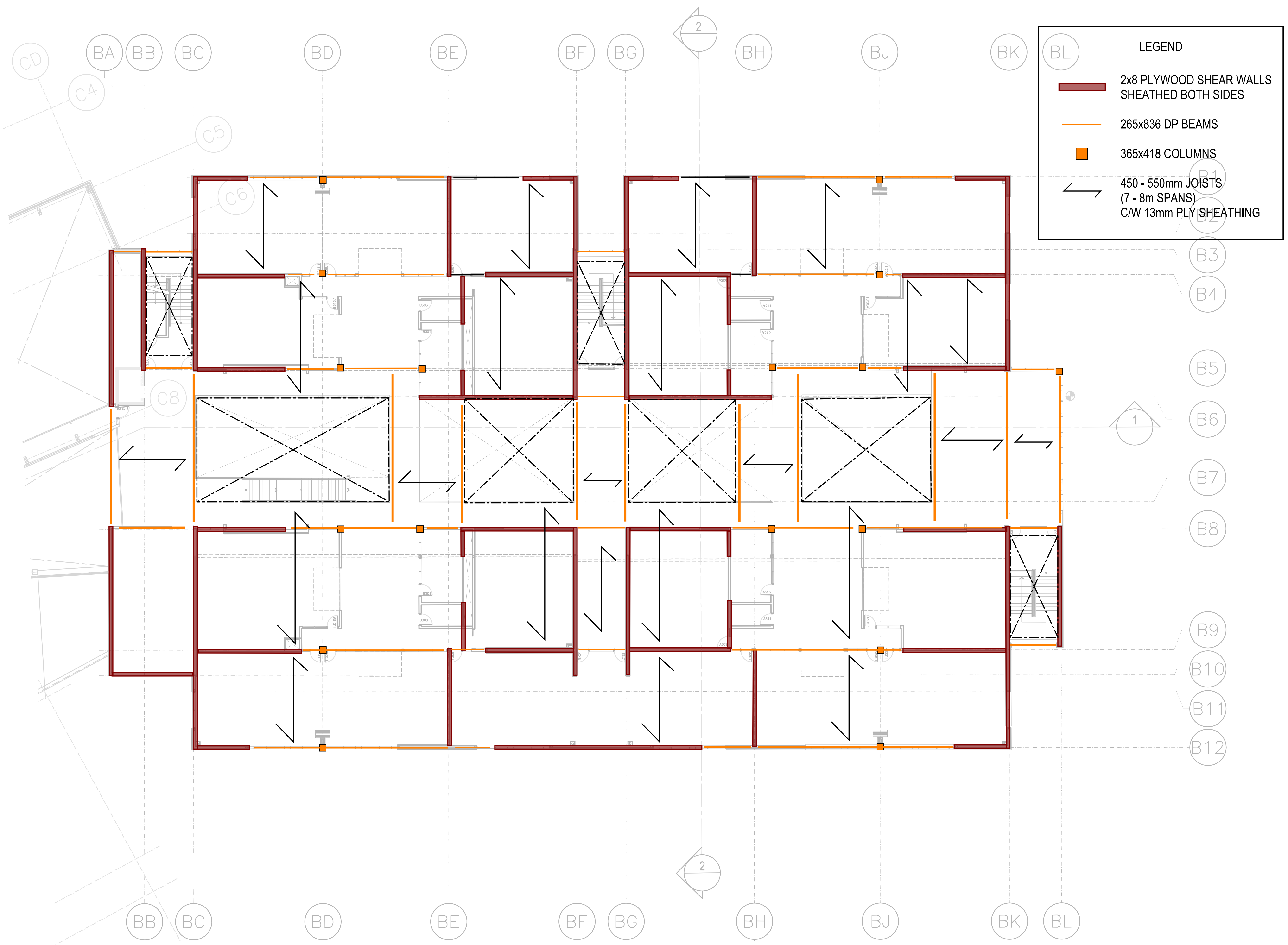
① SECTION 1

- GYM
- ADMIN
- MULTIPURPOSE
- CLASSROOM
- PROJECT SPACE
- SCIENCE LAB
- NEIGHBOURHOOD LEARNING CENTRE
- SERVICE SPACE



② SECTION 2

APPENDIX B: Three-Storey School with Light Wood-Framed Construction



**LEGEND**

- 2x8 PLYWOOD SHEAR WALLS SHEATHED BOTH SIDES
- 265x836 DP BEAMS
- 365x418 COLUMNS
- 450 - 550mm JOISTS (7 - 8m SPANS)  
C/W 13mm PLY SHEATHING

REV.	DESCRIPTION	DATE
	COSTING ISSUE	11/10/2019
	CONCEPT ISSUE	05/04/2019
ISSUE / REVISION		

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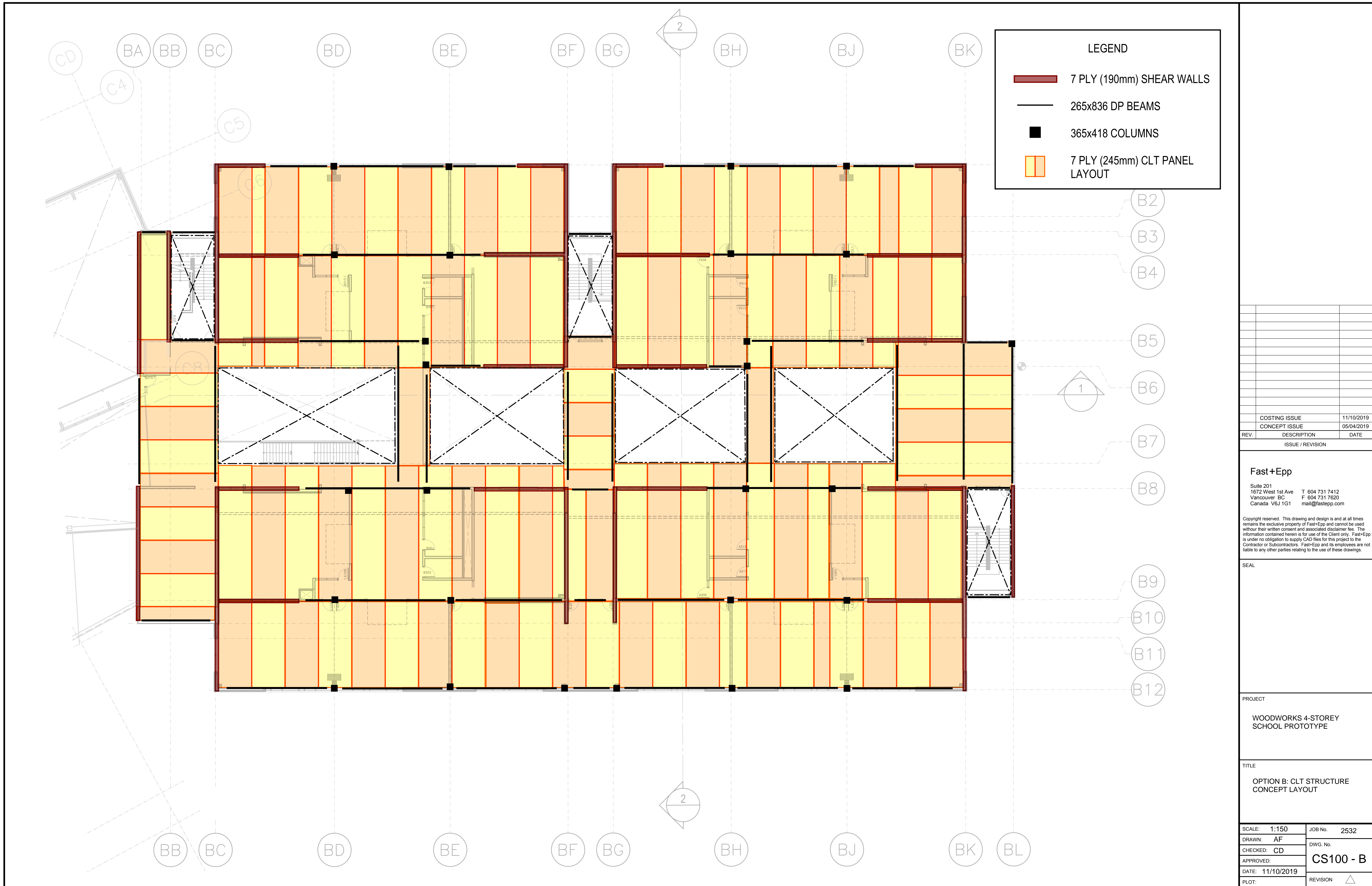
SEAL

PROJECT  
**WOODWORKS 4-STOUREY SCHOOL PROTOTYPE**

TITLE  
**OPTION A: LIGHT WOOD FRAME STRUCTURE CONCEPT LAYOUT**

SCALE: 1:150	JOB No. 2532
DRAWN: AF	DWG. No.
CHECKED: CD	<b>CS100 - A</b>
APPROVED:	
DATE: 11/10/2019	
PLOT:	REVISION <span style="border: 1px solid black; padding: 2px;">△</span>

APPENDIX C: Four-Storey School with CLT Diaphragms on CLT Shear Walls



**LEGEND**

- 7 PLY (190mm) SHEAR WALLS
- 265x836 DP BEAMS
- 365x418 COLUMNS
- 7 PLY (245mm) CLT PANEL LAYOUT

REV.	DESCRIPTION	DATE
	COSTING ISSUE	11/10/2019
	CONCEPT ISSUE	05/04/2019

ISSUE / REVISION		

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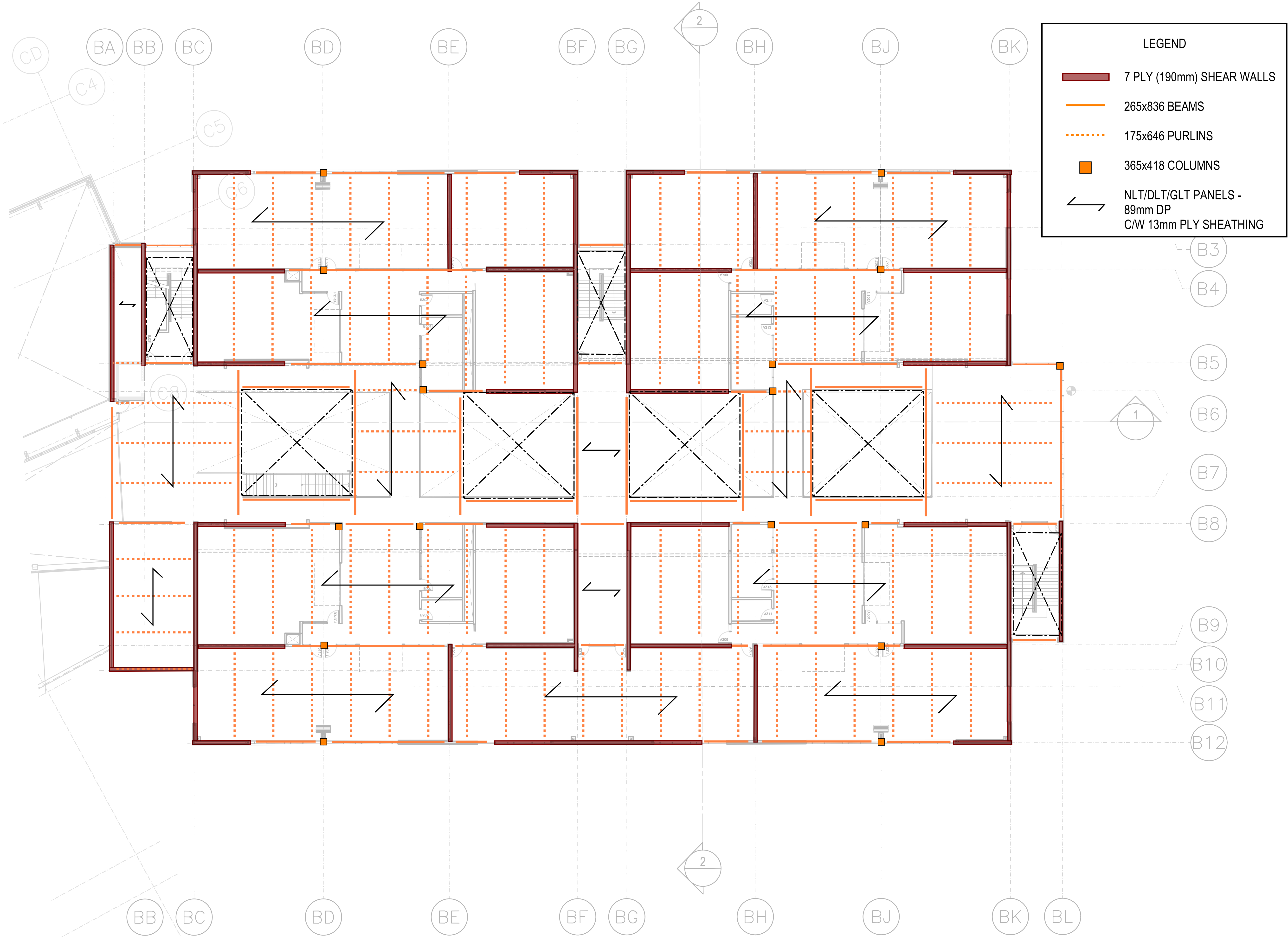
SEAL

PROJECT  
 WOODWORKS 4-STOUREY  
 SCHOOL PROTOTYPE

TITLE  
 OPTION B: CLT STRUCTURE  
 CONCEPT LAYOUT

SCALE: 1:150	JOB No. 2532
DRAWN: AF	DWG. No.
CHECKED: CD	<b>CS100 - B</b>
APPROVED:	
DATE: 11/10/2019	REVISION
PLOT:	△

## APPENDIX D: Four-Storey School with Plywood Diaphragms and Panel on Purlin Framing on CLT Shear Walls



LEGEND	
	7 PLY (190mm) SHEAR WALLS
	265x836 BEAMS
	175x646 PURLINS
	365x418 COLUMNS
	NLT/DLT/GLT PANELS - 89mm DP C/W 13mm PLY SHEATHING

REV.	DESCRIPTION	DATE
	CONCEPT LAYOUT	NOV. 2019
ISSUE / REVISION		

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SEAL

**PROJECT**

DESIGN OPTIONS FOR THREE AND  
FOUR STOREY WOOD SCHOOL  
BUILDINGS IN BRITISH COLUMBIA

**TITLE**

OPTION C: CLT SHEAR WALLS  
WITH NLT, DLT, OR GLT PANEL ON  
PURLIN FRAMING

SCALE: 1:150

JOB No. 2532

DRAWN: AF

DWG. No.

CHECKED: CD

**CS100 - C**

APPROVED:

DATE: 11/10/2019

PLOT:

REVISION

