UNITED STATES FOREST SERVICE WOOD INNOVATION REPORT

MULTI-STORY MASS TIMBER K-12 SCHOOLS

PREPARED BY MAHLUM ARCHITECTS

31 JANUARY 2022
19-DG-11062765-734

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ACKNOWLEDGMENTS & THANKS

This project would not be possible without funding through the USDA and US Forest Service Wood Innovations Grant (Federal Grant Number 19-DG-11062765-734).

Wood Innovations Grants support traditional wood utilization projects, expands wood energy markets, and promotes using wood as a construction material in commercial buildings. In additional to grant funding, the team members listed here supported the project with in-kind donation of time, expertise, and resources.

Beyond the project team, the following individuals have also generously shared their time and expertise in reviewing the work, making comments, and helping synthesize the concepts into a cohesive whole. We owe our gratitude, in alphabetcal order by last name, to:

Hans-Erik Blomgren
TimberLab

Ashley Cagle
WoodWorks

Graham Finch
RDH Building Science Services

Monica Huang
Carbon Leadership Forum

Brad Kahn
Forest Stewardship Council

Steve Kelly
WT North America

Ricky McLain
WoodWorks

Cindy Mitchell
Washington Forest Protection Assoc.

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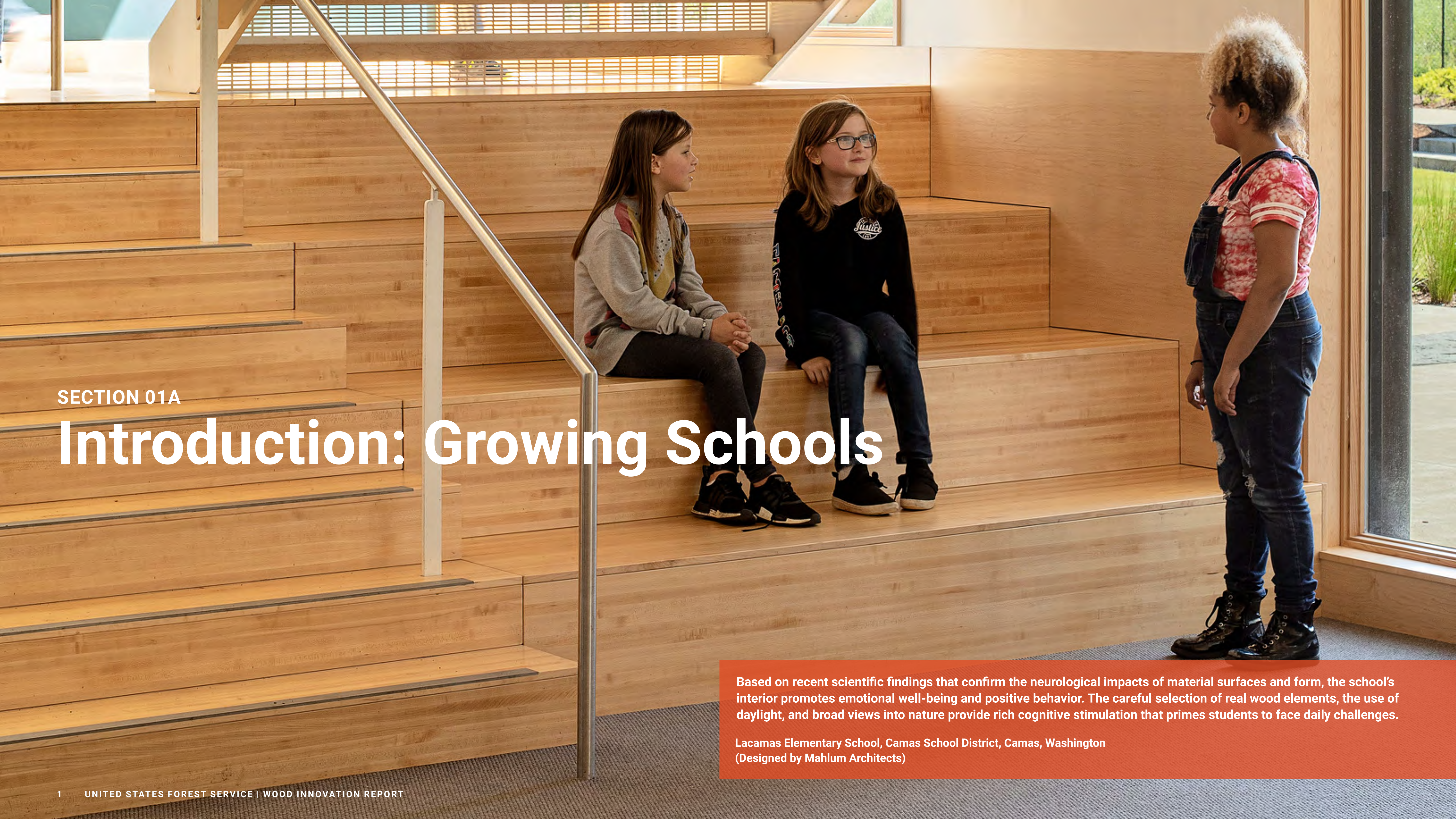


SECTION 01A

Introduction: Growing Schools

Based on recent scientific findings that confirm the neurological impacts of material surfaces and form, the school's interior promotes emotional well-being and positive behavior. The careful selection of real wood elements, the use of daylight, and broad views into nature provide rich cognitive stimulation that primes students to face daily challenges.

Lacamas Elementary School, Camas School District, Camas, Washington
(Designed by Mahlum Architects)

School is a place to expand horizons – a place where students learn about themselves and the world around them.

CLASSROOMS NEEDED

There is a critical need in Washington State for high-quality, healthy learning environments that foster creativity, critical thinking, and growth. As students continue to face new and different types of challenges, the role of school is more important than ever. Our next generation of leaders, thinkers, and doers must be welcomed, nurtured, and empowered by their environment.

WOOD INNOVATION GRANT

This report, partially funded by a United States Forest Service Wood Innovations Grant, explores the use of mass timber to deliver exceptional K-12 educational spaces in Washington State that are cost-effective, resource efficient, and low carbon.

The primary focus of the grant is to study the feasibility of tall, multi-story (up to 3-stories) classroom buildings in Washington State with applicability across the Pacific Northwest as well as other regions of the U.S. The study is based on several overarching presuppositions:

With a growing population and mandated reductions in classroom sizes, Washington State has a capacity crisis and must quickly deliver additional classrooms and learning spaces to meet its Constitutional mandate for basic education. Washington State is not unique in this situation and other states also require additional classroom capacity.

Land is at a premium today and many school districts do not have access to greenfield sites or large swaths of developable land. Often, new school construction must happen on occupied sites, creating unique construction and site planning issues. To deliver additional learning spaces, especially in more urban areas or occupied sites, buildings will need to rise vertically in multi-story construction either as stand-alone structures or additions to existing schools. Construction will need to be quick and quiet on sites which must simultaneously accommodate existing school programs.

Education must be affordable, and likewise new school construction and renovations must be financially within reach of the communities they serve. To be a viable option, mass timber must be cost competitive to other materials used for similar scale school construction.

The world around us is rapidly changing, and consequently the physical landscape of schools must also be capable of change. Creating flexible and adaptable structures that foster fluid learning environments are better suited to meet the diverse needs of students today and in the future.

With impacts from the climate crisis growing, creating more sustainable and resilient buildings has never been more important. Aggressive energy reductions in combination with use of natural, local, carbon-sequestering materials like wood will increase in importance. In 2008 the Washington State legislature, recognizing the urgency of decarbonization, mandated emissions reductions and set limits to be achieved by 2035 and neutrality by 2050. Washington State Governor Jay Inslee has been a strong proponent of climate and decarbonization and in 2021 helped pass cap and trade legislation and clean fuel standards. A national push for climate action has also grown, especially following the extreme weather and natural disasters that are striking with increased frequency. With awareness of embodied carbon in materials also rapidly growing, it is not hard to imagine mandates limiting emissions from building materials.

The following pages share design explorations and solutions to the issues raised here. While each project, site, and school district are unique, we hope that our findings will serve as a template for accelerating the use of wood and mass timber in K-12 schools. Because mass timber schools are a relatively new building type, there is risk involved. This report cannot solve every issue a design and construction team will encounter, but we hope that it will highlight and offer potential solutions, thereby saving time and resources, and ulitmately reducing risk.

Mass timber is currently an available strategy to reduce carbon emissions compared to traditional construction methods.

80%

Carbon emission reduction when comparing a mass timber superstructure with steel.

See Embodied Carbon section for more information

WHY MASS TIMBER?

When we picture the original schoolhouses in this country, we undoubtedly picture a clapboard-sided, wood-framed structure with gable roof. While using wood for schools is not new, the use of mass timber for modern schools is new and presents opportunities, benefits, and challenges.

One opportunity arrived with the 2015 and 2018 Washington State Building Code updates. These updates permit mass timber schools to now be constructed up to nine-stories tall, highlighting our new technical knowledge and understanding of mass timber.

Many studies have indicated a benefit that mass timber can reduce greenhouse gas emissions in comparison to traditional steel and concrete buildings.[1]

The authors of this report found when compared with steel, a mass timber superstructure can reduce carbon emissions by more than 80%.

LOCAL

Using wood sourced from Washington State, combined with mass timber manufacturing in the state, transportation emissions can be reduced. Forest thinning and restoration practices can also make Washington's forests more resilient to wildfires, preventing additional carbon emissions and air quality issues while at the same time providing feedstock for material production that locks-up atmospheric carbon for long periods of time. Mass timber is a currently available strategy to reduce and capture carbon emissions. See the Sustainable Sourcing section.

ABOVE: Schoolhouse located in Dupont, WA, 1880, State Library Photograph Collection, 1851-1990, Washington State Archives

STRUCTURAL

One primary reason for the growing adoption of mass timber is its structural capacity. A mass timber structural frame can manage significant gravity loads while also readily accommodating long spans to promote flexibility and adaptability of interior space. See the Structural Approach section.

FLEXIBLE

Every school district – and every school and user group – will have different needs and goals that will influence how interior space is arranged. A flexible building system can accommodate a diversity of layouts, which is important not only for opening day, but also allows schools to change over time as staff, enrollment, and needs evolve. Ensuring renovations or additions can be easily accommodated in the future reduces the risk of demolition and new construction. While this will save money and reduce disruptions in the long-term, it also is a benefit from a sustainability perspective. Continuity of long-lived structures is paramount to reducing large spikes in greenhouse gas emissions associated with new construction. See the Building Framework section.

EDUCATIONAL

Mass timber and use of exposed wood surfaces introduces a degree of authenticity, softness and biophilia back into our learning environments. These spaces are not sterile boxes made from anonymous materials, but rich and stimulating, just as educational curriculums should be. The building itself can be a demonstration that healthy materials are harvested from natural, sustainably managed resources.

Sustainability elements can be learning tools. For example, the building structure can teach about forestry. Energy efficiency measures can be tools for learning science and math. Biophilic elements like wood and views to nature and daylight can boost learning and satisfaction. Schools should be a vibrant place, and the use of mass timber helps bring them to life in a powerful way. See the Indoor Environmental Quality section.

ECONOMICAL

Light wood framing and mass timber may both use lumber stock as the primary material, but the two are fundamentally different. Mass timber elements, due to their large size and thickness can transfer substantial gravity and diaphragm loads, similar to concrete and steel in multi-story buildings. This, combined with inherent fire-resistiveness due their large size, makes mass timber ideal for taller, multi-story construction like large schools. Light framed buildings are often constructed on-site from a huge number of small pieces and fasteners, whereas mass timber is brought together on-site from a small number of very large elements and connections. This process simplifies construction and makes it exceedingly fast when well-planned. A straight-forward structural system that is quick to build will save money during the build and be a cost competitive option to more traditional types of commercial construction. See the Cost, Constructability & Sourcing section.

The design for a multi-story mass timber school presented on the following pages prioritizes sustainability, flexibility, and creation of learning environments tuned for student success.

What is Mass Timber?

Mass timber is a term that captures several different types of large-format timber components used in construction. Typically, these timber elements are referred to as “engineered wood,” or “structural composite lumber” (SCL) since they are made from smaller pieces of wood combined together into larger sections using either mechanical attachment or adhesives. However, solid-sawn lumber or even whole tree logs are also members of the mass timber family. What differentiates mass timber is the size, thickness, and level of prefabrication of the element.

The International Building Code (IBC) defines mass timber as “structural elements of Type IV [Heavy Timber] construction primarily of solid, built-up, panelized or engineered wood products that meet minimum cross-section dimensions of Type IV construction.” Due to the size and prefabrication of mass timber elements, they promote fast construction and reductions in on-site labor. They are inherently fire-resistive and structurally robust.

While not an exhaustive collection, the items shown below are among the most typical mass timber elements used today.

CROSS LAMINATED TIMBER (CLT)

Structural panels made from layers of dimensional lumber, with each layer oriented 90 degrees from the layer below. The layers are joined together by structural adhesive and layed-up in three, five, seven or more laminations or plies. Panels can be up to 60 feet long and 12 feet wide, depending on the manufacturer. ANSI/ APA PRG 320 standard covers production requirements of CLT.

DOWEL LAMINATED TIMBER (DLT)

Panels made from dimensional lumber with the face of each board parallel to the face of the next. The boards are joined together by hardwood dowels and typically used as floors and roofs. DLT does not transfer in-plane shear forces without an additional structural panel (such as plywood or OSB) being attached. DLT is a proprietary product with code acceptance based on ESR-4069.

GLUED LAMINATED TIMBER (GLT)

Traditionally used as beams and columns made from dimensional lumber glued together on the wide face of boards. GLT can also be used as floor or roof slabs, with a typical format size of 4 feet wide by 65 feet maximum length. ANSI Standard A190.1 provides product manufacturing, testing and certification.

MASS PLYWOOD PANELS (MPP)

Panels made from thin layers of veneer glued together, similar to Laminated Veneer Lumber (LVL). MPP panels can be up to 12 inches thick and 48 feet long and function similar to CLT panels. MPP is certified through ANSI/ APA PRG 320.

SOLID-SAWN AND LOG

Non-engineered timber components typically used as columns and beams and known as Structural Round Timber (SRT) and Sawn Heavy Timber (SHT).

OTHERS

Engineered wood components such as Laminated Veneer Lumber (LVL) and Parallel Stand Lumber (PSL) are also mass timber elements. ASTM D5456 is the product standard for SCL materials.

IMAGE:
Log columns harvested from site and DLT are the primary focus in the design of Lakeridge Middle School, Lake Oswego School District, Lake Oswego, Oregon (Designed by Mahlum Architects)

SECTION 01A FOOTNOTES

1. Several studies have found that use of wood instead of steel or concrete can reduce climate impacts. A few studies are listed below for reference:

   > Allan, K.; Phillips, A.R. Comparative Cradle-to-Grave Life Cycle Assessment of Low and Mid-Rise Mass Timber Buildings with Equivalent Structural Steel Alternatives. Sustainability 2021, 13, 3401. https://doi.org/10.3390/su13063401

   > Cadorel, Xavier & Crawford, Robert. (2019). Life cycle analysis of cross laminated timber in buildings: a review.

   > Melton, P. (2016, April 30). Wood structures could reduce global carbon by almost a third. BuildingGreen. Retrieved January 2021, from https://www.buildinggreen.com/newsbrief/wood-structures-could-reduce-global-carbon-almost-third

   > Pierobon, Francesca; Huang, Monica; Simonen, Kathrina; Ganguly, Indroneil. Environmental benefits of using hybrid CLT structure in midrise non-residential construction: An LCA based comparative case study in the U.S. Pacific Northwest, Journal of Building Engineering, Volume 26, 2019, 100862, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2019.100862

   > Robertson, A.B.; Lam, F.C.F.; Cole, R.J. A Comparative Cradle-to-Gate Life Cycle Assessment of Mid-Rise Office Building Construction Alternatives: Laminated Timber or Reinforced Concrete. Buildings 2012, 2, 245-270. https://doi.org/10.3390/buildings2030245

SECTION 01A IMAGE CREDITS

Page 1: Photo by **Jeremy Bittermann**

Page 2: Rendering by **Mahlum Architects**

Page 3: Photo by **Mahlum Architects**
Historic Photo from **Washington State Archives**

Page 4: Clockwise, starting with far right image:
Photo by **Josh Partee**
Photo by **Josh Partee**
Photo by **Freres Lumber**
Photo by **Fast + Epp**
Photo by **StructureCraft**
Photo by **Fast + Epp**
Photo by **Fast + Epp**

SECTION 01B

Educational Design

Wilkes Elementary School creates and connects spaces with transparency and biophilic aspects of wood. Clusters of four classrooms with shared learning areas create intimate student communities with strong relationships to their teachers, fostering collaboration, connectivity, and opportunities for variation in scales of learning.

Wilkes Elementary School, Bainbridge Island School District, Bainbridge Island, Washington
(Designed by Mahlum Architects)

Schools need to provide varied learning spaces with spatial opportunities to support a student's unique cultural identity and individual interests.

IMAGE:
Learning outdoors under a tree is what architect Louis Kahn described as the "first school."
Moss Street Children's Center, University of Oregon, Eugene, Oregon
(Designed by Mahlum Architects)

In developed communities around the world, schools are essential learning systems and have existed for thousands of years.

The first schools in the United States started during the colonial period, but a call for free, compulsory education was not widespread until the mid-1800s.[1] In our more recent past, formal schooling was often a privilege available only to upper-class, white males – an example of how education systems used to expand opportunities for some, but reinforced systemic barriers for underrepresented communities. Centering justice, equality, diversity, and inclusion, we ask how our learning environments support all students in their academic journey.

How do we spark curiosity and a passion for learning, as well as mutual understanding, empathy, and collaboration? We recognize our learners come with different lived experiences and they express unique interests, capabilities, strengths, and weaknesses. To support a diverse cohort of students, schools need to provide varied learning spaces with spatial opportunities to support a student's unique cultural identity and individual interests.

Too often, students become caught within the system and are left behind for no fault of their own. The following chapter explores ways the physical space of schools can be arranged, rearranged, and adapted to support the various needs of learners today and provide successful outcomes into the future.

EDUCATIONAL CONTEXT

From 2012-2024, The National Center for Education Statistics predicts total enrollment in Washington State K-12 schools will increase by nearly 16 percent.[2] Accommodating this rapid growth in student capacity requires thoughtful planning of educational facilities that not only meet today's construction costs but provide flexibility for program evolution and prioritize holding long range maintenance and renovations costs below thresholds that may trigger costly replacement.

The design of schools has a long trajectory. The architect Louis Kahn once said that *"...schools began with a man under a tree, and around him the listeners to the words of his mind."* While we may wish this to be true, a grove of trees is seldom part of the modern school program. Beginning in the industrial era, individual, enclosed classrooms have been the favored building block for schools. A one-size-fits-all model has flourished: rows of individual desks with students facing forward while the teacher imparts information. Like water filling a glass, knowledge is supposedly transferred through rote memorization, repetition, and testing. Outside the classrooms, corridors, and cafeterias are less like learning spaces, but functional requirements in an institutionalized, mass production approach to education. While this may appear egalitarian, often it is too rigid to acknowledge and support learning differences.

Schools from the 1960s and 70s explored open, loose-fit designs. These interconnected classrooms celebrated porous boundaries and offered different spatial opportunities for learners to engage with one another. While varied learning experiences are important, classrooms from this era were often unsuccessful due to compromised acoustics, visual distractions, and teachers lacking the experience to create program approaches supporting students to thrive in this unfamiliar environment. **Both open and closed classrooms may contribute to learning and achievement, but how can we leverage the successful elements from each and develop new models for differentiated learning experiences that better supports diverse student communities?** How can the physical spaces of schools be arranged to truly connect students to content and create real and authentic learning?

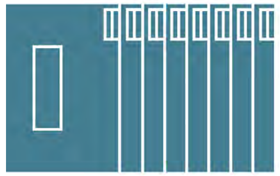
To prepare learners for success in their future, Student-Centered Learning focuses on active, exploratory, and collaborative learning practices. Rather than all learning taking place in a single-setting classroom, learning communities with multiple types and scales of spatial experience may be more successful in meeting diverse student needs. Here, the focus is not on an individual classroom, but how a collection of diversified learning spaces can function together wholistically, like a community, to improve learning outcomes. Such a model is made from a variety of programmatic elements that support interaction between them. Spaces such as specialized science and technology labs, seminar rooms, maker spaces, food science, gardens, outdoor learning, small group learning, integrated support services, and shared collaboration areas are all settings that can fit into this landscape of a learning community. **Creating learning spaces to support all students foregrounds universal accessibility and culturally responsive design solutions, so all students feel reflected in the environments around them and have equal access to learning experiences.** With the physical space needs inside schools constantly evolving to keep up with best practices in learning, schools environments must be capable of on-going change.

DIAGRAMS: While designing Arlington Elementary School, Mahlum discovered that 77% of the time learning ideally occurred with groups of 15 students or less. This discovery challenged typical programs assigning groups of +/-30 students to a single classroom – geared towards direct instruction. The design team utilized a functional programming process to understand their spatial needs. This led to an agile learning model, where each learner/teacher is given a core instruction space, a shared learning project lab, a flexible shared learning area, multiple small group rooms and a secure outdoor learning space, in the same (or less) square foot per student as the traditional mode.

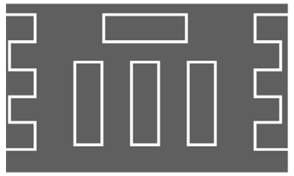
TARGET USAGE BY TIME

23%

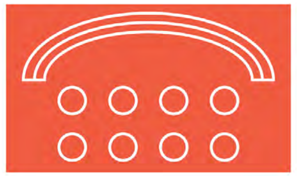
OF A STUDENT'S DAY IS SPENT IN LARGE GROUP LEARNING:



LARGE GROUP
FORUM / PRESENTATION
25-50 PARTICIPANTS
1600 SF



LARGE GROUP
EXPERIMENT / CREATE
25-50 PARTICIPANTS
1400-1600 SF



LARGE GROUP
COLLABORATE / GATHER
25-50 PARTICIPANTS
1600 SF

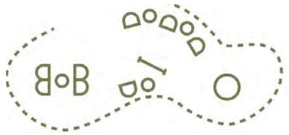
77%

OF A STUDENT'S DAY IS SPENT IN SMALL GROUP LEARNING:

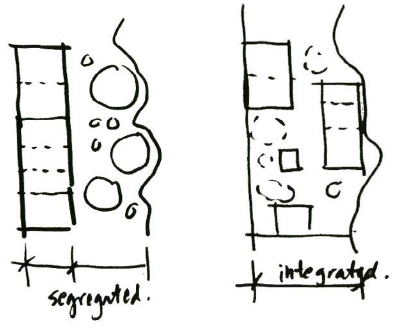
LARGE FLEX
15 PARTICIPANTS
600-800 SF

SMALL FLEX
10 PARTICIPANTS
200-300 SF

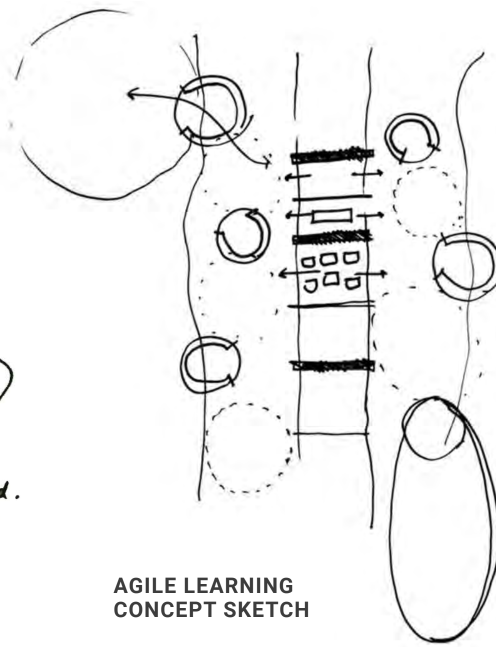
SMALL GROUP
5 PARTICIPANTS
120-150 SF



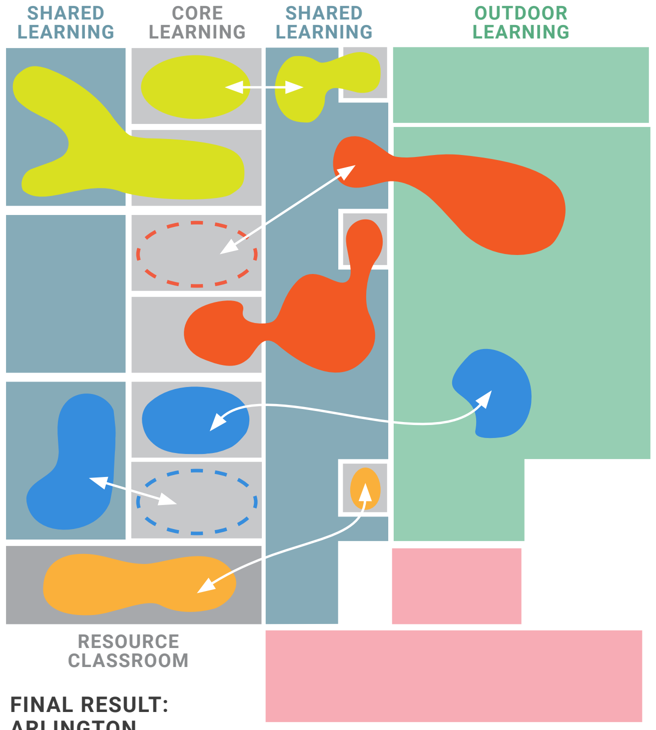
INDIVIDUAL STUDY
1 PARTICIPANT
ANYWHERE



LEARNING COMMUNITIES: SEGREGATED VS INTEGRATED



AGILE LEARNING CONCEPT SKETCH



FINAL RESULT: ARLINGTON ELEMENTARY PROGRAM

EDUCATIONAL ENVIRONMENTS ARE FOR LEARNING, NOT TEACHING

To allow discovery to happen, students will transition from dependent to independent learning through learning models like gradual release of responsibility (GRR) where the responsibility of learning shifts from teacher to student driven. While some will thrive in an active, potentially loud, group setting, others may prefer small group or quiet focus time by themselves. Quiet reading may be complemented with hands-on activities to activate learning, establish real connection to content, and promote understanding over short-term memorization.

Different activities often require different types of spaces for focused learning. This points to the need for a variety of spaces, but also the ability to adapt spaces as learning needs change over time. In this way a school can and should look different from year to year as educators find the best ways to connect with and support their students.

In today's digital world, access to information is readily available and learning experiences are less dependent on the physical school environment to access content. While digital content might supply knowledge acquisition, learning must also encompass broader social, creative, and critical thinking skills. In the book *Learning by Design*, the authors identify ten critical 21st century literacies.[3] These include:

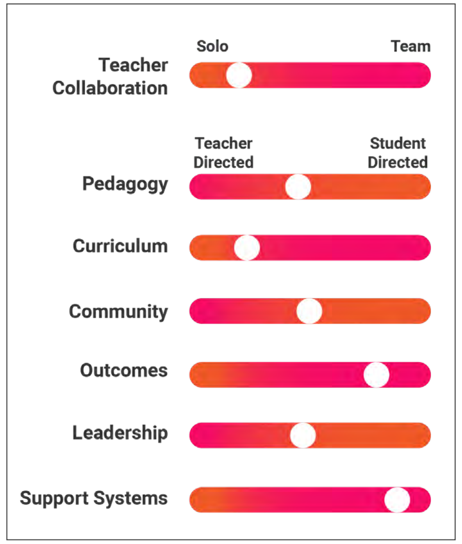
1. Complex problem solving
2. Critical thinking
3. Creativity
4. People management
5. Coordinating with others
6. Emotional intelligence
7. Judgment and decision-making
8. Service orientation
9. Negotiation
10. Cognitive flexibility

A routine learning approach which prioritizes forward-facing, direct instruction in isolation will not foster these kinds of skills in isolation. When asked how to foster the 4Cs (creativity, critical thinking, collaboration, and communication), a poll of teachers overwhelmingly indicated that student-led learning as superior to teacher-led.[4] **Allowing students ownership of their learning is a key to success,[4] which involves having the right type of spaces to support this type of learning.** Moreover, real learning happens when we actively engage with content. When we play with content, make it our own and create something new from it, information is transformed into understanding.

In the book *The Language of School Design,* Prakash Nair identifies 20 learning modalities that a school must support.[5] What is clear is that the traditional classroom, while good for lecture-based teaching, cannot adequately support these different modalities, especially when taking place concurrently and throughout the day.

Multiple physical learning settings (see page 10) provided with dynamic furniture to meet learner needs will better support different modes of learning identified. A variety of learning environments allows different ways for students to connect authentically to subject matter while at the same time offering teachers the ability to personalize learning with each student. Learners may easily transition from individual focus skills to team collaboration by shifting from one area of the room to another.

As time, pedagogy, and priorities change, spaces should be able to change, too.



ABOVE: Each school has its own learning spectrum. The physical structure of the school largely determines what type of learning can occur there. A flexible building allows learning environments to change over time. (Diagram adapted from the book *The Language of School Design* by Prakash Nair.)

IMAGE:
Learning can happen anywhere.
Arlington Elementary School, Tacoma Public Schools, Tacoma, Washington
(Designed by Mahlum Architects)

Alternatively, teaching itself can flip back and forth from teacher-led to student-led. Students can work in both formal or informal settings, driven by project needs. Teachers can develop professional learning communities to collaborate on content and learn from each other new methods of skill building with their students. **Stepping outside of the enclosed classroom can propel students and teachers alike.**

The concept of a learning community also serves to break-down the scale of larger schools and create a sense of belonging among the students, teachers, and staff. A community of approximately 150 students is believed to be the upper threshold where a population can meaningfully know everyone. Subdividing a school into communities of this scale or smaller leads to positive outcomes as anonymity is eliminated and positive peer support can activate learning and unite the community.

Furniture type and arrangement plays a critical role in how spaces may be set up to create a dynamic learning landscape. From a practical standpoint, lightweight furniture promotes adaptability, movement, and different ways to customize learning. The ability to move and adapt furniture to transform an environment from traditional direct instruction space to collaboration zones to small group work or other space types. A table may be used as a touch-down space or area for brainstorming. Tall-backed seating can promote individual work and self-reflection or can be combined for small group tasks. A diversity of seating types and configurations offers students choice and personal autonomy in how they learn.[6]

TEACHING AND LEARNING SPECTRUM

Not all schools are ready to step away from the traditional classroom teaching approach with direct teacher instruction as the main learning experience. However, changes can occur incrementally over time as educators develop their practices in support of students. First steps to community style learning could include:

> The use of hallways for break-out spaces.

> Operable partitions between classrooms.

> Convert portions of classroom space to support open, or small group learning styles through furniture-based interventions.

Circulation spaces and areas outside stairwells are often overlooked as part of the learning landscape, but these spaces may also be harnessed for learning opportunities. Providing seating and tackable surfaces in hallways transforms them from simple paths for circulation into valuable zones of learning where student work can be displayed and discussed. Providing visual transparency between learning spaces affords an increased awareness of activities throughout the school and can help connect formal and informal learning spaces together as it allows easy, passive supervision by educators.

As best practices in learning continually evolve, pedagogy and priorities change. Our education spaces should be able to change as well. Two classrooms might be transformed into a multi-purpose lab or open library commons. A central classroom could be transformed into a small group work zone with soft seating and storage for student's belongings. A small kitchenette could be carved-out of existing space to function as both a café and resource space. Or a dining commons could become multiple smaller cafes with small group seating and booths that better supports peer-to-peer learning experiences. **By thinking about space differently, a traditional classroom focused environment may transform into a learning community supporting multiple ways of learning and intelligences.** Variety is important to develop the type of "soft" skills needed once students transition to college, career, or life experiences. Unfortunately, many schools are not designed with change in mind, and creating even simple renovations could prove impossible if the building was not constructed to anticipate change.

Adapting to change goes beyond pedagogical priorities. Changes in student enrollment, classroom sizes or demographics also impact needs surrounding physical space. Unforeseen crises can also emerge, like the COVID-19 pandemic, requiring more space per student, shifting our circulation patterns, or even changes to health and wellness facilities. Adding early learning facilities to support early childhood education or upgrading safety and security are other common areas that impact space. **Schools that allow for walls to be easily moved and accommodate different arrangement of spaces, from small, medium to large, or even clustered spaces, will benefit over time as enrollment, curriculum, and circumstances change.** Allowing schools to break down walls will keep them relevant and adaptable with minimum impact on occupants and budgets.

When a school has been designed for flexibility and adaptability, renovations can be completed in just weeks or months with low-cost impacts allowing the school environment to be substantially changed when students come back from summer breaks.

ABOVE:
Different learning modalities as described in the book, *The Language of School Design*, by Prakash Nair

IMAGE:
Flexible learning environments can support different types of learning.
Northwood Elementary School, Mercer Island School District, Mercer Island, Washington (Designed by Mahlum Architects)

Technology is another critical area where change is occurring rapidly and often out pacing building system modernizations. As we shift to more devices in our educational environment the computer lab is transitioning to be in the hands of every student, every day. **Technology should be easy to use and widely dispersed throughout to provide equal access to all.** Allowing adequate space for technology to be updated or expanded is crucial. Obsolescence increases with a facility's inability to deal with change, whether that is physical or technical.[7]

Allowing the community into schools and listening to evolving needs will increase the school's relevance to the neighborhood as well as support student and families who are most at risk. In addition, schools that can be planned for future capacity expansions with minimal disruption to the facility will benefit districts over time. Allowing future additions and expansions to seamlessly tap into an existing school will save money and reduce complicated design and construction efforts. Designers and educators should think of schools with flexibility and adaptability at the heart as this will support the widest number of students and staff while promoting facility longevity and reduced financial burdens on school districts and communities.

LONG-LIFE, LOOSE-FIT

A National Center for Education Statistics report from 1995 found that around three-fourths of schools reported having undergone at least one major renovation.[8] A 2020 report from the U.S. Government Accountability Office found that an estimated 54% of public school districts needed updates or replacement of major features.[9] **Renovations will occur, but with good design, their impact can be minimized and disruptions to learning from construction held to a minimum.**

Certain building typologies have proven adaptable for the long term (see the Building Framework section for more discussion). Instead of being torn down, they are renovated to remain relevant and often loved by their occupants.

For a building to have a long life, one proven strategy is it must also have a loose-fit. As Stewart Brand notes in the book *How Buildings Learn*, "specialized space hinders future flexibility."[10] Raw spaces that are not over-specified support multiple uses over time. In the Pacific Northwest at the turn of the last century, for example, a common multi-story commercial building type was a heavy timber post and beam structure with solid wood floors. Even after the Seattle fire of 1889, Seattle and other cities across the region continued to build these structures. In a testament to their utility, many are still standing, having been renovated and reused countless times. The reasons this typology was popular in the past is still applicable today: inherent flexibility, use of local resources, fire-resistiveness, simple construction, robust structure, aesthetic benefits of exposed timber and connection to place.

It is often said that the only constant is change. Societal needs, social attitudes and behaviors, and our understanding of childhood development all change over time. Consequently, learning frameworks and school environments will continually evolve. While we can't predict the exact needs of future learners and teachers, we can offer the capacity for diverse learning environments today and, perhaps more important, be capable of change tomorrow. Rather than ready-made solutions, a flexible building allows human interaction between students, staff, and educators to arrange the environment that best suits their needs.

SECTION 01B FOOTNOTES

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SECTION 01B IMAGE CREDITS

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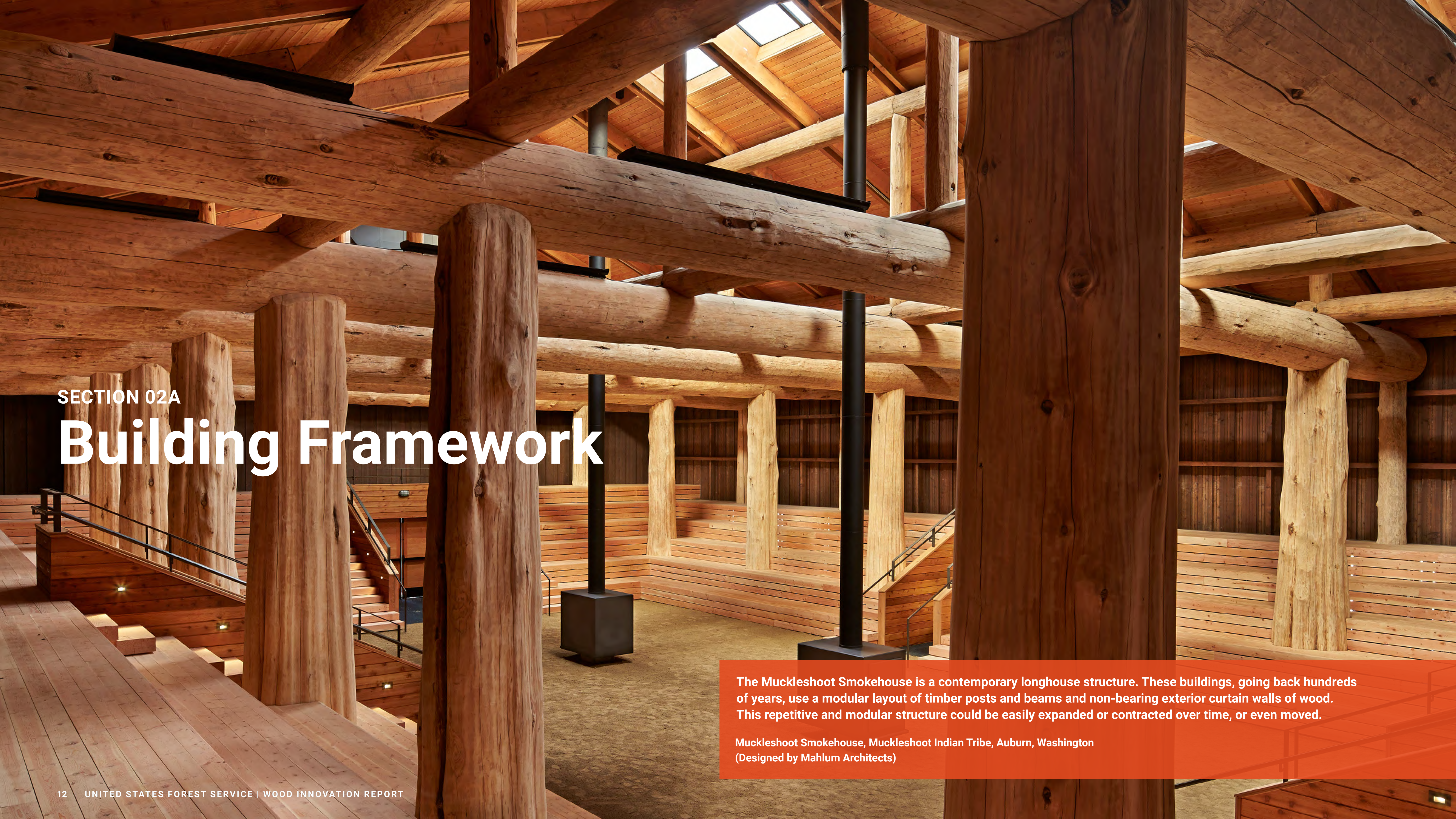


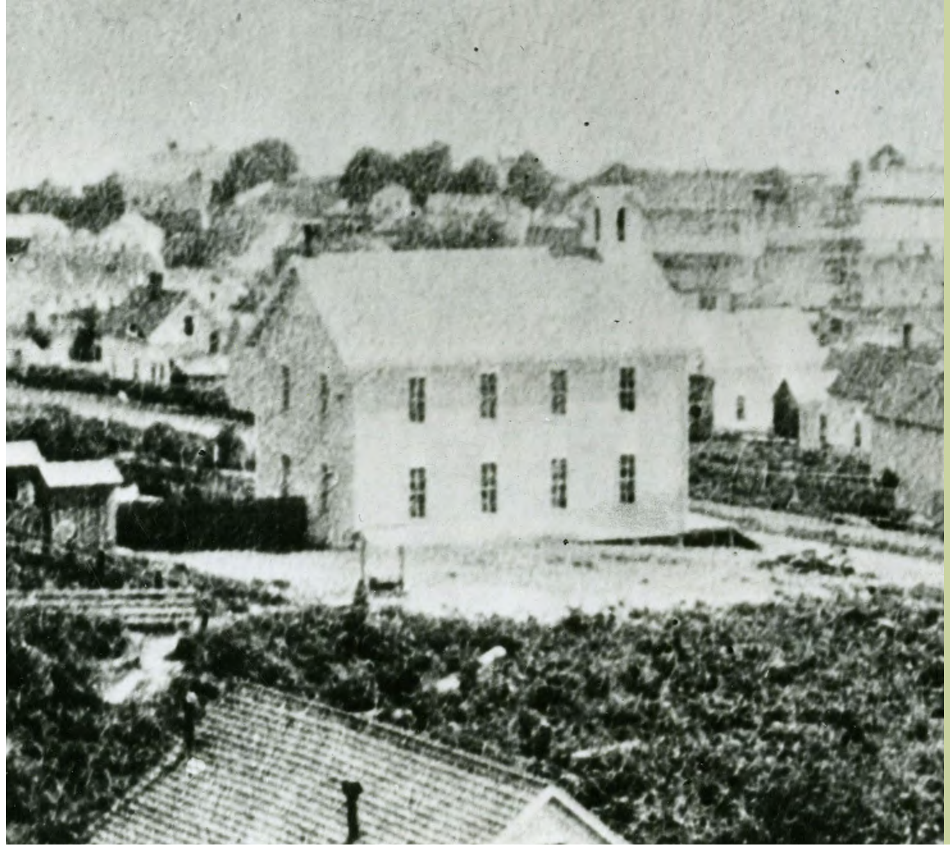
SECTION 02A

Building Framework

The Muckleshoot Smokehouse is a contemporary longhouse structure. These buildings, going back hundreds of years, use a modular layout of timber posts and beams and non-bearing exterior curtain walls of wood. This repetitive and modular structure could be easily expanded or contracted over time, or even moved.

Muckleshoot Smokehouse, Muckleshoot Indian Tribe, Auburn, Washington
(Designed by Mahlum Architects)

Structures that endure over time often exhibit common design principles.



Washington State Wood Schoolhouses

Some of the first schools in Washington State (in the sense of how we think of schools today), were undoubtedly found in frontier log cabins. As time passed, the humble log cabin was replaced by wood framed schools, serving as both centers for learning and for community gathering. By the turn of the last century – and with heavy industry arriving to the Pacific Northwest – wood was largely replaced by masonry architecture for both a sense of permanence and fear of fire.[1] Unfortunately, load-bearing masonry and reinforced concrete construction are relatively inflexible and not prone to adaption.

A truly flexible building can adapt to multiple users and uses over time. While larger, multi-story schools built from timber are rare in Washington State, the time to reconsider wood for their use has arrived.

IMAGE:
First school in Seattle, multi-story and wood framed, 1870, State Library Photograph Collection, 1851-1990, Washington State Archives, Digital Archives

PERENNIAL STRUCTURES

Many utilitarian structures, such as warehouses, barns, and halls tend to endure over the long term. These buildings exhibit a simple form with logical, repetitive, and massive yet unobtrusive structural elements that create a container adaptable to multiple uses over time.

These structures can be thought of as general-purpose rather than specialized, which keeps them open and flexible instead of over-constrained. They are large enough to allow a variety of interior uses, but not too deep to prevent good daylighting, and typically have generous floor to ceiling heights.

Such buildings can be easily added to, whether with a simple lean-to or an entire new wing. Wood is often cited as the most flexible building material because it can be easily cut, drilled, added to, subtracted, replaced, reinforced, and fastened together with simple screws, nails, and saws. Timber structures are strong enough to support heavy loads, allowing a former warehouse to transition to an office, to a lab, or even a library, for example.

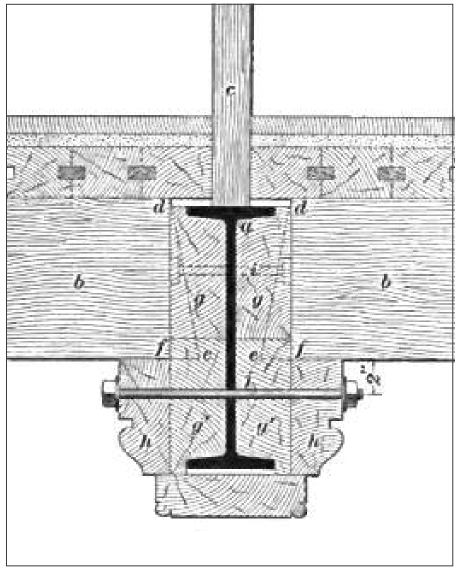
FORM FOLLOWS FRAMEWORK

Schools are often designed around current pedagogy, emphasizing the relationships of grade level classrooms to support spaces and the corridors that serve them. Classrooms might be arranged in a line, or clustered around a small, shared space or distributed between shared spaces. While a wall may be able to open between classrooms, rarely does the design allow for classrooms to change size or shape, or even be re-distributed all together over time. Too often structural elements, vertical distribution of services, building systems, stair cores or the shape of the building itself prevents substantive change. Because adaptability is often not a core tenet during school design, even seemingly simple tasks of making classrooms slightly larger or smaller over the building's life could be extremely difficult, costly, or impossible.

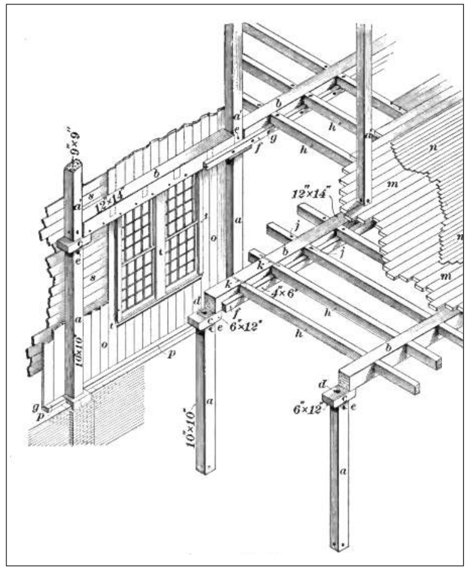
A building's inability to change presents a major roadblock to schools that want to update curriculum, pedagogy or to accommodate fluctuations in enrollment. Today, with change occurring faster than ever, material costs rapidly escalating, and the environmental crisis growing, designing buildings that cannot adapt to change is simply not sustainable or acceptable.

There are several design strategies to build-in flexibility and adaptability into school design. The American Institute of Architects (AIA) notes in their report, *Buildings That Last: Design for Adaptability, Deconstruction and Reuse,* that long-lived buildings exhibit certain traits that allows them to adapt to multiple uses and users over time. These include:

> Clear spans
> Generous floor-to-floor heights
> Flat floors
> Interior non-load-bearing partitions
> Regularly spaced structural elements
> A stronger structural system
> Early engineer engagement
> Separation of systems
> Use of durable materials
> Use of mechanical fasteners
> Clear and effective documentation
> Beauty and quality design



ABOVE: Wood insulates a steel beam in traditional heavy timber floor construction to protect it in the event of a fire. (See the Building Code section for more information on fire resistance and contemporary practices.)



ABOVE: Heavy timber construction, also known as "slow-burning" or "fire-resistive" construction was used throughout the U.S. to build cost-effective, adaptable, multi-story structures.

The text on this page describes the framework and core principles used to design a prototype K-12 mass timber school while utilizing the strategies listed on the previous page.

FIXED V. FLEXIBLE PARTS

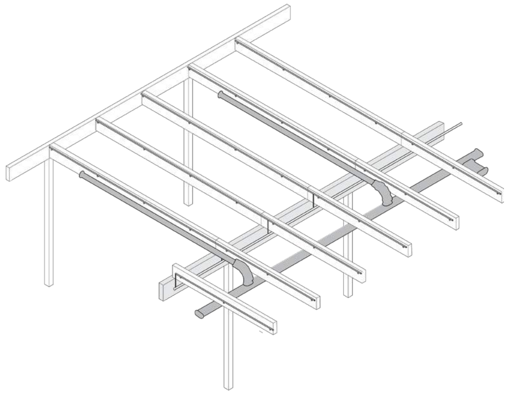
Elements of this building design can be thought of as fixed versus flexible parts (see diagrams at right). **Fixed parts include the primary building superstructure and lateral force resisting system (LFRS).** These elements are distributed for maximum flexibility allowing the location of corridors, classrooms, and other spaces to move without conflicting with fixed elements. **While the primary structure is fixed, there is flexibility here too.** Additional floor-to-floor height or number of stories can be added with minimal design changes. Sections of floors can be removed to create double height spaces or new stair connections and vertical distribution of services. If the building shape is changed to an “L” or “U”, for example, fewer LFRS elements are required overall, leading to even greater freedom. (For additional discussion on implications of taller buildings, see the Building Code and Structural Approach sections.)

The code required egress stairs that are also a fixed component, integrated into the building’s LFRS – providing double-duty for the vertical cores. Additional stairs can be easily added. The building’s vertical mechanical shafts are also fixed elements. Their integration with stair cores at the perimeter of the building keeps the shafts consolidated and allows the most flexibility for interior space.

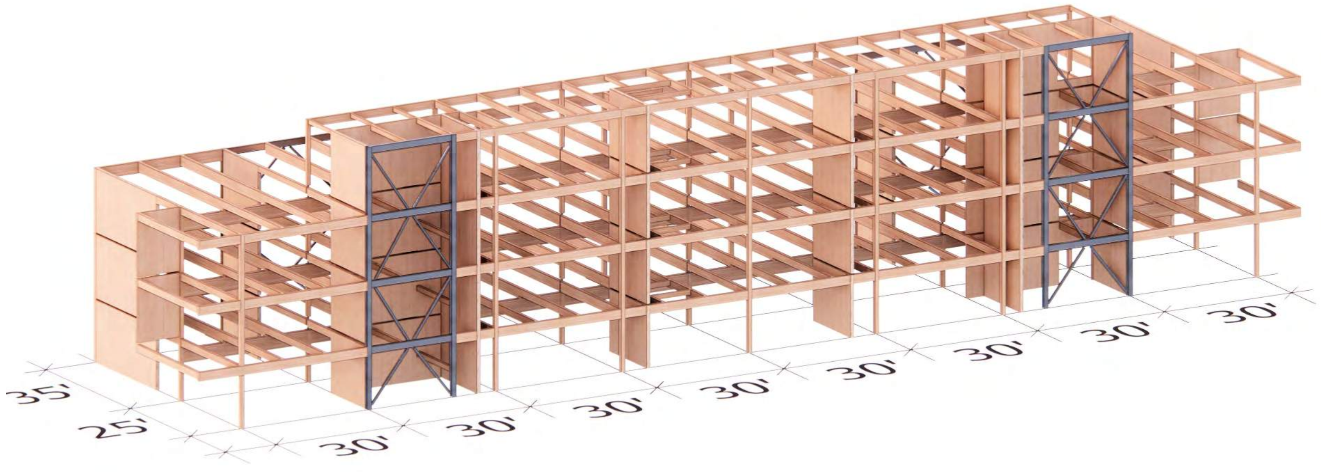
Shafts are consciously pushed to the building perimeter and eliminated from the interior space to preserve future flexibility. To maximize long-term flexibility and to simplify plumbing and mechanical routing, stacked non-gendered restroom cores are also thought of as a fixed element, repeating from floor to floor. Keeping these bathroom cores along the perimeter of the building maximizes flexibility of interior space while also providing daylight and openness into these spaces.

The fixed elements listed above result in an interior space that is flexible and adaptable to different uses. A post and beam structure allows all exterior and interior walls, except shear walls, to be non-load bearing and capable of relocation as needed. Exterior and interior glazing can be sized and positioned to fulfill architectural requirements and optimized indoor environmental quality. Perimeter beams provide connection points for heavier exterior cladding types or exterior shading systems, translating to a wide freedom in exterior architectural expression of the building.

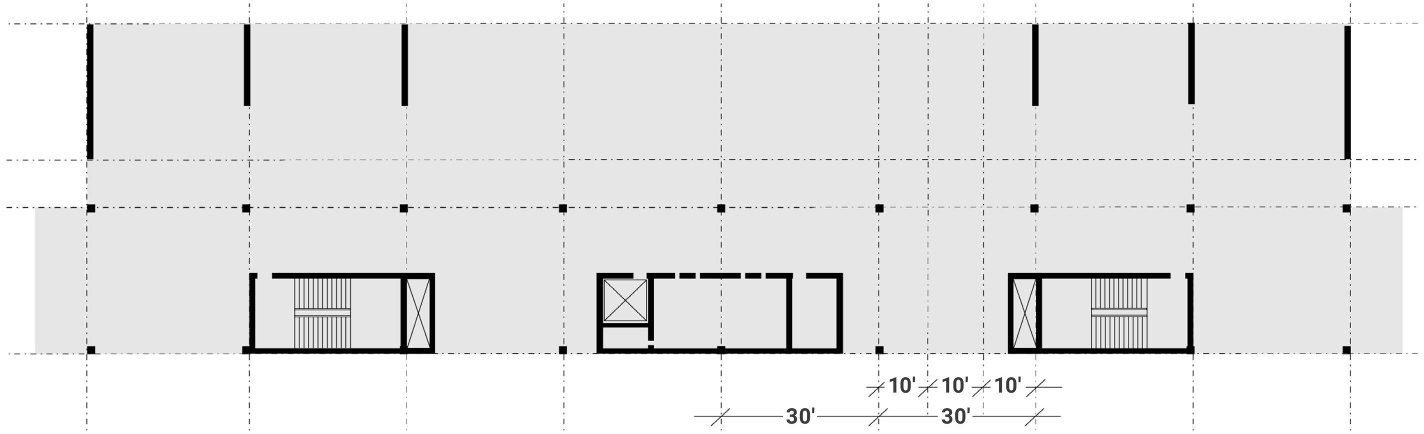
An emerging pattern for mass timber buildings is the use of dropped beams to facilitate mechanical, electrical, plumbing and fire protection routing throughout the building. This not only benefits the initial construction, but allows for renovations that are easier, quicker, and less costly. (For additional information of service routing concepts in the building, refer to the Mechanical, Electrical, and Technology Approach section.)



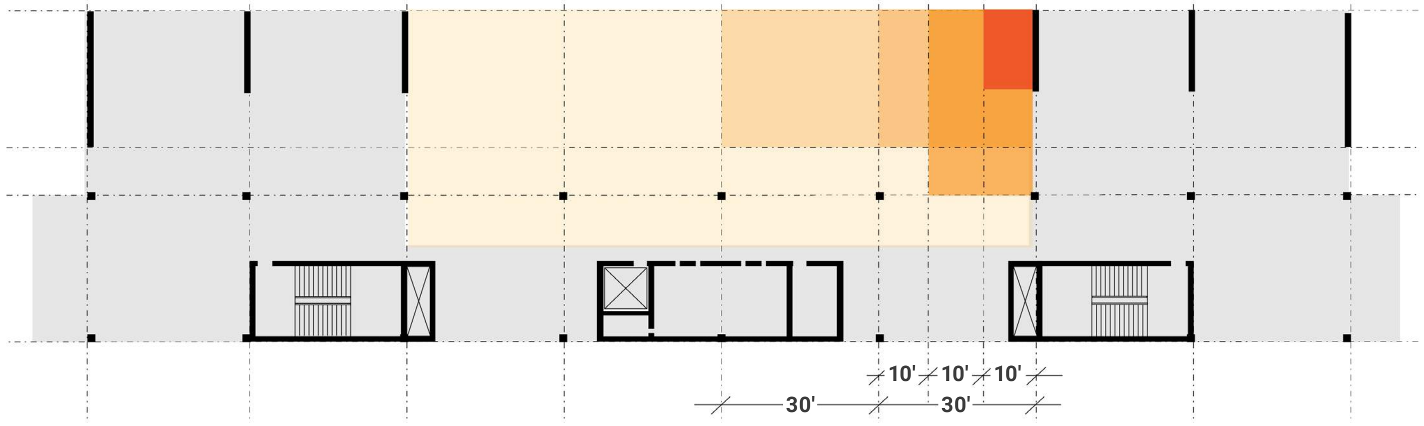
ABOVE: A dropped interior beam adjacent to the central service spine of the building allows ducting and other services to move throughout the building unimpeded.



ABOVE: Mass timber structural framework with steel brace frames and CLT shear walls designed for flexibility. (CLT floor and roof deck not shown for clarity.)



ABOVE: Fixed parts (black) and flexible space (gray).



KEY

5,500 SF
COMMONS

1,500 SF
MUSIC, STEM, ART

900 SF
GENERAL EDUCATION

700 SF
SMALL CLASSROOM

150 SF
OFFICE

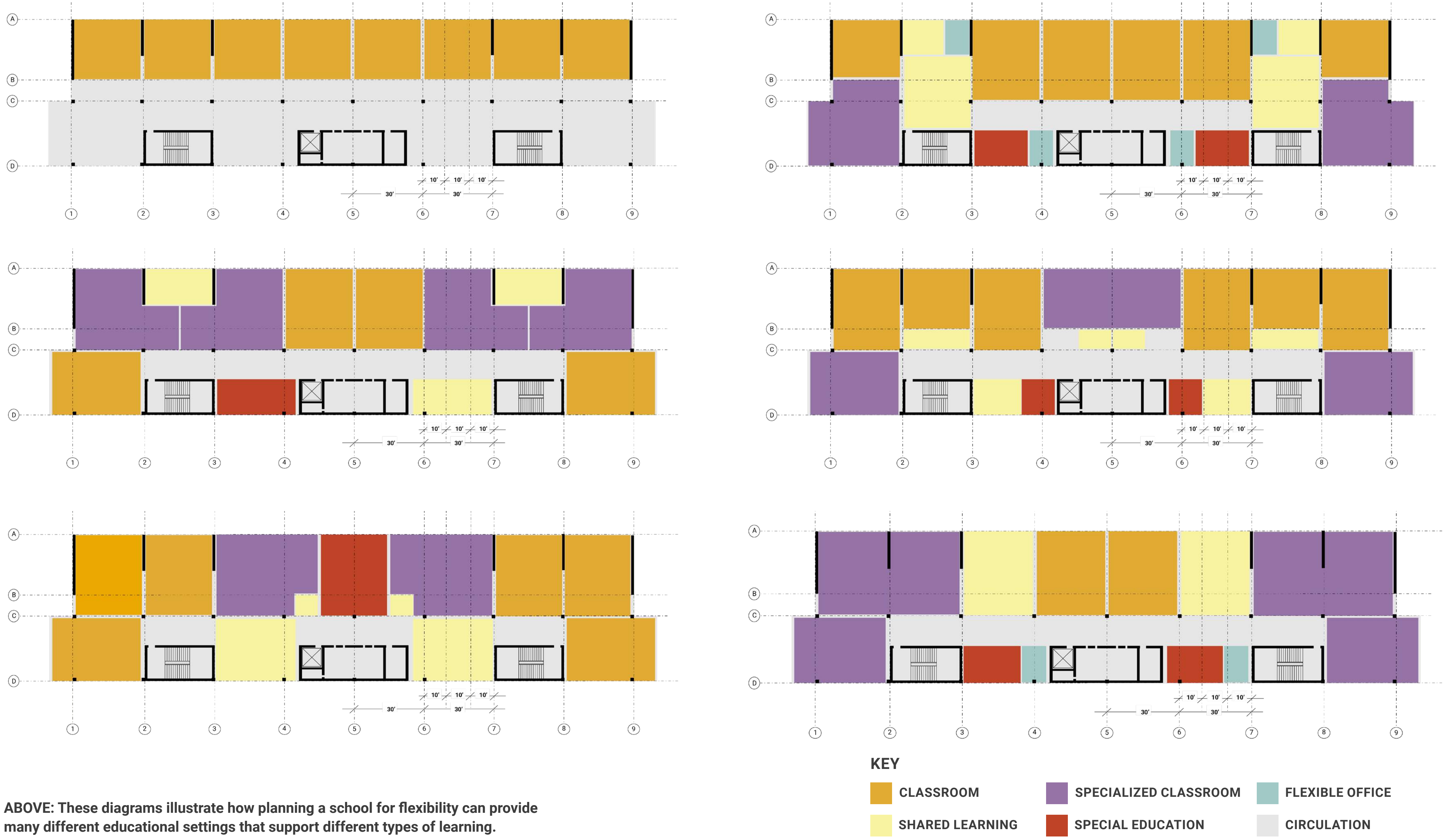
ABOVE: Building framework promotes a variety of different space types to be used within the same structural grid.

MASS TIMBER AND SCHOOLS

An adaptable building structure allows schools to shape floor plan layouts around the learning activities that are important to them, not just around classroom boxes. A post and beam structure eliminates the need for load-bearing interior walls, which can greatly impede options for future renovations. Long-span structural elements limit the number of columns falling within spaces, allowing for flexibility. A structural grid that can be divided into 10' intervals for exterior glazing allows large, medium, and small spaces to be arranged along window walls. In this way, a column-free commons space could be subdivided into classrooms or even offices and windows do not need to be moved. Generous floor-to-floor heights allow building services such as mechanical ducting and sprinklers to travel unimpeded throughout the building and dropped beams provide ultimate flexibility for distributing services anywhere in the building.

Throughout this report, we explore strategies to achieve a long-life-loose-fit school optimized for change and adaptation over a long lifetime. Schools that are not designed to accommodate change typically result in costly renovations. If renovations become complicated, then demolition and replacement leads to further cost impacts, as well as environmental impacts from material production, procurement, and construction related emissions.

Designing schools that anticipate renovations over time and reduce costs associated with these activities can save money over the lifetime of a facility and reduce environmental and operational impacts on the communities they serve.



ABOVE: These diagrams illustrate how planning a school for flexibility can provide many different educational settings that support different types of learning.

Mass Timber? Steel? Hybrid?

Structural steel and mass timber column and beam structures offer many similar benefits. Both can afford a great deal of openness resulting in flexibility of layout and architectural possibilities. Both utilize largely prefabricated elements and straightforward installation that reduces construction time and can drive down costs. If steel construction uses bolted rather than welded connections, both steel and mass timber can be disassembled after a building's functional use and incorporated into new constructions. Structural steel has the advantage of being recycled easily where mass timber can be reused or down-cycled into other uses. Finally, both are relatively lightweight compared to reinforced concrete construction, leading to lower foundation costs compared to concrete structures.

Despite the similarities, there are several key differences between steel frame construction and mass timber to consider. Steel sections can be smaller than timber elements, meaning that they take less space, or may have larger column spacing or shallower beams. Timber can span similar distances, but each material has a range for optimization. Steel has been used for decades and is well tested for lateral bracing systems. Mass timber bracing systems, like CLT shear walls or timber brace frames, are still developing with ongoing testing. This can lead to additional structural engineering and time for building code approval if unfamiliar lateral systems are proposed. This makes a hybrid mass timber structure with steel bracing elements an attractive option for mass timber schools at this time, especially since both systems are fast to erect and hybridize well.

In steel systems, corrugated steel decking only spans in a single direction while products like CLT can span in two directions. Corrugated metal decks are typically filled with cast-in-place concrete to create composite floor decks. Structural composite elements are more difficult to re-use or recycle since different materials are acting as a homogeneous element. CLT floor decks can also use composite construction with concrete. However, CLT can also use a self-leveling gypsum-based floor topping and acoustic mat, saving time, costs, and carbon emissions over typical steel floor systems. Because the elements are not composite, they can be separated and reused at the end of the building's life. CLT can often be left exposed as an architectural finish and need not be covered. (see Acoustics section for more information).

Mass timber, due to its large cross-sectional dimensions, has inherent fire-resistant properties. Where timber elements do not lose their strength at elevated temperatures encountered during a fire, steel quickly loses strength and risks failure when left exposed. Instead, timber develops a layer of char to protect the inner portion of wood. See the Building Code section for more discussion.

In practice, both structural systems have their own unique strengths and weaknesses. All mass timber buildings will utilize some concrete for the foundations and steel for connections and fastening. Each material should be used for its greatest benefit, which will point to hybrid structures that are time, cost, and climate smart.

Mass timber post and beam construction with CLT floor deck.

Two-story steel frame.

Hybrid mass timber and steel brace frame.

Hybrid mass timber and steel frame.

SECTION 02A FOOTNOTES

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SECTION 02A IMAGE CREDITS

Page 12: Photo by **Benjamin Benschneider**

Page 13: Historic Photo from **Washington State Archives**
Bottom right drawing obtained from: ***A Treatise on Architecture and Building Construction, Vol. 5: Prepared for Students of the International Correspondence Schools, Scranton, Pa*, 1899**

Page 16: Photos from left to right:
Photo by **Mahlum Architects**
Photo by **Mahlum Architects**
Photo by **Mahlum Architects**
Photo by **StructureCraft**

SECTION 02B

Massing & Form

The repetitive structural module of the prototype design lends itself to a variety of exterior expressions which can be tuned to solar exposure, building siting, and context. The prototype design provides one of an infinite number of these options.

K-12 Mass Timber Prototype
(Designed by Mahlum Architects)

A kit-of-parts using mass timber can lead to faster design and better cost control.

K-12 Mass Timber Prototype
(Designed by Mahlum Architects)

DESIGN CONTEXT

Available land for development in many districts around Washington State is low and acquisition costs are high – especially in populous areas.

Building schools vertically is one solution to meet population demand amid shrinking developable land. While this study focuses on a maximum three-story school, the building system can be adapted to shorter or taller structures with minimal design changes. (Refer to the Building Code and Structural Approach sections for more information.)

To test design options, the project team used a mostly vacant site owned by the Sequim School District, a partner in the project. While having a real site grounded the project, the design can be adapted to almost any site.

Three different design massing options will be presented in this section, demonstrating how the same structural system can be used to create different shaped buildings based on unique site constraints. A kit-of-parts approach using mass timber can lead to faster design and better cost control without sacrificing flexibility for interior spaces. Throughout this section we will demonstrate planning flexibility that adapts to the age of students or programmatic needs of the school.

FUNCTIONAL PROGRAM

To test how mass timber can be used for a K12 school, the team developed a hypothetical program for primary learners vetted by the Sequim School District. The building is based on an approximate capacity of 450 students spread across 16 classrooms with adjacent shared learning spaces. The program also includes specialty classrooms that can be used for science and art (STEAM), as well as a large learning commons that functions as a dining hall and library.

The building also includes administrative offices, staff support space and building support for an approximate total gross square footage of 45,000 SF (see full program listed at right).

Because the Sequim School District has a full commercial kitchen serving the entire district located on the project site, a kitchen was not included in the prototype design. Likewise, a music facility is available in an existing building directly adjacent to the site, so it was not included in the main building framework. However, these elements can be added as stand-alone structures or appendages to the main building, depending on the specific site.

SEQUIM K-12 PROTOTYPE PROGRAM

CORE LEARNING SPACES

(16) Classrooms
(8) Shared Instruction Areas
(8) Teacher Prep and Storage
(1) Learning Support and Resource Room
(1) Small Conference and Therapy
(2) STEAM Rooms
(1) Learning Commons
(1) Roof Garden and Outdoor Learning

ADMINISTRATION & SUPPORT SPACES

Administration Area
Reception and Waiting
Offices
Conference and Workroom
Storage and Support

Student Services:
Counselor, ELL, Speech, Psychology
Health Room

Faculty and Staff Support:
Kitchen
Staff Room

Building Support:
Toilets
Custodial

Unassignable Areas:
Mechanical Rooms
Shafts and Walls

ABOVE: Covered play is imperative in the rainy Pacific Northwest, as shown here at Arlington Elementary School in Tacoma, Washington (Designed by Mahlum Architects)

The prototype design illustrated on the following pages is linear but the structural system can accommodate a variety of shapes, whether L-shaped, U-shaped, or a finger scheme (two of which will be presented later).

DESIGN RESPONSE: SEQUIM SITE PLAN

A long, linear design places more intense loads on the building's lateral force resisting system than an L-shape or U-shape, due to the latter shapes' inherent stability. **Therefore, the linear option was chosen for development as it would require the most structural elements and implications for resolving interior space with integration of structure and building services.** Resolving the design for a linear building meant that other shapes would be possible without adding additional structure that could limit design options.

On the Sequim site (shown at right), the building is stretched in the east-west direction to maximize daylight potential for interior spaces. The building is shifted to the north of the site to allow for a **large outdoor play area** with south facing exposure. This also allows easy access to **bus and parent drop-off** along the perimeter of the site.

The building is carved away on the east and west ground floor to create a welcoming and **covered main entry** at the east and protected **outdoor classroom space** at the west.

The ground floor has ample connection to the outdoors, **expanding learning spaces and connecting students to nature** by promoting movement and learning through physical activity and play.

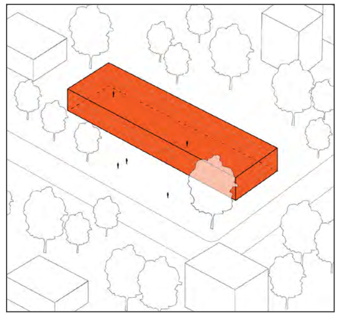
ABOVE: Sequim Prototype K-12 School Site Plan

A **multi-purpose gym** is shown to demonstrate how another structure can accommodate a **gym, auditorium, or larger specialized learning environment.**

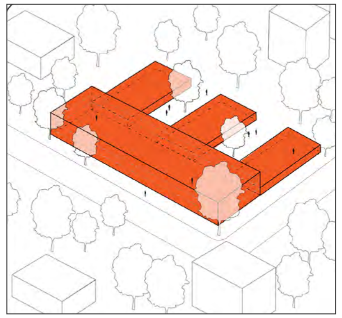
Covered play is located below the roof of the gym at the west and a covered pick-up waiting area is located at the east.

A series of **natural play areas,** hardscape play, and different scales of climbers are oriented around the outdoor area.

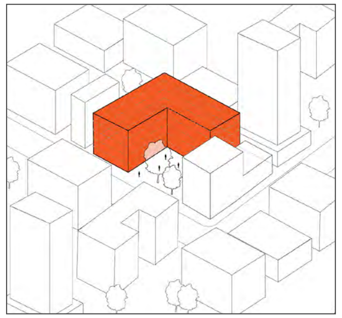
BELOW: The building's structural system can accommodate different planning configurations and heights, making it adaptable to site-specific needs, whether that be a rural, suburban or urban area.



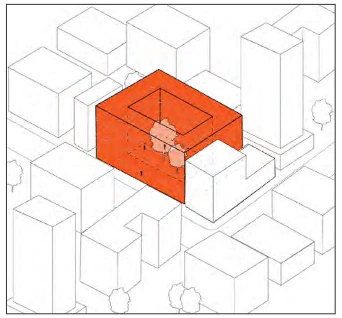
LINEAR



FINGER-SCHEME



MULTI-STORY L-SHAPE



MULTI-STORY DONUT

FLEXIBLE AND EFFICIENT

Flexibility was the ultimate driver for integration of the structural system and architectural plan. Building structure and services constrain planning with rigid elements driving interior arrangements. A mass timber framework provides increased flexibility with clear structural spans. This can be achieved by minimizing interior structural elements, using long span options, and locating services where they will not interrupt options for spatial arrangements. The following pages illustrate how a variety of planning approaches can be accommodated using the same structural approach.

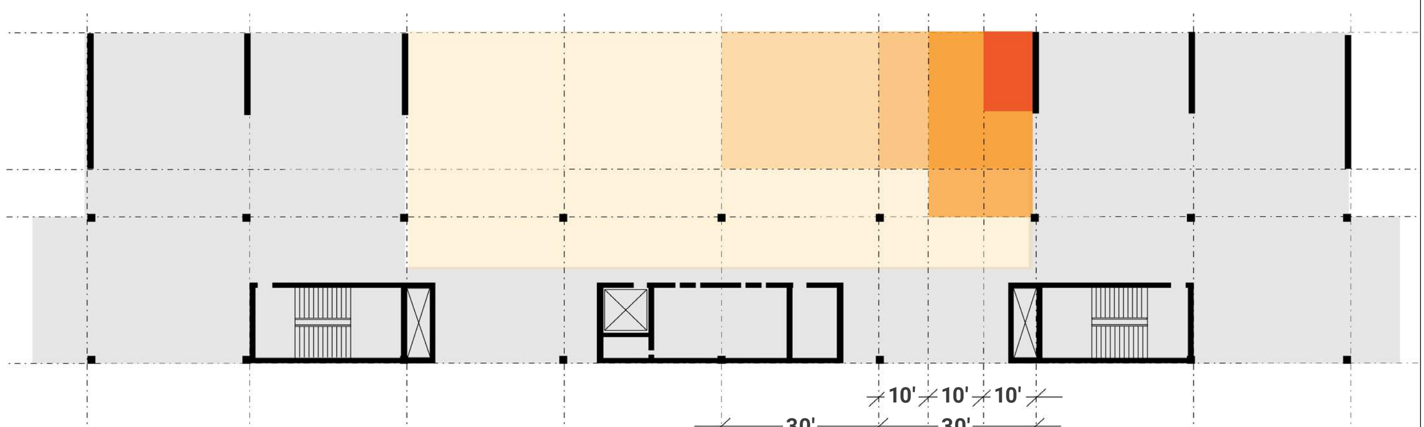
The structural elements are based on a 30-foot grid spacing in the east-west direction and a 35-foot and 25-foot grid spacing in the north-south direction. The structural grid requires only a single row of interior columns, spaced 30-feet apart in the east-west direction. This spacing allows for classrooms of approximately 900 SF, but also learning spaces of varied sizes – both smaller or larger.

Interior spaces may maximize individual classroom environments, create learning communities with interconnected classrooms and open breakout spaces, or completely open learning environments. Interior walls are not load bearing, with the exception of a few shear walls. The absence of load bearing elements means spaces can easily change. If the school's arrangement of classrooms is no longer best serving the school after a number of years, then learning spaces can change without running into structural elements or services that can't move.

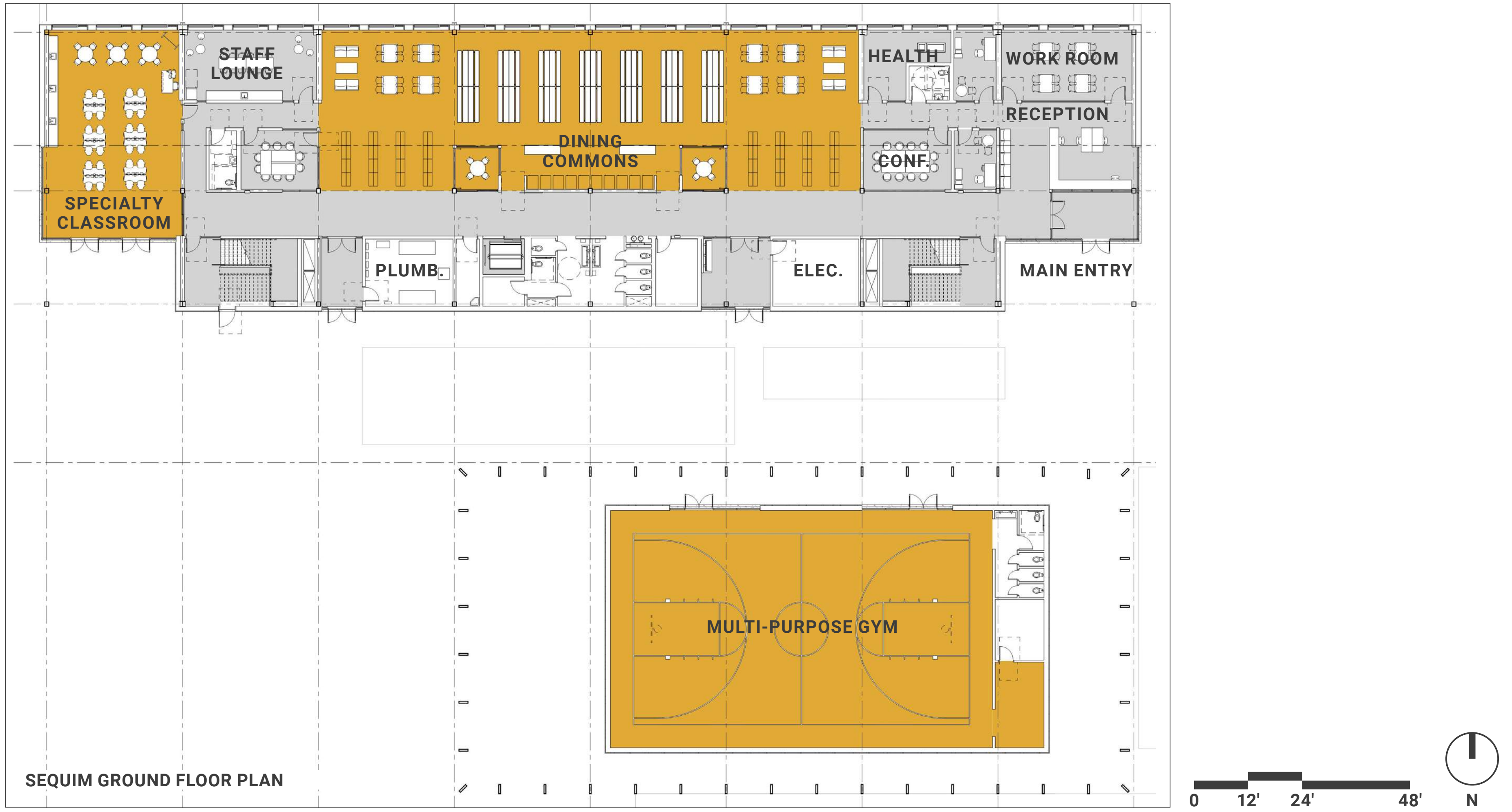
The corridor location is flexible and can also shift within the building, depending on whether a double-loaded or single-loaded corridor configuration is desired. In the east-west direction, the exterior walls are divided into 10-foot window bay modules. This arrangement allows for small offices, medium classrooms or large seminar spaces to occupy the same floor without having to modify the exterior windows. Spaces can easily evolve over time, with a group of offices changing to a classroom for example, and the exterior wall does not need to be renovated.

For cost and construction efficiency, the timber structural system stacks from floor to floor. Timber construction is most efficient when load bearing elements stack, which eliminates deep and costly transfer beams and connections. Such elements can also impact future flexibility. Therefore, clear repetition of structural elements was prioritized.

Too many ins-and-outs along the facade can create waste from cut CLT panels, as well as detailing complexities and possible thermal bridging. **To eliminate waste, the design concentrates on using full CLT panels.** This saves costs by minimize cutting time on CNC machines and reducing wasteful cut-offs from CLT panels. A simple rectangular building supports mass timber design, reduce overall costs and make the system cost competitive with other types of construction.



30-FOOT E-W GRID BUILDING FRAMEWORK



SEQUIM GROUND FLOOR PLAN

ABOVE: The roof deck at Lynndale Elementary School in Edmonds, Washington is used as an outdoor learning environment and as a place of respite for staff (Designed by Mahlum Architects)

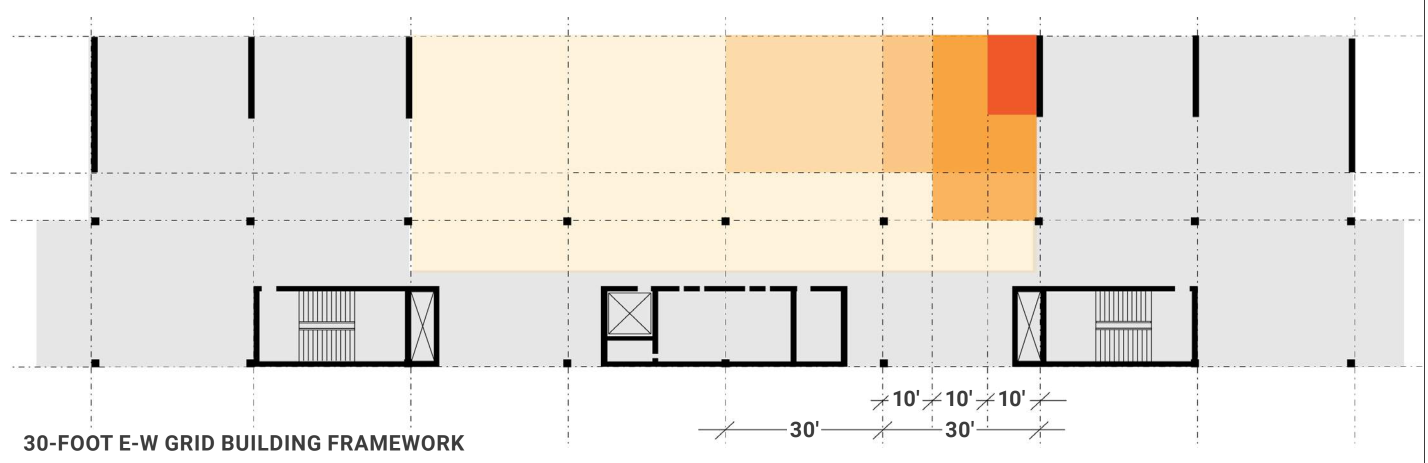
BUILDING ORIENTATION

The building is oriented with its length running in the east-west direction, which provides optimal north and south daylighting where learning spaces and windows are concentrated. The east and west facades, which are more difficult to shade and prone to glare and overheating, have fewer openings and take advantage of this opaqueness to include shear elements to brace the building. **Solar shading is included on the south façade to prevent glare and overheating and maximize occupant comfort throughout the year.**

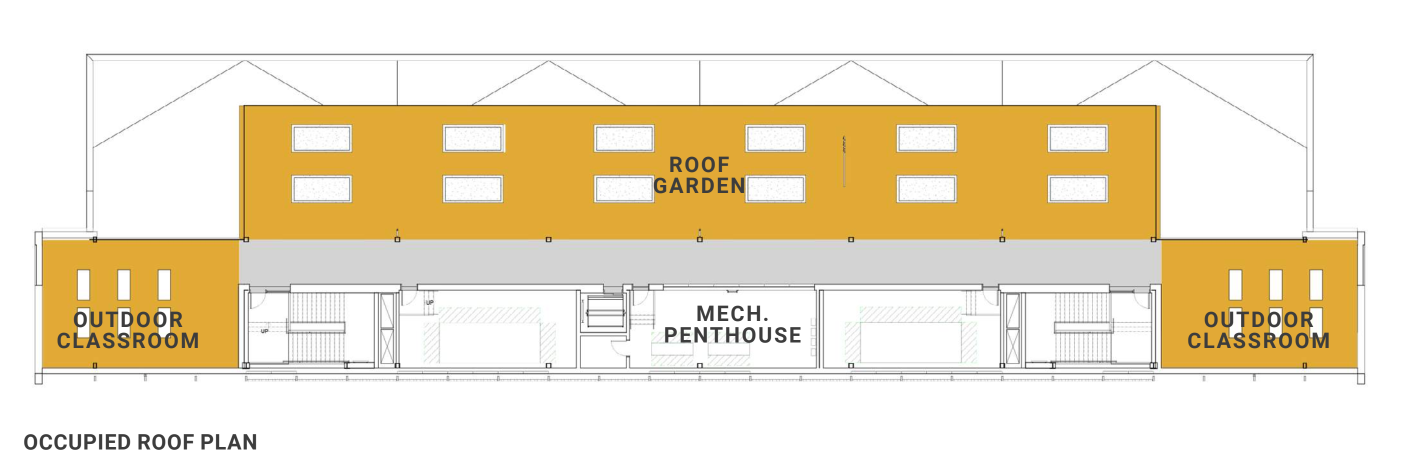
ROOF ENVIRONMENT

The top floor contains a mechanical penthouse, creating additional height on the south side of the building and offering architectural differentiation between the two primary elevations. **To drive down the building's Energy Use Intensity (EUI), a PV array is located above the mechanical penthouse for on-site power generation.**

The roof, often a neglected place, is utilized for outdoor learning as well as open air classrooms and gardening plots. The ability to interact with sun, rain, plants, and soil allows learning to be more experiential and authentic.



30-FOOT E-W GRID BUILDING FRAMEWORK



OCCUPIED ROOF PLAN

HIGH ROOF PLAN

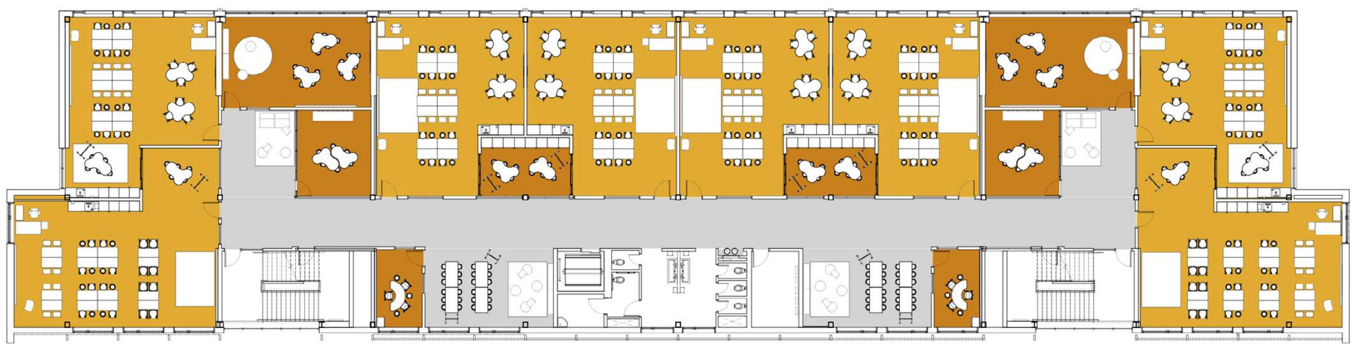
0 12' 24' 48' N

ABOVE: The large glass expanse shown here at Madrona K-8 School in Edmonds, Washington, is a movable wall partition which allows paired classrooms to open up to each other for team teaching (Designed by Mahlum Architects)

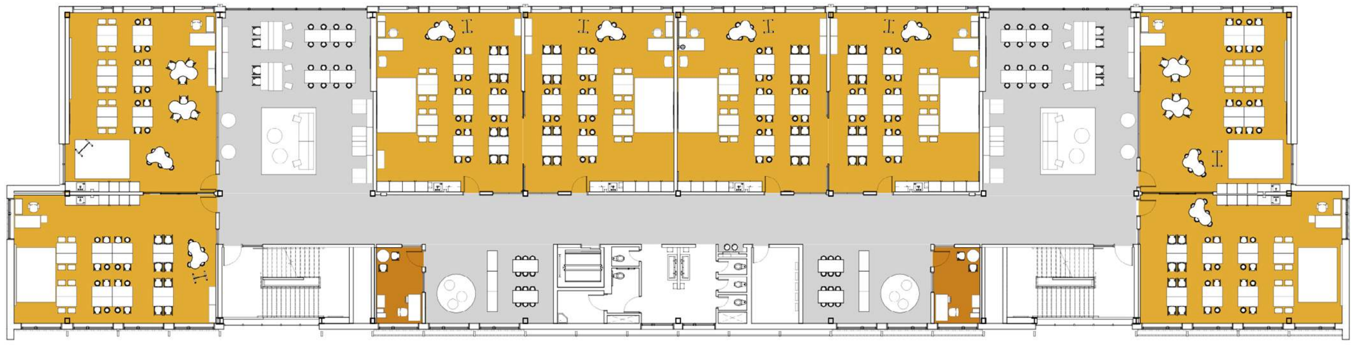
LAYOUT OF LEARNING COMMUNITIES

Educational spaces are defined by large window expanses wrapping around a central bathroom core with vertical circulation extending upward on either side. Each floor of the building may be arranged as two individual learning communities served by their own circulation stair to prevent disruption of students from one community circulating through the adjacent one. The flexibility of the structural approach allows for various classroom planning configurations that respond to unique program needs and explore differentiated learning spaces supporting students of varied ages.

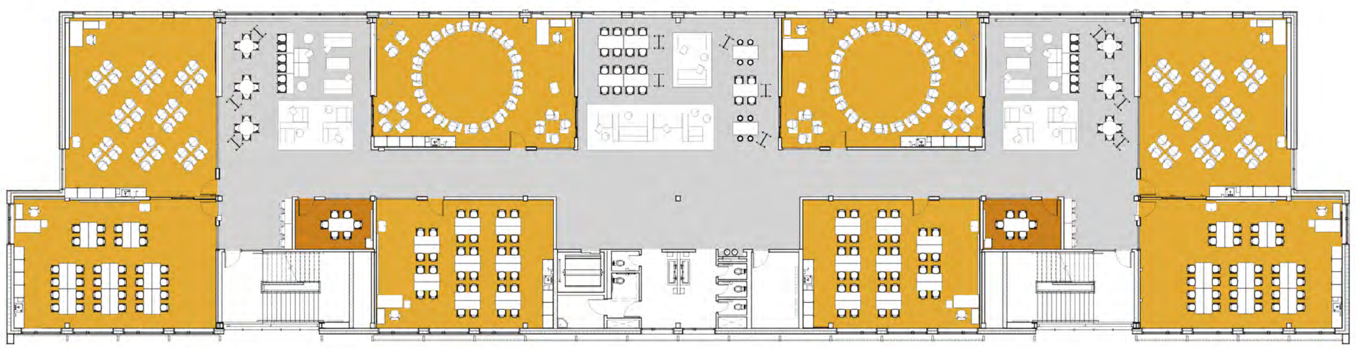
In the plan options shown at right, all three accommodate eight enclosed learning spaces. The flexible container allows for differences in how those enclosed spaces are shaped and how they relate to one another and the instructional support spaces which surround them.



L-SHAPED CLASSROOMS



PAIRED CLASSROOMS



DISTRIBUTED SHARED LEARNING

L-SHAPED CLASSROOMS

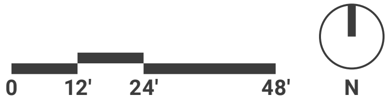
L-shaped classrooms provide multiple spatial experiences within one classroom. Large, direct instruction space allows for students to work together in small groups. Adjacent, intimately-scaled study areas allow a learner to step away from the larger group to self-regulate their emotions or work one-on-one with instructional support. This classroom typology is well suited to elementary level learners. Enclosed, shared learning areas are planned adjacent to the learning communities to support intervention services within the community.

PAIRED CLASSROOMS

Classrooms can be arranged in pairs, allowing for co-teaching. Large, sliding doors connect and divide open two classrooms. Acoustic separation is provided when the doors are closed and classrooms are focused inward. Open shared learning spaces weave throughout the plan with classrooms, providing easy access and clear sight lines for supervision to the break-out spaces. As students are gaining independence, this classroom and shared learning arrangement allows for spatial variety where learners can move to find a space best suited to their needs.

DISTRIBUTED SHARED LEARNING

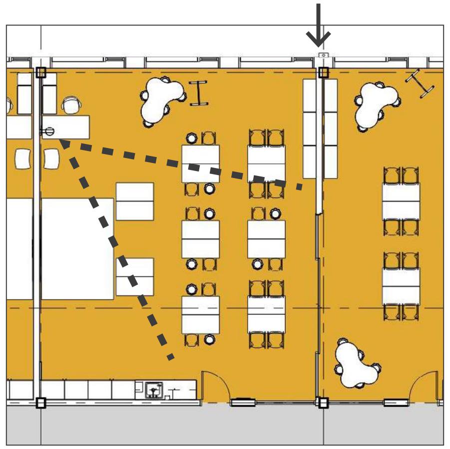
This option demonstrates a double-loaded corridor arrangement of classrooms rather than single-loaded as shown in the options above. Each classroom opens directly to a larger shared learning space, providing the ability to grow classrooms and have more fluid educational experiences between enclosed and open spaces. Secondary students with more autonomy in their learning process would benefit from the larger shared spaces.



RIGHT: Two renderings display the same classroom space with different furniture and casework arrangements to support the needs of primary school students and secondary school students.

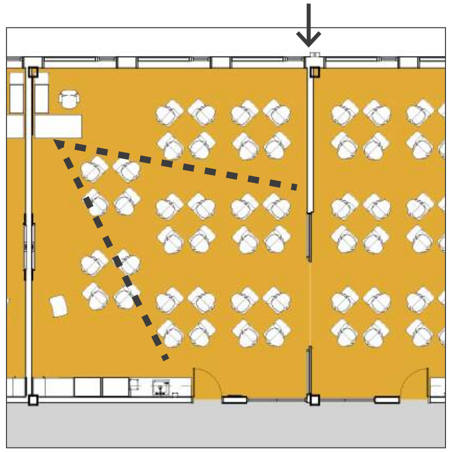
BELOW: The dashed gray lines in the diagrams indicate the views represented in the renderings at right.

MOVABLE WALL



PRIMARY LEARNING CLASSROOM FURNITURE LAYOUT

MOVABLE WALL



SECONDARY LEARNING CLASSROOM FURNITURE LAYOUT

ADAPTABLE CLASSROOMS

Classrooms are adaptable to accommodate learners of varying ages with different approaches to furniture and casework. Light-weight and movable furniture promote different ways of learning, whether individual, small group, or lecture – the building system can accommodate multiple settings.

The physical and spatial aspects of classrooms will either help or hinder learning. Creating break-out spaces and different learning zones benefit students, especially younger students engaged in play-based learning activities.

Room shapes have also been found to impact learning. Varied room shapes are preferred by younger learners, like the L-shaped classroom, whereas more square-shaped rooms are preferred by older students. Providing adequate wall area for display and storage is also important.

SHARED LEARNING AREA

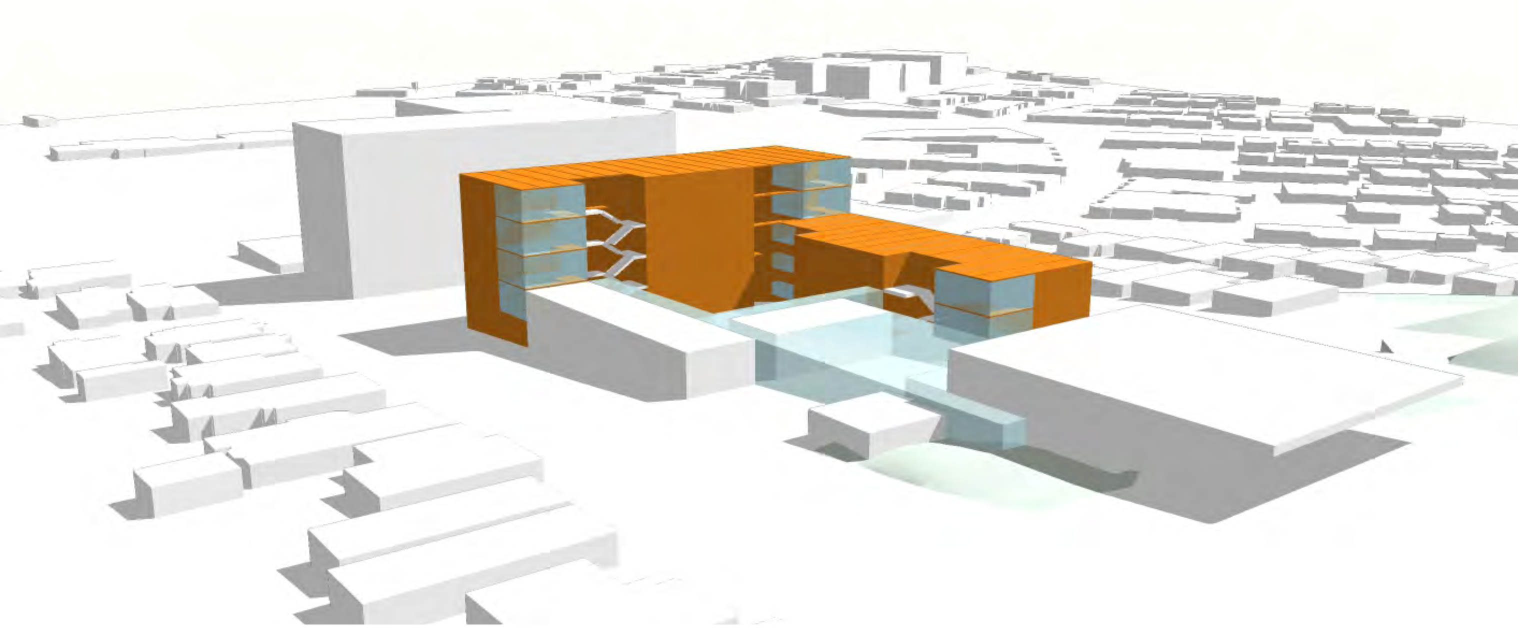
Open shared learning areas allow different types of learning environments and opportunities for students. These can be highly flexible spaces that highlight the natural, biophilic qualities of mass timber. The rendering on the following page celebrates these elements.

PRIMARY LEARNING CLASSROOM

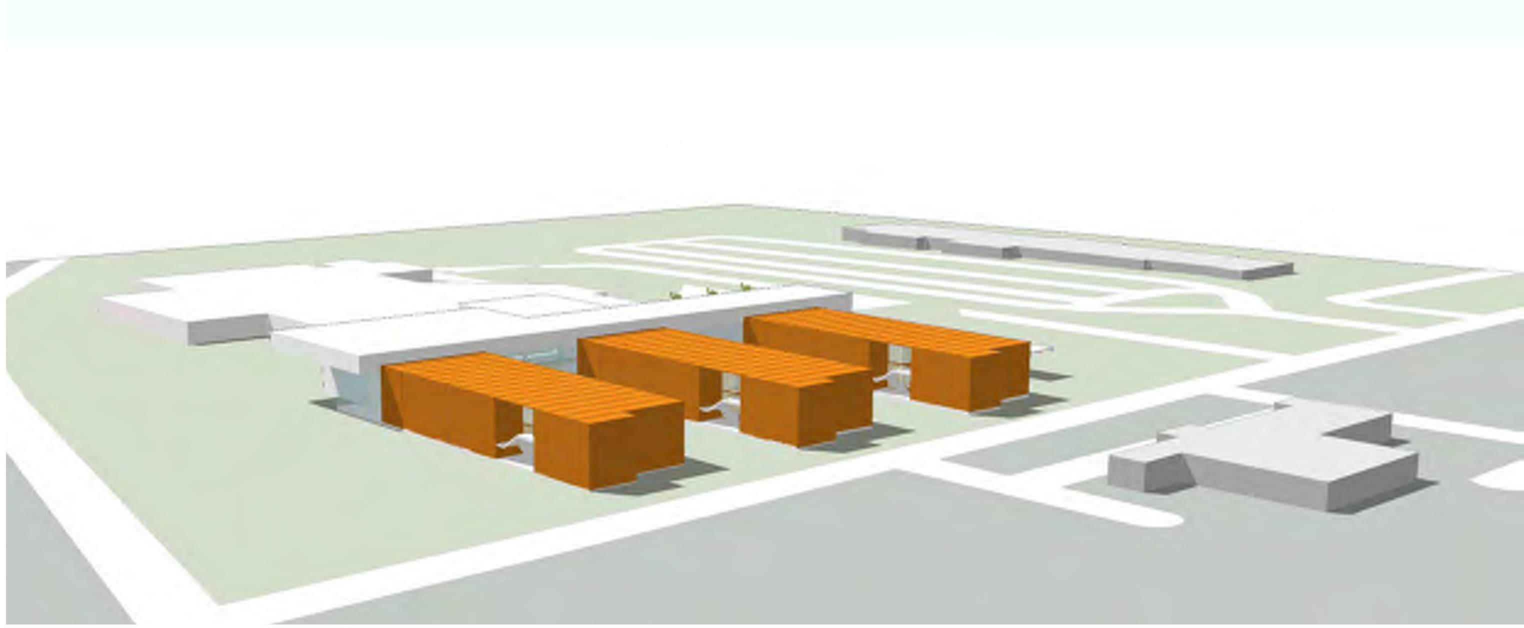
SECONDARY LEARNING CLASSROOM

SHARED LEARNING AREA:
A highly flexible space that highlights the natural, biophilic qualities of mass timber.

BELOW:
Design study for a five-story urban school utilizing the structural layout described in this section



BELOW:
Design study for a conventional two-story suburban school utilizing the structural layout described in this section



SITE RESPONSE VARIATIONS

To prove-out the concept of this prototype design and its flexibility, the team studied two additional sites in Washington State to see how different educational programs and site constraints would impact building form. One site is in an urban area and the second is a suburban area, each offering different challenges and possibilities for design response. For these two design studies, the exact same structural module explained previously was used. Rather than a linear building, different building shapes were used to better accommodate specific program and site requirements.

URBAN STUDY

The urban site is steeply sloped and bound on the north by an existing nine-story residential building with single-family residential structures on the remaining sides. The north and east areas are zoned for multi-family buildings, while the south and west are zoned for single-family. The site is near commercial developments and a community park. The building consists of nearly 40 classrooms, ranging from Pre-K through the fifth grade, as well as shared learning areas, library, art, music, gym, dining, administrative offices, and building support spaces.

To preserve as much outdoor area as possible, negotiate the existing grade on site, and provide the best views and daylighting, the team created a stacked, five-story wing at the north of the site. The tallest classroom wing is across the street from the existing nine-story building, strengthening the urban response to existing context. On the east side, facing a multi-family zone, the building steps down to a three-story classroom wing. Younger learners are located on lower levels and older students on the upper levels.

To minimize travel distance for students entering the school from the west (which faces the single-family zone), the building steps down to two-stories and accommodates administration and the library. A dining commons connects the lower part of the site with the upper play fields. An existing gym structure is renovated on the upper area and opens directly onto south-facing fields.

Utilizing the same structural grid, the building can easily adapt to a courtyard donut shape rather than a linear shape as shown in the prototype. A five-story Heavy Timber building is permitted under the current Washington State amended building code. This building would be classified as Type IVB and would require two-hour fire ratings on primary structure and floors, which is achievable using mass timber – even while exposing the timber elements. The same fire-ratings would be required for a non-combustible construction type at this height. See the Building Code section for more discussion on construction type, height and fire ratings.

SUBURBAN STUDY

The suburban site has an existing school present which must remain open during construction of a new school. This necessity pushes the new school to the east of the site and allows for parking and drop-off reconfiguration to the north.

The building is divided into three wings – or pods of five classrooms each including a central shared learning area with intervention support spaces – to meet the school district's educational specifications. The building is two-stories, resulting in six learning communities or 30 classrooms. The classroom wings rigorously follow the same structural layout as shown in the prototype. The building's finger-scheme configuration allows good access to daylight for all spaces and shared outdoor learning opportunities between the pods. The building's central spine contains shared uses, such as entry, administration, library, gym, commons, and special education. The spine does not use the same structural module as the classroom wings but could readily be designed as mass timber as well.

CONCLUSION

The three studies presented in this chapter demonstrate that a mass timber structural framework can accommodate many different floor plan arrangements and building forms. Such a system acknowledges that learning is not a one-size fits all system, but needs to accommodate different users and needs while also capable of change.

SECTION 02B
IMAGE CREDITS

Page 18: Rendering by **Mahlum Architects**

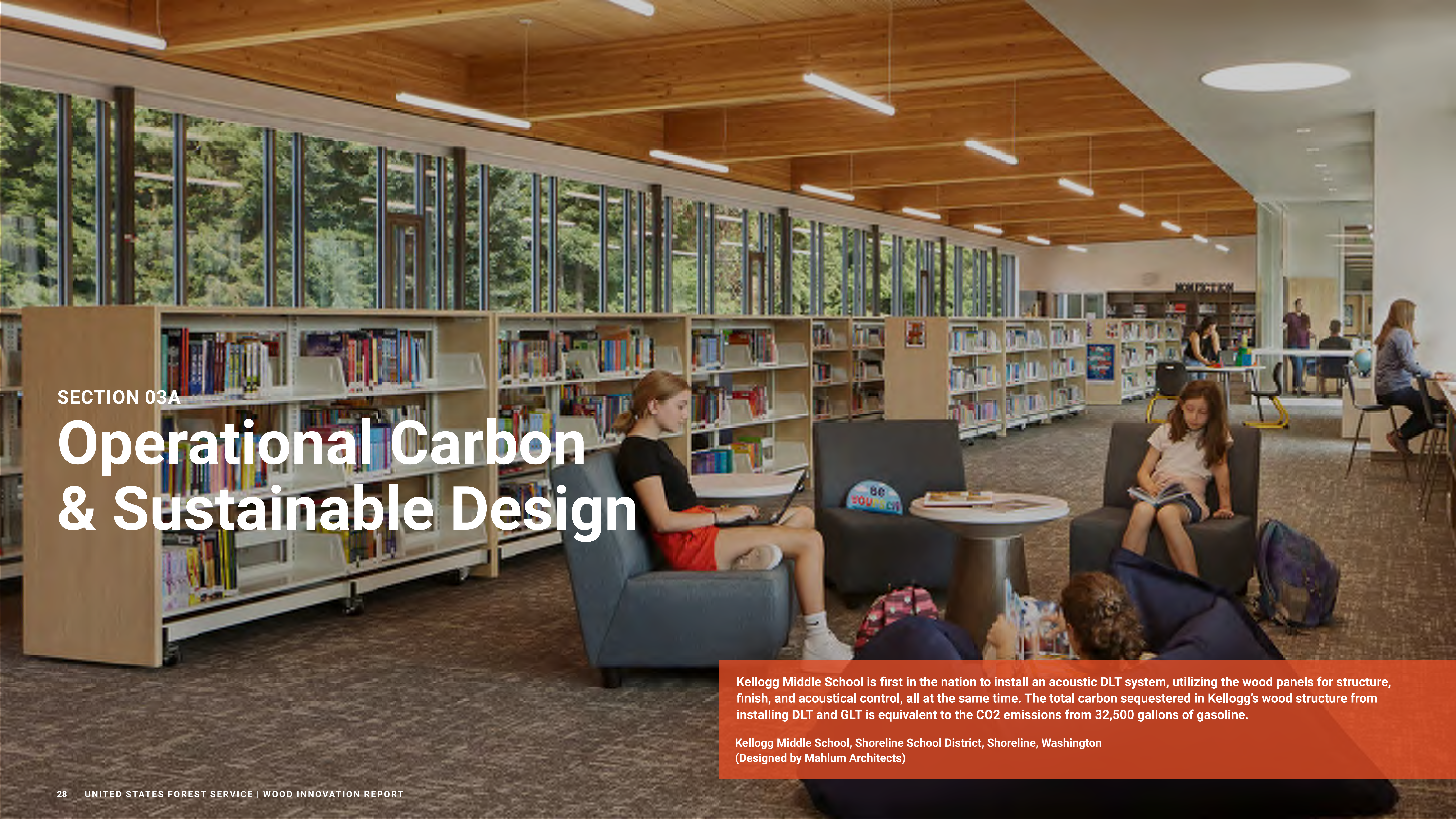
Page 19: Rendering by **Mahlum Architects**

Page 20: Photo by **Benjamin Benschneider**

Page 22: Photo by **Benjamin Benschneider**

Page 24: Renderings by **Mahlum Architects**

Page 25: Rendering by **Mahlum Architects**



SECTION 03A

Operational Carbon & Sustainable Design

Kellogg Middle School is first in the nation to install an acoustic DLT system, utilizing the wood panels for structure, finish, and acoustical control, all at the same time. The total carbon sequestered in Kellogg's wood structure from installing DLT and GLT is equivalent to the CO2 emissions from 32,500 gallons of gasoline.

Kellogg Middle School, Shoreline School District, Shoreline, Washington
(Designed by Mahlum Architects)

Emissions resulting from building operations were at their highest level ever in 2019.

CLIMATE IMPERATIVE

A report from the United Nations Environment Programme found that carbon emissions related to buildings and building construction have not decreased in the years since signing the Paris Climate Agreement.

In fact, emissions from building operations were at their highest level ever in 2019, accounting for around 28% of total global energy related CO2 emissions.

Over half of global energy production (55%) is attributed to building operations. When CO2 emissions from materials and construction are included, the building and construction sectors combined account for around 38 percent of total global energy related CO2 emissions.[1]

Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened.[2]

Unprecedented heatwaves, drought and wildfires have swept through the Western states in past years with increasing severity. The Intergovernmental Panel on Climate Change (IPCC) has concluded that it is "virtually certain" heat extremes have increased since the 1950s and that there is "high-confidence" that human-induced climate change is the main driver.[2] **Humanity is at a precipice.**

With the IPCC targeting a maximum temperature rise of 1.5-2 degrees Celsius (2.7-3.6 degrees Fahrenheit) to stave off catastrophic effects of climate change, global warming emissions must drop dramatically, and all buildings need to be net-zero emissions by 2050. The IPCC has concluded that "limiting human-induced global warming to a specific level requires limiting cumulative CO2 emissions, reaching at least net zero CO2 emissions, along with strong reductions in other greenhouse gas emissions."[2]

Having already surpassed the 1-degree Celsius warming mark in 2017, the window to make effective changes is closing fast.

Business as usual will not achieve the year-by-year reductions required to meet the IPCC target, meaning that **we all must be disruptors**. It is a monumental task for the building industry to meet these CO2 reductions and will require a radical rethinking of design, construction, operations, and disposal.

By focusing on reduced operational energy use and material strategies that reduce life-cycle carbon emissions, the building industry can contribute to meeting the IPCC's goals.

REDUCE OPERATIONAL ENERGY USE

PASSIVE SYSTEMS

UTILIZE **NATURAL VENTILATION** SYSTEMS TO REDUCE RELIANCE ON MECHANICAL SYSTEMS AND DRIVE DOWN ENERGY USE

Use operable windows for **natural ventilation** cooling

Use **stack ventilation** to exhaust warm air without mechanical systems

Position windows for maximum **thermal efficiency**

REDUCE OPERATIONAL ENERGY

HI-PERFORMANCE ENVELOPE

OPTIMIZE AMOUNT OF INSULATION, GLAZING AND ORIENTATION TO REDUCE NEED FOR HEATING AND COOLING AND SIZE OF MECH. EQUIP.

R-30 wall assemblies

R-50 roof insulation

Fiberglass windows

Triple versus double pane windows

Air-tight envelope

Window orientation:

Maximize windows at north

Shade windows at south

Minimize glazing at east & west

HIGH PERFORMANCE MECHANICAL SYSTEM

DOAS VENTILATION

DIRECT OUTDOOR AIR SYSTEM (DOAS) REDUCES FAN ENERGY AND USES ENERGY RECOVERY WHEEL TO CAPTURE WASTE HEAT AND COOLING

100% outdoor air reduces risk of contamination

Optimal system for reducing spread of air-born pathogens

Low-velocity air movement reduces energy demand on fans

Energy-recover ventilation (ERV) unit **captures waste heat** and **cool from exhaust air** to pre-temper ventilation air

Ceiling fans increase **thermal comfort** with minimal energy requirements

ON-SITE ELECTRICITY GENERATION

PV ARRAY

BY REDUCING DEMANDS ON OPERATIONAL ENERGY, **ON-SITE POWER GENERATION** CAN MEET FULL NEEDS OF BUILDING

All electric building (no fossil fuels)

REDUCE EMBODIED GREENHOUSE GASES

EMBODIED CARBON

TIMBER EMITS FEWER **GREENHOUSE GASES** IN THE ATMOSPHERE THAN STEEL OR CONCRETE STRUCTURES

ABOVE: Net-Zero measures implemented in proposed mass timber school design

Resilient Schools and Climate Preparedness

Reductions in operational carbon not only reduce climate burdens, but also provides resiliency for occupants and school districts. Impacts from power loss, wildfires, and flooding are increasing now 10 times faster than population growth, costing the country an average of $100 billion annually.[3]

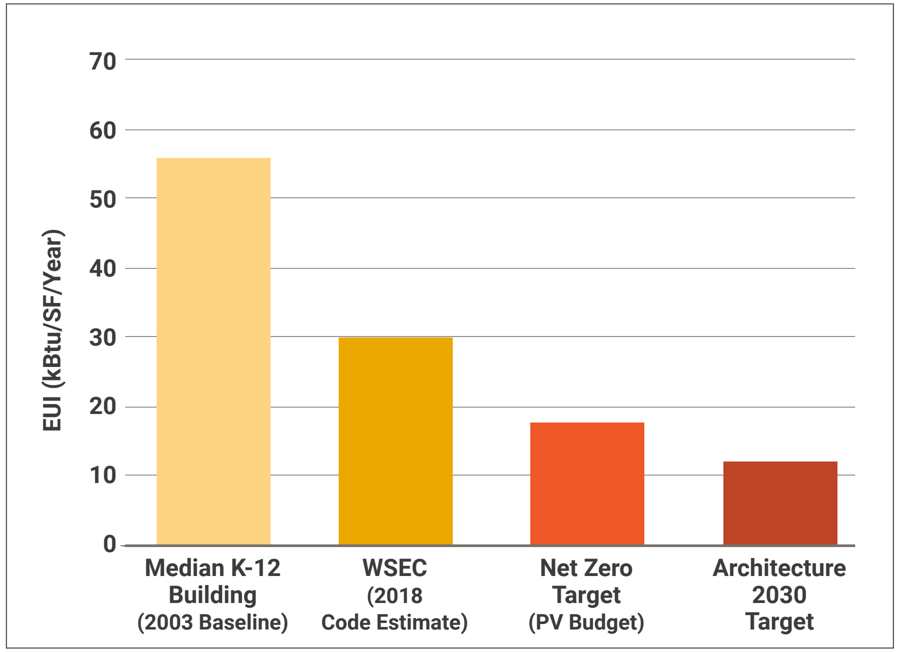
A building that can maintain critical operations during a crisis is a real benefit to the community. With climate change inducing environmental crises with increasing frequency, buildings must be designed from day one to deal with them effectively.

The use of photovoltaic cells (PVs) can reduce burdens on the power grid. In the future, networks of buildings with PVs can form virtual decentralized power plants to meet load demands and provide electrical grid services during emergencies. All-electric buildings not only eliminate the use of fossil fuels in the building but can utilize electricity from many different renewable energy sources.

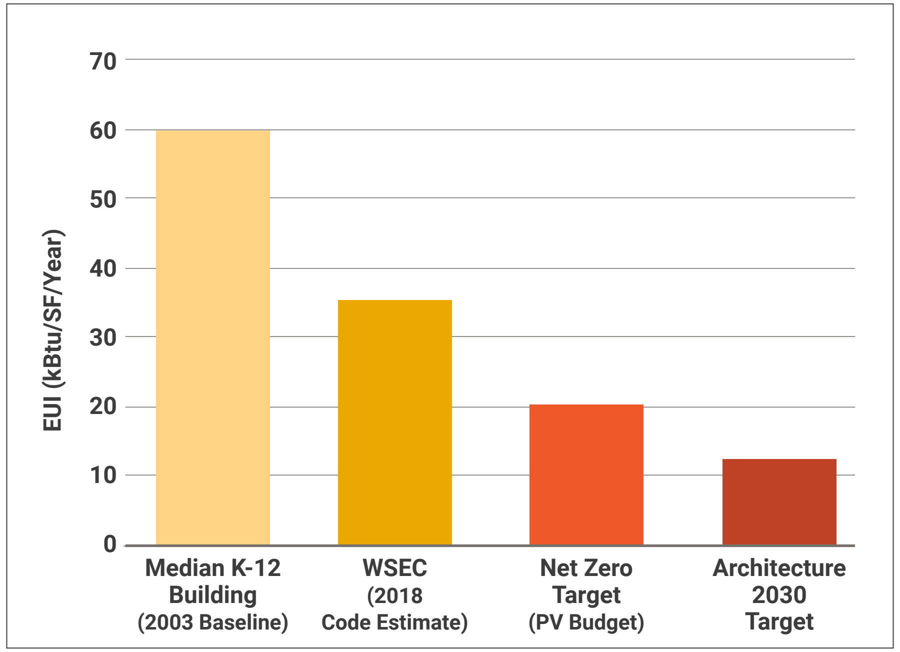
A robust, thermal envelope and air tightness can maintain interior heat for longer in winter and stay cool for longer in the summer, even without mechanical heating and cooling. **Passive ventilation** can provide cooling naturally and generous windows and skylights can keep spaces usable without electric lights.

Beyond energy, **efficient plumbing fixtures, irrigation, and rainwater catchment systems** can offer prolonged access to water during droughts or other crises.

Because schools are often the place communities gather in a crisis, implementing these design strategies will not only save energy and other resources, but can potentially save lives and help communities adapt to the unknowns of a rapidly changing climate. Throughout this section, we explore design strategies to reduce operational energy use, increase resiliency, prepare for our future climate, and move toward a carbon-free society.



ABOVE: Typical & Target School Energy Use: Climate Zone 4C (Seattle, Washington)
PV Budget is the target based on available solar resource
Washington State Energy Code (WSEC)



ABOVE: Typical & Target School Energy Use: Climate Zone 5B (Spokane, Washington)
PV Budget is the target based on available solar resource
Washington State Energy Code (WSEC)

LOW ENERGY (CARBON) AND SUSTAINABLE PRINCIPLES

On the path to sustainability, there are at least six major principles that must be included during the design process from the start. These include:

> Set aggressive project goals, such as the 2030 Challenge (reduce energy use by at least 80%), net-zero energy or net-zero carbon

> Design to the local climate

> Reduce energy and water use

> Design highly efficient mechanical and electrical systems and eliminate systems for passive options where possible (Refer to the Mechanical Approach section for detailed discussions of these topics)

> Utilize on-site renewable energy sources

> Commission the building and meter everything

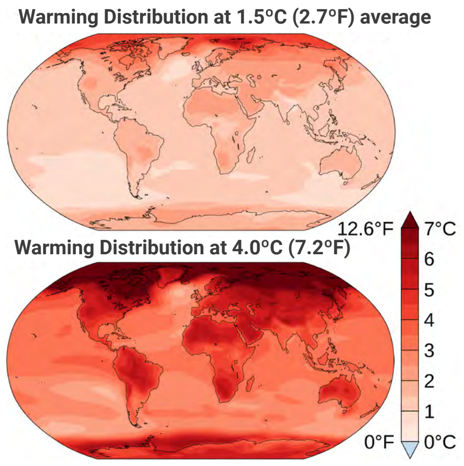
PROJECT GOALS

The mass timber school design presented here has been tailored with the intent of achieving net zero energy. A net-zero energy building generates as much renewable energy as it consumes on an annual basis. Net-zero buildings often utilize photovoltaic arrays – a well-established technology which has seen significant cost reductions over the last decade – to generate energy. When the solar resource is low during winter, the building draws extra energy from the electrical grid. When the solar resource is high during summer, the building produces excess energy and feeds it back to the grid.

For a building which pursues net-zero, steps are taken during design to reduce the projected energy consumption of the building such that it is possible to provide sufficient renewable energy generation to meet the project's energy demands.

The bar charts above illustrate the energy use for various schools normalized on a square footage per year basis for the two major climate zones in Washington State. It shows the energy use of a typical existing school building in this region (2003 CBECS Baseline), an estimated code minimum building, the target based on available solar resource, and the 2030 Challenge goal (an 80% energy reduction from the 2003 CBECS Baseline).

Designing a building that uses significantly less energy will require focusing on many elements: envelope, lighting, mechanical and electrical equipment, and equipment used by the occupants (plug loads).



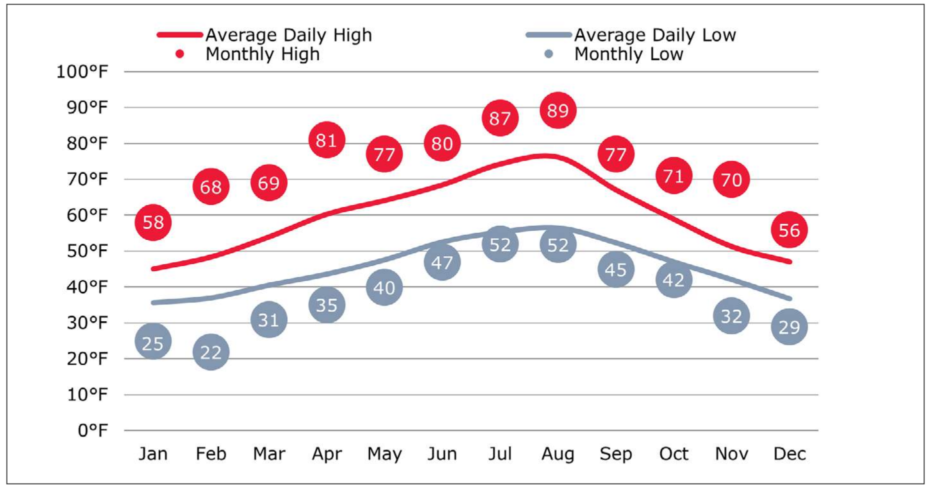
ABOVE: Distribution of temperature changes as predicted by the IPCC in AR6 relative to 1850-1900 baseline[4]

CLIMATIC CONDITIONS

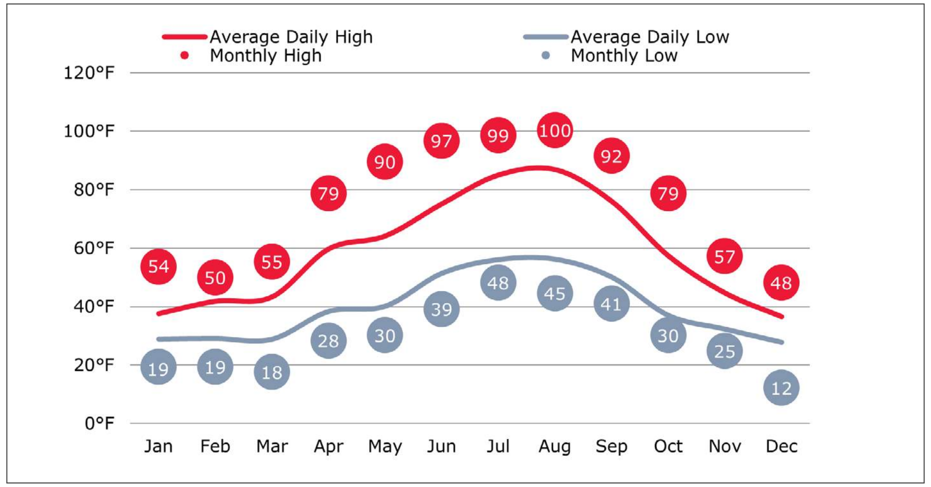
The intent of this study is to provide a template for classroom buildings anywhere in the Washington State. Based on ASHRAE climate data, two climate zones are prevalent: Zone 4C and Zone 5B.

Zone 4C covers the area of the state west of the Cascades and is characterized as mild and marine. **Zone 5B** stretches east of the Cascades and is characterized as cold and dry.

For the purposes of this study, Seattle was chosen to represent Zone 4C and Spokane was chosen to represent Zone 5B. The climate summary for both climate zones is shown in the charts below.



ABOVE: Zone 4C Average Monthly Temperatures with Maximum and Minimum (°F)



ABOVE: Zone 5B Average Monthly Temperatures with Maximum and Minimum (°F)

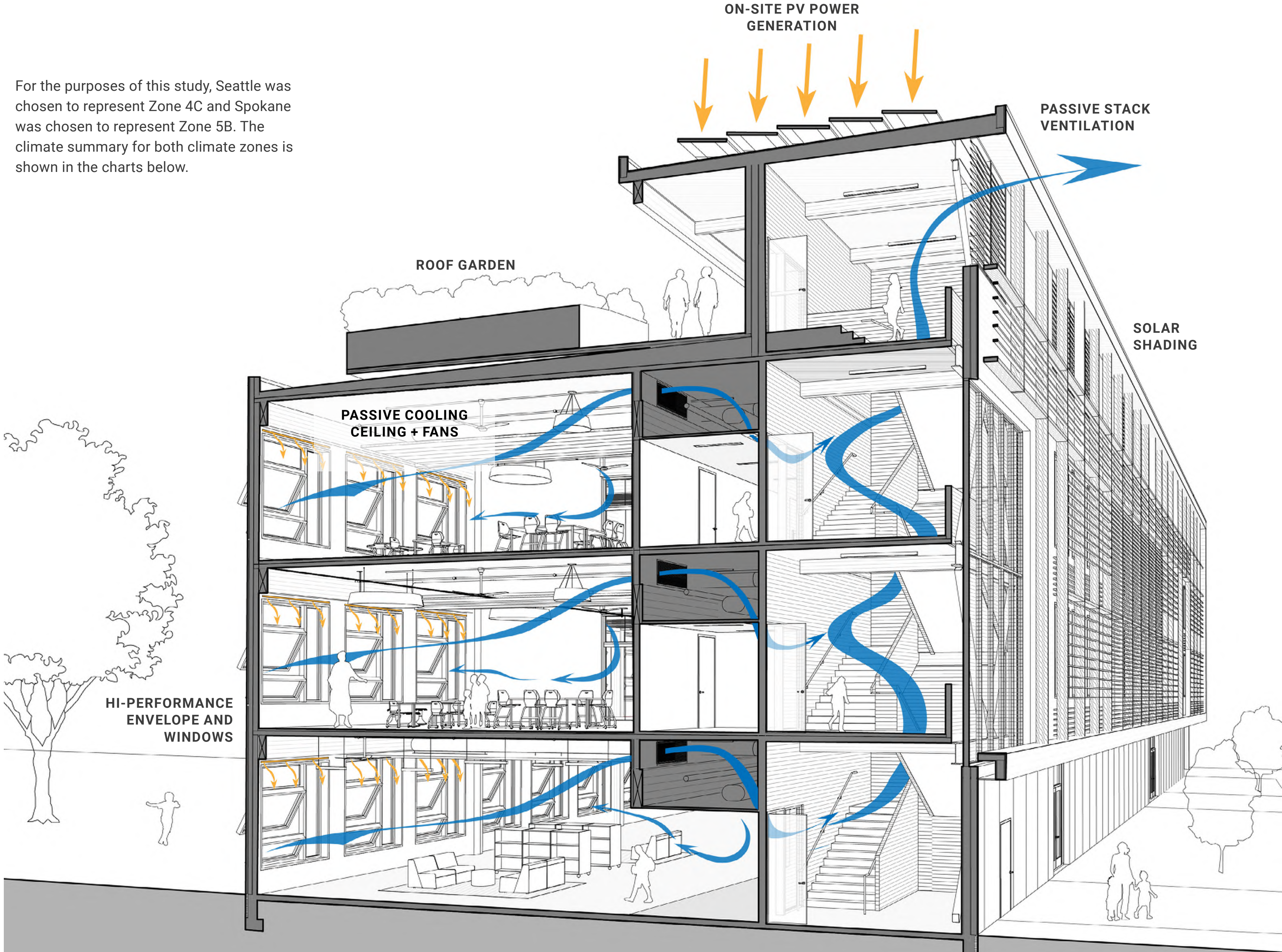


IMAGE:
Section highlighting key sustainability principles used in prototype design

Water Use and Rainwater

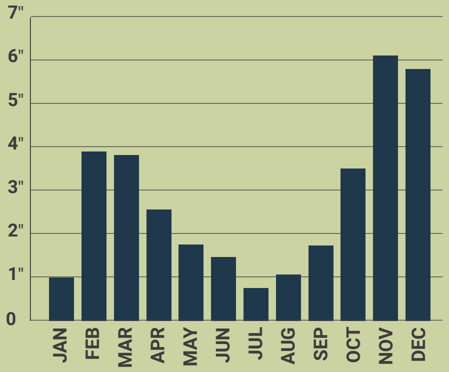
A completely sustainable building would use no more water than the amount of rainfall that falls on its roof annually. However, prior to designing a rainwater reclamation system for the building, it's critical that all applicable water use reduction strategies are pursued.

An aggressive targeting of low-flow fixtures throughout the school can potentially achieve a **30% reduction in annual water use,** when compared to a code building. Additional water use reduction can be achieved through the reuse of gray water for non-potable applications like flush fixtures and irrigation.

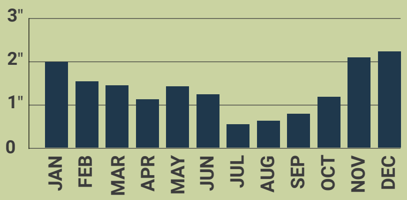
Once all water-use reductions have been established, the local water resource should be assessed for a rainwater capture system. Seattle receives an average of 38" of precipitation annually. This results in over 350,000 gallons of water falling on the roof of the building annually (assuming a 15,000 SF roof), making it a good candidate for rainwater reuse.

Alternatively, Spokane receives an average of 16" of precipitation annually for a total of 150,000 gallons annually, making it a less viable candidate for rainwater reuse.

ANNUAL SEATTLE, WA PRECIPITATION
(TOTAL INCHES: 38.27")



ANNUAL SPOKANE, WA PRECIPITATION
(TOTAL INCHES: 16.14")



ENERGY REDUCTION

Before turning to renewable energy production, the building must be designed to reduce energy consumption first. The following envelope, lighting, and mechanical measures have been studied and are recommended for energy reduction:

High Performance Envelope

- Fiberglass windows: 30% better than code (U-value ≤ 0.27)
- Shading on south façade to reduce solar gain
- Walls insulated at R-10 better than code: R-21 batt + R-10 continuous exterior insulation
- Roof insulated at R-12 better than code: R-50
- Airtight building construction targeting at most 0.25 CFM/SF air infiltration at 75 Pa pressure
- Daylight harvesting and dimming
- Windows placed in façade to maximize daylight potential, focusing on north and south orientations
- Provide shading at south façade to reduce Annual Sunlight Exposure (glare)
- High efficiency lighting design: 25% below 2018 IECC code
- Passive cooling and natural ventilation
- Operable windows in all classrooms
- Return/exhaust air paths provided to use stairs as relief stacks in natural ventilation mode (See passive strategies in Mechanical Approach section)
- Building HVAC systems designed to be able to operate as "mixed mode", providing both natural ventilation and supplemental heating and cooling.
- 65 percent effective heat recovery for mechanical ventilation air
- High-efficiency heat pumps for supplemental heating/cooling of mechanical ventilation air

From past experience we know that utilizing high-performance strategies outlined above does not have to translate to higher costs than using traditional systems. In fact, with careful planning the strategies above can actually save costs overall by reducing the need for mechanical equipment and investing that money into a better envelope and other passive strategies.

Not only can construction costs be reduced but reducing the dependence on mechanical equipment will cut operating costs and save school districts money year after year – money that can be then invested in maintenance, new construction, or other critical educational needs (see Mechanical Approach section for additional detail).

REFRIGERANT REDUCTION

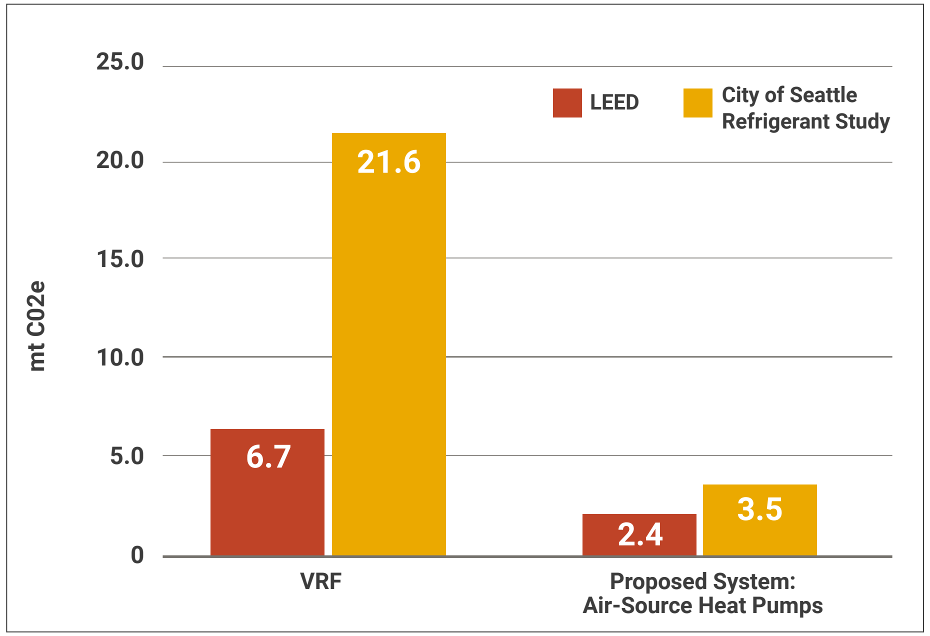
A central component of the proposed HVAC system design is that refrigerants can be used as energy-saving tools. Heat pumps and variable refrigerant flow (VRF) systems are increasingly common as efficient, cost-effective, all-electric systems for sustainable buildings. Refrigerant emissions have not traditionally been included when looking at heat pump technologies, and the impact of refrigerants on the climate is rarely discussed. However, if released into the environment, many refrigerants have thousands of times the global warming impact of CO_2. With this in mind, reducing refrigerant use is an important goal for sustainable projects.

VRF systems use refrigerant to move heat in and out of spaces. A typical VRF system contains nearly three times the amount of refrigerant of a heat pump system that uses water or air to move heat.

Due to the larger number of field connections, VRF systems are also more likely to leak refrigerant into the environment.

For this building, the typical annual impact is reduced by the equivalent of 18 megatons of CO_2, equivalent to the table below:

	VRF SYSTEM DESIGN	PROPOSED SYSTEM DESIGN: AIR-SOURCE HEAT PUMPS
TOTAL ANNUAL OPERATING GHGe (ALTERNATIVE UNITS)	21,621 kg CO_2e per year	3,549 kg CO_2e per year
	28.1 acres of forest per year to sequester emissions[5]	4.5 acres of forest per year to sequester emissions[5]



ABOVE: Operating Emissions from Refrigerant Leaks

IMAGE:
PV Rooftop Array at Sue Buel Elementary School, McMinnville School District, McMinnville, Oregon (Designed by Mahlum Architects)

ON-SITE RENEWABLES

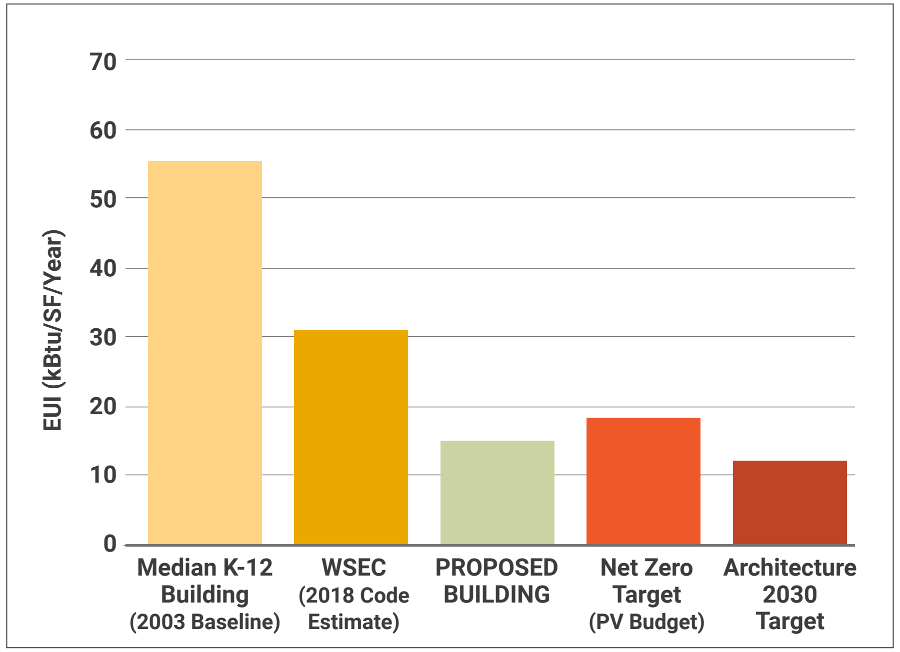
A Net-Zero Energy Building generates all the energy needed for its annual operation through on-site renewable energy. Typically, excess energy is generated in the summer and is sold back to the grid through net-metering to offset a deficit of renewable energy in the winter. Solar photovoltaics (PV), solar thermal, and wind are all potential energy sources. PV systems are currently the most cost-effective for most applications.

For this project, rooftop photovoltaics (PV) have the potential to generate about 253,500 kWh and 281,000 kWh of electricity in Seattle and Spokane, respectively. Based on modeling estimates of the energy reductions strategies outlined, the building energy use can be reduced to an EUI of 18.1 kBtu/SF/yr for Seattle or 20.1 kBtu/SF/yr for Spokane, which means the PV system would be sufficient for net zero operation. The table above summarizes the requirements for net zero energy operation for each location.

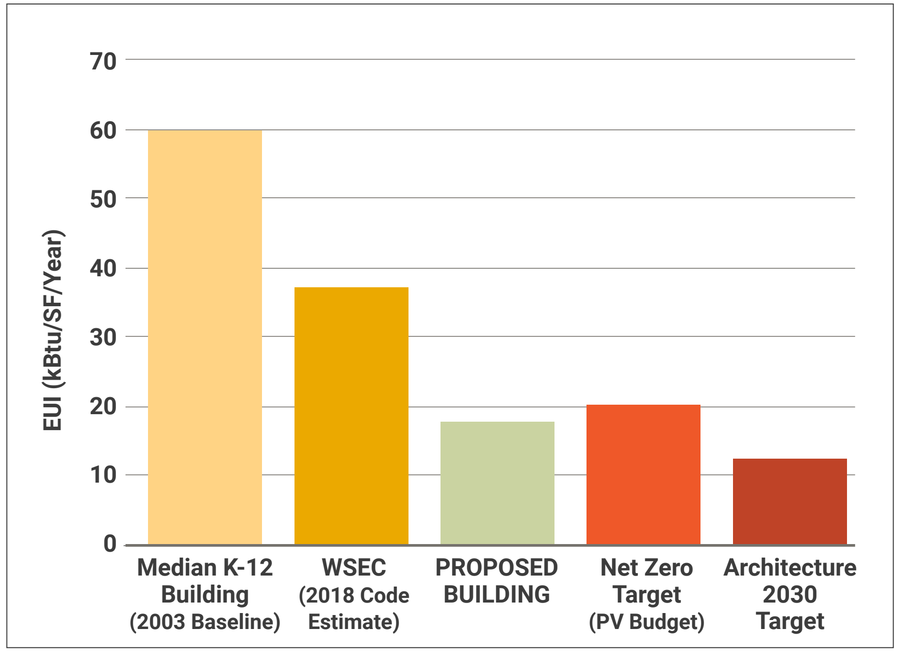
Both tables at right revisit the energy targets with the results of the proposed building, demonstrating that a net zero building is achievable in either climate. Also the bar charts on the right and on the following page are further results of the energy end-use for both proposed design buildings.

CALCULATION INPUTS	SEATTLE	SPOKANE
PT Panel Tilt (degrees)	10	10
Solar Harvest (kWh/kW)	1050	1165
PV Density (W/sf)	20.5	20.5
PV Cost ($/W)	3	3
kBtu per kWh	3.412	3.412
Total Building Area	**47,800**	**47,800**
Available Roof Area	**11,777**	**11,777**

	EUI TO BE 100% ONSITE GENERATION (NET-ZERO ENERGY BASED ON ROOF AREA)	
Building Energy Use Index EUI (kBtu/SF/Year)	**SEATTLE 18.1**	**SPOKANE 20.1**
PV kWh	253,495	281,258
PV kW	241	241
PV Panel Square Feet	11,777	11,777
Percentage of Roof Area Covered by PV Panels	100%	100%
PV Installed Cost	**$720,000**	**$720,000**
PV Installed Cost ($/Bldg SF)	**$15**	**$15**



ABOVE: Typical, Target, & Proposed School Energy Use: Climate Zone 4C (Seattle)



ABOVE: Typical, Target, & Proposed School Energy Use: Climate Zone 5B (Spokane)

COMMISSIONING AND METERING

Commissioning and monitoring of energy using systems is critical for achieving any high-performance K12 project. A good commissioning process during and post-construction helps to ensure the building is functioning and will continue to function as intended. Some key benefits of commissioning are:

> Potential energy savings and decreased utility costs

> Improved building system function, operation, and maintenance

> Extended equipment life cycle

> Third party verification of proper design, installation, and operation

> Improved building documentation for future solutions

The following commissioning processes should be integrated into project design requirements and the commissioning team should be brought on as early as possible to get design input.

BUILDING ENVELOPE COMMISSIONING

Building envelope commissioning is an integral part of the commissioning process, both during design and construction.

The building envelope systems regulate heat into and out of the building and a well commissioned system will ultimately result in less energy use in the building.

During design it is recommended that a commissioning team be brought in early to provide feedback on potential constructability issues. During construction is its recommended that the contractor conducts regular site walks for visual inspection to identify any potential areas of concern.

It is strongly recommended that typical envelope assemblies leverage envelope testing of assembly mock-ups to ensure target performance levels are to be achieved, prior to installing the assemblies throughout the building.

SYSTEMS COMMISSIONING

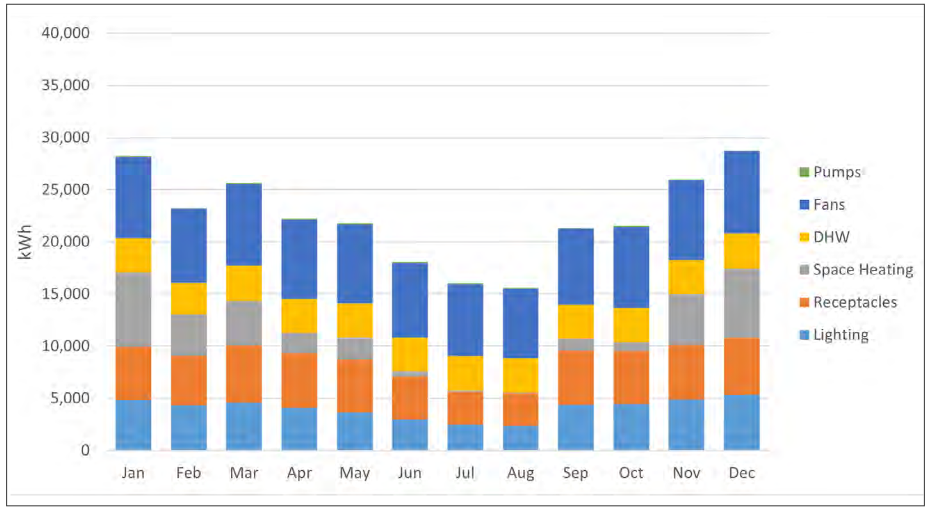
To ensure all of the key building energy using systems operate as intended, a systematic approach needs to be taken in the system setup and start-up process.

The building systems commissioning process involves a design review and functional performance testing (FPT) of all active systems within the project scope (i.e. HVAC, Lighting Controls, DHW, Solar PV). All new systems should undergo a full FPT process to ensure systems are functioning as expected.

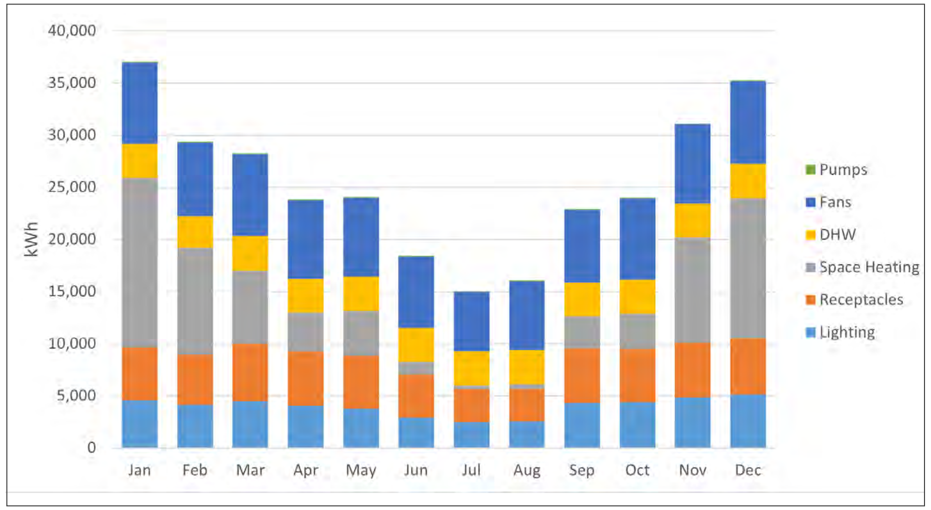
Seasonal commissioning follow-up may be warranted for systems with high seasonable performance variability (i.e. heating systems installed during the summer will likely need additional testing during the first heating season).

METERING AND MONITORING

Installation and tracking of all key energy using equipment is key to ensuring the building continues to operate as design. Energy end-use submetering helps provide the project team with enough information to calibrate the energy modeling for the school building, which can identify areas of operational or performance misalignment.



ABOVE: Proposed School Energy End Use Breakdown: Climate Zone 4C (Seattle)



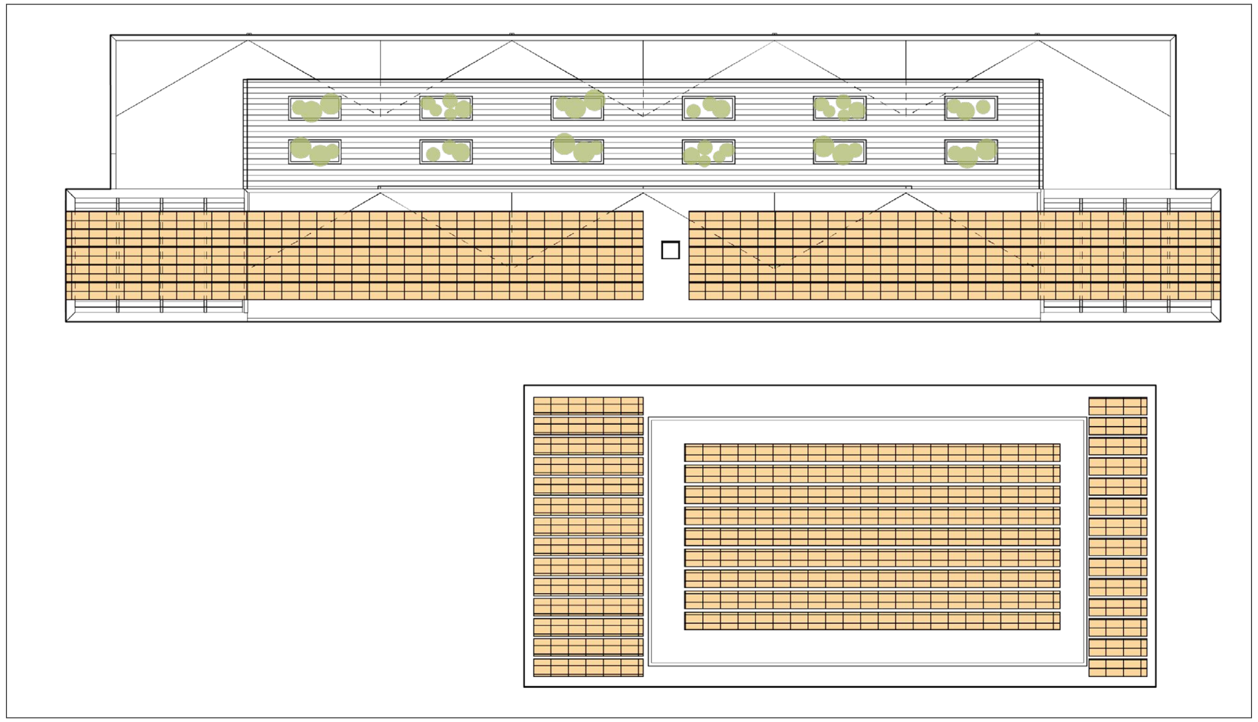
ABOVE: Proposed School Energy End Use Breakdown: Climate Zone 5B (Spokane)

Continuous monitory of the energy data is critical to ensure that the building is able to maintain an operation budget that is within the annual solar budget for net-zero operation.

INTEGRATIVE DESIGN PROCESS

All of the approaches outlined for the sustainable design of a K-12 project ultimately rely on a cohesive design team working together to achieve the carbon neutral design goal. This process involves bringing all key stakeholders into the design discussions early and often, with the sustainability target progress being evaluated through performance analysis at key decision points.

The value of the owner, facilities, contractor, and commissioning teams' input during the process cannot be understated. The success of the project relies not only on the design, but also on those who will be setting up and operating the building.



ABOVE: Roof plan showing extent of roof-top PVs on classroom building (top) and pavilion (bottom)

SECTION 03A FOOTNOTES

1. 2020 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION. UN Environment Programme and Global Alliance for Buildings and Construction, 2020, globalabc.org/sites/default/files/inline-files/2020%20Buildings%20GSR_FULL%20REPORT.pdf
2. "Climate Change 2021: The Physical Science Basis." The Summary for Policymakers (SPM), Intergovernmental Panel on Climate Change (IPCC), 2021, www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf
3. A Roadmap to Resilience Incentivization. National Institute of Building Sciences, August 2020, https://www.nibs.org/files/pdfs/NIBS_MMC_RoadmapResilience_082020.pdf
4. IPCC Sixth Assessment Report SPM.5
5. NOTE: Trees sequester carbon by absorbing CO2, but refrigerant emissions can be in the form of HFCs, PFCs, etc. While we commonly equate CO2e to forested area for other processes, refrigerant emissions are often GHGs other than CO2.

SECTION 03A IMAGE CREDITS

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SECTION 03B

Embodied Carbon

Deconstruction and reuse of existing building components is a powerful strategy for reducing embodied carbon emissions of materials. Engineered wood products can be reused, such as from the school demolished to make way for the new Gray Middle School which used these beams in the final structure.

Gray Middle School, Tacoma Public Schools, Tacoma, Washington
(Designed by Mahlum Architects)

Each new building creates a spike in greenhouse gas emissions and pushes us further down the road of unchecked climate change.

SCHOOLS AS CARBON SINKS

The global building stock is expected to double by 2060 to support an estimated 10 billion people living in cities.[1]

The need to replace and build new schools will continue to grow, but each new building creates a spike in greenhouse gas emissions and pushes us further down the road of unchecked climate change. Instead, what if the materials we use for new buildings could act as carbon sponges and actually reduce emissions? Instead of seeing buildings like schools as carbon emitters, let's design them as carbon sinks and create a building-based carbon pool.

Buildings can be designed to store more carbon and emit less carbon, a dual pronged approach that will get us closer to the Paris Agreement's goal of limiting temperature rise and achieving a carbon-neutral built environment by 2050. To create buildings that act as a carbon sink, architects should select materials that store sequestered atmospheric carbon. If carbon is stored in building products for a longer period of time than it takes to regrow the material, then atmospheric carbon dioxide can be potentially reduced.[2] Theoretically, every ton of carbon sequestered in a building product has pulled 3.67 tons of CO_2 from the atmosphere.

Displacing materials that have high carbon emissions for those that have low carbon emissions is a second complementary strategy. Biogenic, bio-based materials generally have lower embodied carbon than those that require significant amounts of energy to manufacture. That is because natural materials largely grow by free energy from the sun and producing bio-based materials typically doesn't require the high energies that other conventional materials require, which often rely on fossil fuels. It is estimated that the production of concrete, iron, and steel alone account for somewhere between approximately 9%[3] and 15%[4] of all annual global GHG emissions. Building materials that both sequester carbon and have low embodied carbon will have an immediate effect in offsetting carbon emissions compared to business as usual (BAU) approaches to design and material selection.

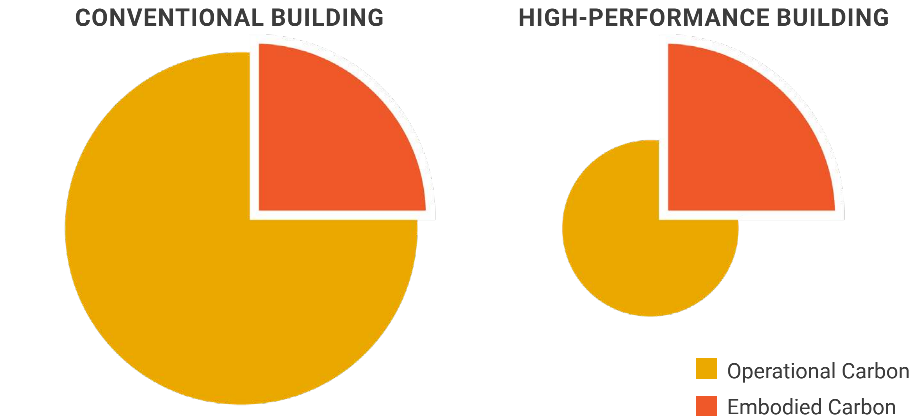
PAY-BACK TIME

For decades the emphasis for buildings has been on operational energy performance, focusing on optimizing mechanical systems to reduce energy use, increasing air tightness of the envelope, and selecting high-performance options for insulation and glazing. Traditionally, operational energy accounted for 80-90% of a building's total life cycle emissions, so focusing on this piece of the pie made sense.[5] Buildings today, however, are often much more efficient and the energy grid is getting cleaner. In general, operational energy use is decreasing, but embodied energy of materials and construction is not. Today, embodied carbon could account for half to three-quarters of a building's total GHG emissions for new construction.[6]

High performance buildings should reduce operational carbon emissions, and this is extremely important. However, depending on the site and materials used, a typical high-performance building may have significant embodied carbon emissions. It could take decades or more of reduced operational energy use in newly constructed buildings or renovations to offset the emissions generated from its construction and material use. In some cases, the use of materials with high embodied carbon may never offset the energy savings gained using such materials. For example, using additional foam insulation with a high global warming potential (GWP) may never reach a return on carbon investment. Therefore, the pay-back period in operational carbon savings must be closely scrutinized. If a material strategy is not carbon beneficial by 2050, then it is a poor choice and other alternatives should be examined. In this case, choosing a bio-based or mineral-based insulation is often preferable due to the tendency for these materials to offer lower embodied impacts.

In super low energy use buildings, such as those using passive house design principles or net-zero energy (NZE), a significant portion of total carbon impact will come from materials since operational energy is so low (see example pie charts at right). The same is true for buildings whose operational energy comes from inherently low carbon sources. In fact, for a NZE building, all of its carbon impacts will come from materials and construction and none from operations.

The embodied carbon in buildings has a short-term and immediate impact on emissions, while emissions related to operations accumulate over years or decades. As a building opens, nearly its entire carbon footprint is from materials. Embodied carbon is so important that several green building certification systems, such as LEED and the Living Building Challenge, now include credits for reducing it or mandate reductions or offsets at both a material scale and building scale. To create immediate reductions in carbon emissions and stabilize the climate, cutting down embodied material carbon will be key.



ABOVE: As buildings become more energy efficient, embodied carbon represents a larger share of the overall climate impacts over a building's life due to GHG emissions related to construction and construction materials

ABOVE: Salvaged glulam beams waiting to be refinished and reused at Gray Middle School, Tacoma Public Schools, Tacoma, Washington (Designed by Mahlum Architects). See photo of finished project on page 41

Let's bring to light the environmental impacts of buildings.

CALORIE COUNTING CARBON

Life Cycle Assessments (LCAs) are a way to track and expose environmental impacts of building products – or even whole buildings – through their life cycle. The data from which an LCA is based comes from life cycle inventories (LCI). LCIs are collected in databases and report all of the inputs and outputs from different processes used to create a material or product, such as raw material inputs, energy and water use, and emissions. Different LCIs can reflect regional variations in production, such as the type of energy or grid used in manufacturing. An LCI of a wood product will track these resource inputs and outputs (i.e. emissions) from forestry and manufacturing operations, including planting, fertilizing, thinning, harvesting, transporting, processing and finishing. A Life Cycle Inventory Assessment (LCIA) turns the inputs and outputs into impacts. This data can then be used to generate Environmental Product Declarations (EPDs) or inputted into LCA software to conduct assessments and comparisons.

DESIGN "HOT SPOTS"

To obtain LCA results for a product system, all of the material and process impacts for each environmental impact category are summed to give the overall impacts for that product or system. The five most commonly tracked LCA impact categories include: global warming potential (GWP), ozone depletion potential, eutrophication potential, acidification potential and smog formation potential.[7] GWP is the metric for embodied carbon. All building products have some amount of embodied carbon, which can be expressed in units of kgCO2eq.

LCAs are a useful tool for making decisions on building products and systems by highlighting "hot-spots" in the design that have large environmental impacts. Once hot-spots are identified, LCA can be used to compare alternate, lower carbon options. See page 42 of this section for a LCA study comparing mass timber to steel.

Life Cycle Assessments Modules

LCA data can be reported as cradle-to-gate, cradle-to-site, cradle-to-grave or even cradle-to-cradle. Often product LCAs, such as for a glued-laminated beam, are analyzed from cradle-to-gate, which represents LCA scopes **A1** (raw material supply), **A2** (transport) and **A3** (manufacturing).

For products, a cradle-to-gate boundary is often used because impacts generated after the product has left a manufacturer's facility (gate) can no longer be controlled by that manufacturer. LCA scopes **A4** and **A5** represent transportation and construction/installation. LCA scopes **B1-7** represent the building use stage and **C1-4** track end-of-life processes.

Module D tracks emissions beyond the LCA system boundary, such as avoided environmental burdens due to recycling of materials or energy recovery. This module is intended to quantify potential benefits from avoided use of future materials and fuels, such as recovered wood products.

For a broad picture of impacts, a whole building LCA (WBLCA) can be used to track all phases from resource extraction to construction, building operations, maintenance and end-of-life. LCAs for buildings are approximations of very complex systems and supply chains, of which each one is unique and not entirely predictable.

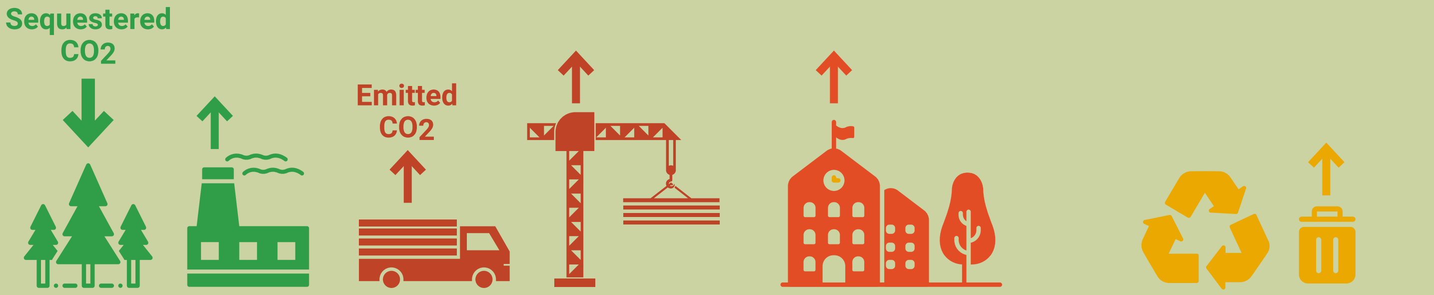
Consequently these models may include significant assumptions about materials, as well as a building's future use, such as its lifespan, maintenance, operations and end-of-life treatments.[A] Different LCA software often yield different results based on variation in the underlying LCI data and assumptions used.[B]

EPDs typically report environmental impact of a material for a unit of measurement, such as cubic meters. Comparing a cubic meter of glued-laminated timber to a cubic meter of structural steel does not provide useful information to designers. For comparison, functional equivalency between the two products must be first established.[C]

A W18x35 steel beam (volume) may be functionally equivalent to an 8.75" x 27" glued-laminated beam (volume) in a school floor structure, for example. In addition to structural capacity, other functional attributes (for example, service life), quality and maintenance must be defined to accurately compare products and overall impacts.[D] A building's structural system may be the largest source of embodied carbon on most projects, so focusing on this area and working closely with a structural engineer can lead to meaningful reductions in embodied carbon on a project.[E]

BELOW:
This graphic represents life-cycle stages as defined by EN15978. Bold font included in Tally LCA software modeling scope. ***Italic font*** **indicates optional processes.**

LCA study using Tally software is explored in this section on page 42.



MODULE A — Product
- **A1. Extraction**
- **A2. Transport (to Factory)**
- **A3. Manufacturing**

MODULE A — Construction
- **A4. Transport (to Site)**
- *A5. Construction Installation*

MODULE B — Use
- B1. Use
- **B2. Maintenance**
- **B3. Repair**
- **B4. Replacement**
- **B5. Refurbishment**
- *B6. Operational Energy*
- B7. Operational Water

MODULE C — End of Life
- C1. Demolition
- **C2. Transportation (to Disposal)**
- **C3. Waste Processing**
- **C4. Disposal**

MODULE D
- **D. Benefits and Loads Beyond the System Boundary From:**
  1. **Reuse**
  2. **Recycling**
  3. **Energy Recovery**

CRADLE TO GATE

CRADLE TO GRAVE

For wood products, forest management practices influence environmental impact and sustainable forestry practices must be followed for wood to have a benefit over other materials.[8]

ENVIRONMENTAL PRODUCT DECLARATIONS (EPDS)

EPDs utilize LCA data to create a kind of nutrition label for a product's environmental impacts. Cradle-to-gate (LCA modules A1-A3) EPDs for wood products include impacts from certain forest management activities and wood product production. Forest management activities include site preparation, thinning, fertilization, extraction, and production and planting of new seedlings. Production includes transportation of logs to sawmills, sawing, kiln-drying, transportation of lumber to engineered wood products manufacturing facility, finger jointing, planing, gluing under pressure and planing again.

THE PRODUCT CATEGORY RULES (PCR)

The PCRs for North American wood product EPDs consider biogenic carbon dioxide emissions from bio-energy production as carbon neutral. That is because emissions from combustion of wood fuels are considered equal to the carbon uptake in forests during tree growth.[10] Per ISO 21930, this assumption is allowed because North American forest stocks are stable or increasing. Wood biomass energy is used primarily for kiln-drying dimensional lumber.

FORESTRY OPERATIONS

While forestry operations rely on fossil fuels, only around 6% of total energy use in North American lumber production is from forestry operations, while the remaining 94% is from lumber production of drying, cutting, planing, etc.

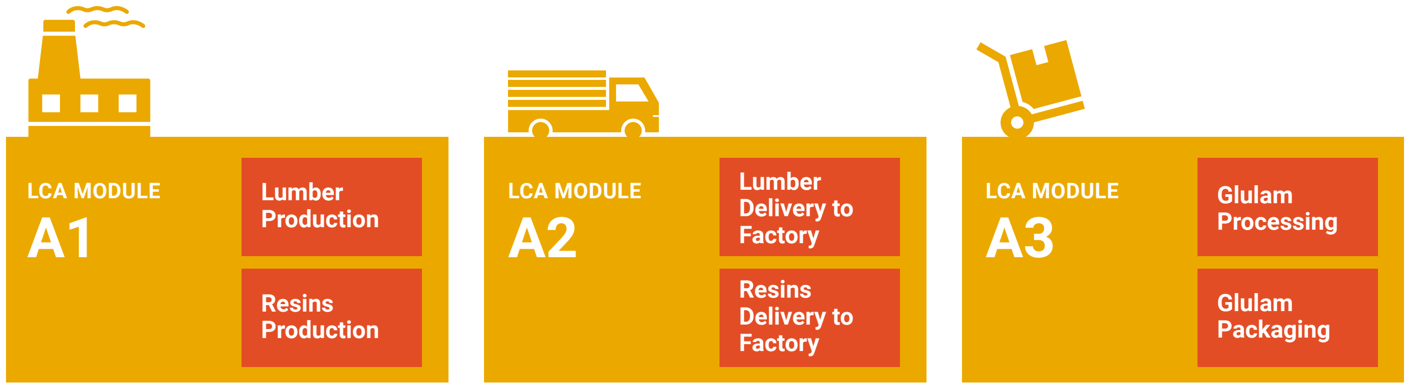
For total cradle-to-gate energy use for dimensional lumber, around 55% is from wood biomass.[11] Of the total cradle-to-gate energy use of North American glued laminated timbers, about 38% is from biomass.[12] About 60% of the energy used in lumber production is renewable, with about 58% from biomass and 2% from hydropower.

Primary forests are considered carbon neutral as they will sequester as much carbon through growth as is emitted through decay. Managed forests may also be considered carbon neutral if at least as many trees are planted as removed and as much carbon that is emitted during forestry operations is sequestered in new growth.

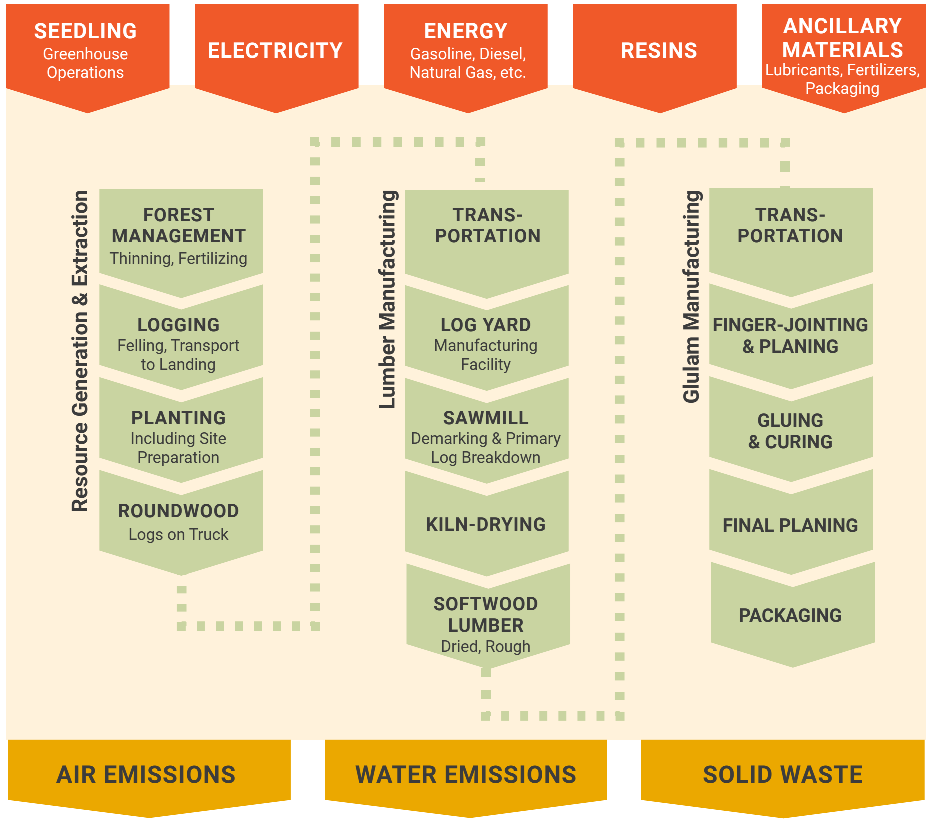
However, if less carbon is added and maintained than extracted in forestry operations, then carbon neutrality should not be assumed, even though LCA standards may allow an assumption of carbon neutrality. Such assumptions are based on historical measurements over a large geographic scale (see discussion of ISO 21930 on the following page) and loose definitions of sustainable forest management that do not account for the range of carbon management practices between forests within individual ownership boundaries. (See Sustainable Sourcing section for more discussion of sustainable forestry in Washington State.)

Moreover, if a forest is converted to a non-forest use, then there can be no carbon benefit claimed. In this case, any carbon released during harvesting, manufacturing or final end-of-use will never be re-sequestered.

Conclusion: forests must remain forests to have a carbon benefit.

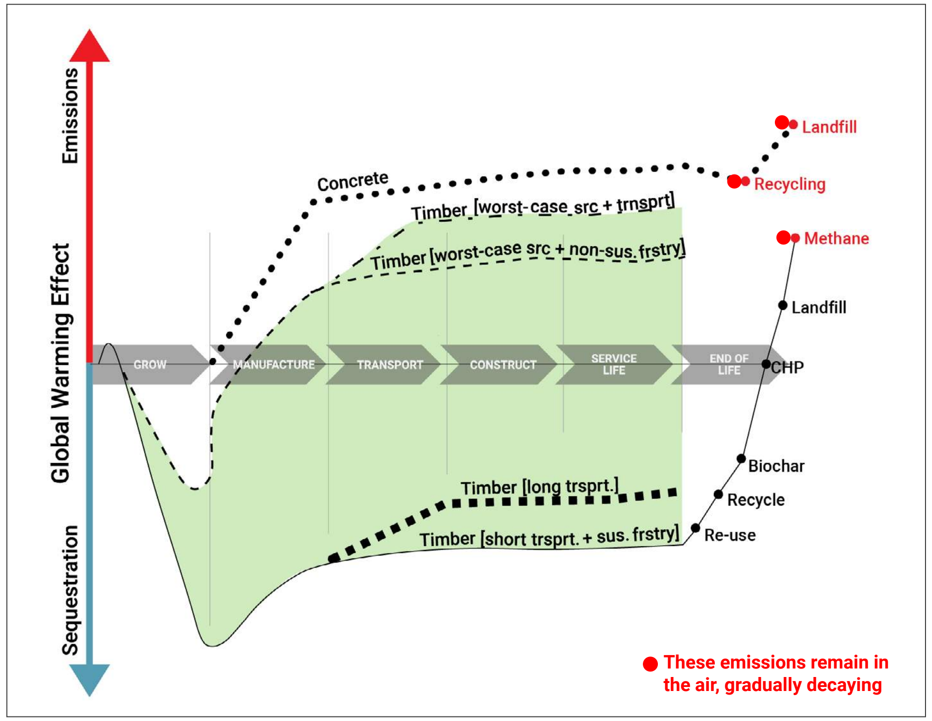


ABOVE: Cradle-to-gate LCA modules for glulam production.



ABOVE: Cradle-to-gate inputs and outputs from glued laminated timber production.

Tracking life-cycle impacts begins at the forest and includes emissions related to forest management and reforestation. Once harvested, logs are transported to sawmills where they are sawn, kiln-dried, and transformed into an engineered wood product through finger-jointing, gluing under pressure, and planing.



LEFT:
Estimated life-cycle impacts of wood under different forest management regimens compared to concrete

ADDRESSING BIOGENIC CARBON

Biogenic carbon is "the emissions related to the natural carbon cycle, as well as those resulting from the combustion, harvest, digestion, fermentation, decomposition or processing of biologically based materials." [9]

When conducting an LCA for a building or assembly that uses wood products, the issue of biogenic carbon needs to be addressed.

Biogenic carbon can refer to the woody biomass used for energy in the production of kiln-dried lumber, sequestered carbon captured in the finished wood product or emissions from incineration not used for energy and landfill emissions (could be as CO2 or methane). An LCA may count sequestered carbon as a “negative” carbon emission and give credit to biomass derived energy as an avoided fossil fuel emission. To have a positive impact on climate, sources of biogenic carbon must come from sustainable, renewable resources.

ISO 21930, the standard governing EPDs of construction products, notes that “sustainably managed forests” can be those with stable or increasing forest carbon stocks as identified by national reporting in accordance with the United Nations Framework Convention of Climate Change (UNFCCC). This annual report for the US indicates increasing and/or stable forest carbon stocks over the last several decades, allowing this biogenic carbon neutrality assumption at a national level.

In the LCA software Tally, "including biogenic carbon" means that the carbon stored in the product is initially counted as a credit (A1-A3) but then biogenic carbon is released in end of life phases (C2-C4), through incineration, landfilling, or recycling. A portion of the landfilled material is considered to be permanently stored.

Biogenic Carbon Explained

Living plants sequester carbon from the atmosphere through photosynthesis, the process through which sunlight is used to produce glucose from carbon dioxide and water. This type of carbon, known as biogenic carbon, can be stored in plant tissue biomass, like wood, which is around 50% carbon by weight (with the remaining being around 46% oxygen and 4% hydrogen).[F]

Some plants may store carbon for a short period of time, such as a single growing season, while others like trees can store carbon for extended periods of time, even centuries. The most productive forests, like old-growth redwoods in Northern California, can store 2,600 metric tons of carbon per hectare.[G]

Photosynthesis by trees and other plants can be represented by this chemical equation:

$$6CO_2 + 6H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Photosynthesis is perhaps the most important process on the planet and makes life possible. Comparing the atmospheres of Earth and Mars, the oxygen content on Earth that gave rise to and sustains life is undoubtably due to the photosynthesis of organisms.

While massive amounts of biomass are stored in living trees, about one-third of a natural forest's above-ground carbon could be stored in snags and downed trees.[H]

Forests act as a global carbon sink when the amount of carbon stored in trees, soil, and other vegetation is greater than the emissions from respiration, decay, and disturbances from forest fires, harvesting and processing. In a natural state, as plants die some biogenic carbon may be sequestered in soil while the rest will eventually be released back into the atmosphere. It is estimated that the world’s forests and farms could store around 2.5 gigatons of carbon.[I]

There are many building products that store sequestered carbon, like bamboo, cork, and straw, but wood is unique in that it is the only biogenic material that can currently be harnessed on a large scale for structural use in taller buildings and is already incorporated into building codes.

In medieval Europe, timbers were handed down from building to building and continually reused.

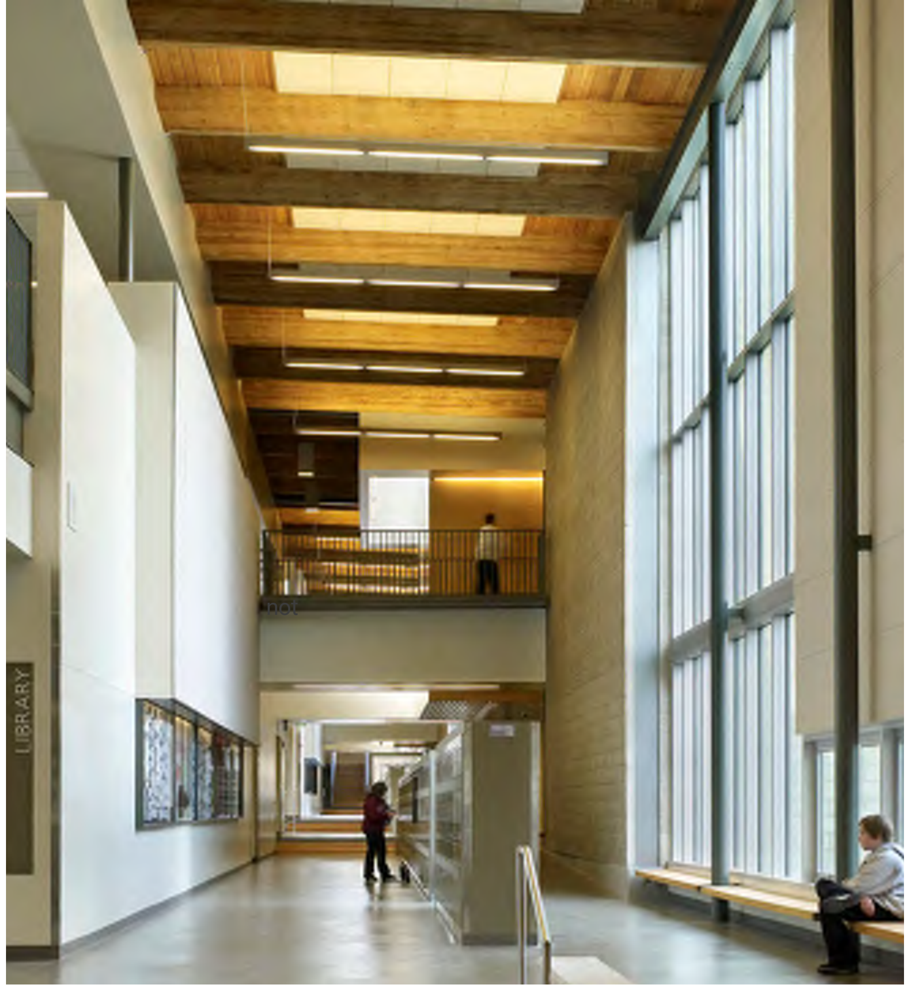
LCA END-OF-LIFE AND BEYOND

The value used for sequestered carbon in wood products depends heavily on forest operations, manufacturing efficiency and a product's end-of-life treatment.[13] There are several scenarios for a wood product's end-of-life: landfill, incineration, reuse or recycling (usually downcycling). LCA studies will assume an average percentage share of how much wood is land-filled, incinerated, or recycled.

For example, Tally, an LCA software tool, assumes that 63.5% of wood is land-filled, 22% is incinerated and 14.5% is recycled. The GWP emissions associated with wood will be greater when products are assumed to be land-filled rather than reused at the end of their lives.

If land-filled, wood products may release CO_2 and CH_4 (methane) back to the atmosphere as they decay. LCA modules C3-C4 account for emissions of land-filled biomass, while module D accounts for the fact that some of the gas emissions from land-filled biomass may be captured for energy and thereby function as a credit for avoided fossil fuel emissions. Similarly, incineration at end-of-life appears in C3-C4 while if this is used for energy that displaces fossil fuels, this avoidance can be a credit in Module D.

Lastly, there is evidence that even land-filled wood products will have a carbon sequestration benefit while releasing very low levels of greenhouse gases over extended periods of time.[14, 15]



ABOVE: Salvaged and refinished glulam beams were utilized at Gray Middle School, Tacoma Public Schools, Tacoma, Washington. (Designed by Mahlum Architects)

While light wood framing is currently not often reused, mass timber elements do provide a greater opportunity for reuse. The timber frame was the original design for disassembly construction type.

In medieval Europe, timbers were handed down from building to building and continually reused.[16] This is a concept we need to return to today. Reusing mass timber is a compelling option due to the large size of elements, greater economic value, use of mechanical fasteners, fewer connections (than light framed construction types), and easier disassembly and recapture.

Mahlum has reused glulam beams in past projects, so from first-hand knowledge this strategy is imminently possible. Non-composite construction facilitates reuse and the grade of wood used for structural elements should always be clearly labeled on each piece so that reuse at a later time is facilitated. Without knowing the grade of a wood element, a conservative value for its strength could be assigned, thus decreasing its value and potential for reuse. Typically, salvaged large timbers rely on job-specific visual grading and engineering approval. Because there are no "expressly acknowledged" lumber grading rules for reclaimed wood, working closely with the local jurisdiction is essential, especially for light wood members.[17]

Steel Production Impacts

In nature, iron reacts readily with oxygen to create iron oxides. Iron ore, the basis of steel production, is rich in iron oxides. To create a useful construction material, a principle step in creating steel is to remove the oxygen from iron compounds.

In traditional blast furnaces (BFs), this is done by heating crushed ore to high temperatures with charcoal, coke, or limestone. During the heating process, carbon monoxide (CO) is released. The carbon monoxide then reacts with oxygen from the iron ore to create large amounts of carbon dioxide (CO_2), a principal greenhouse gas. The pig iron produced here is then used in a basic oxygen process (via Basic Oxygen Furnaces or BOF), where oxygen is used to lower the carbon content of the molten alloy and create low-carbon steel. The majority of global steel production is through the basic oxygen BF-BOF process.

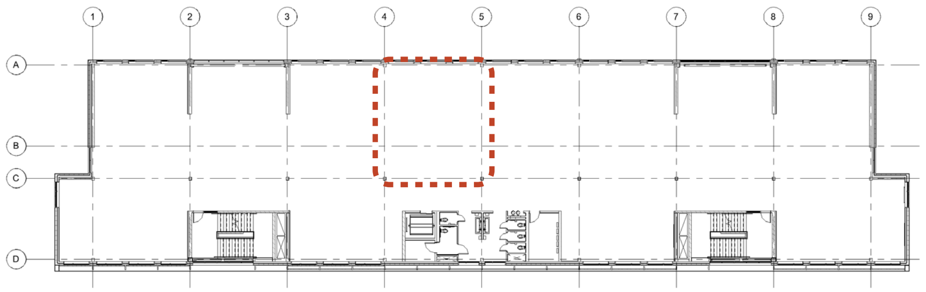
The World Steel Association reported that in 2018 every ton of steel produced emitted an average 1.85 tons of carbon dioxide. **The production of steel alone may have equated to as much as around 8 percent of global CO_2 emissions.**[J] In addition to CO_2, steel production also emits CO, SOx, NOx, PM2 which impact air quality, and produces hazardous wastes and wastewater that may contaminate waterways.[K]

ELECTRIC ARC FURNACES (EAF)

Electric arc furnaces (EAF) are typically smaller operations that do not require a steady supply of coke to heat scrap iron. Instead, they use electricity that passes through giant graphite electrodes to create an arc and heat the metal to 3,000 degrees F. While electric arc furnaces are more efficient than blast furnaces, both require heating iron to high temperatures and are extremely energy intensive. EAFs also require a steady supply of quality scrap iron. Nucor in Seattle, for example, is an EAF and also the city's single largest industrial power consumer.[L]

For electric arc furnaces, this translates to a large demand in energy and subsequent environmental impacts from grid-based energy production. The vast majority of domestically produced steel is through EAFs, while internationally most of the steel (more than 60%) is manufactured by BF-BOFs.[M] Electric arc furnaces are only able to use recycled steel. Any new steel production, based on demand, needs to be produced at blast furnaces.

While the steel industry is looking for ways to reduce its carbon footprint, and emerging technologies that show promise will take time to implement, designers should consider reducing demand for new steel by using salvaged steel or lower carbon materials whenever possible.



ABOVE: Location of Typical Bay

LCA STUDY USING TALLY

Several whole building LCA studies have been conducted that indicate mass timber construction could be utilized in place of traditional steel or concrete design to reduce a project's embodied carbon impact. If considering only fossil fuel emission (embodied carbon) avoidance, a mass timber design may generally see GWP reductions between 10% to 45%, depending on how much wood is used in the design.[18] If long-term carbon storage is also considered, the reduction can be as high as 70-100% (or more) for GWP. For this project, we used Revit and Tally LCA software plug-in to compare the superstructure impacts between a mass timber design and structural steel design.

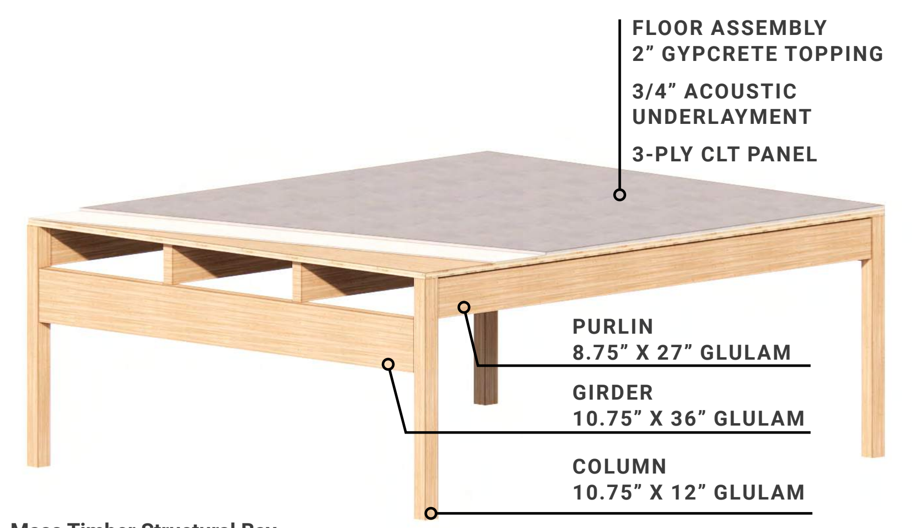
Instead of comparing the full structure and floor assembly of the building, here we have taken a single typical bay (35' x 30') of the building as a representative sample. Because schools are often designed around a classroom bay, this study could be applied to almost any school and easily adapted to different bay sizes. While not as complete as an LCA of the full building, an LCA analysis of a bay reduces the number of components to manage and therefore the number of errors and omissions that could occur in analysis. A close approximation to the full structure and floor assembly GWP impacts can be extrapolated from this bay study.

To the right is a bill of materials and Tally material definitions used in this LCA study. In some cases, an exact material match in Tally was not possible, so a proxy material was used in its place.

The service life of all elements listed was set to the life of the building (assumed 60 years). This study did not include interior materials or exterior wall materials because these would largely be identical between design options. Foundations are assumed to be similar enough between options to exclude from study. The only exceptions are that the steel option has additional dropped ceilings and thicker non-bearing walls to encapsulate steel structural elements. While not included in this analysis, it is likely these additional materials increase the embodied carbon impacts for the steel frame option.

No fire-resistance rated construction was assumed for either the mass timber or steel options. Acoustic performance of floor assemblies between options meet standards outlines in Acoustic section of this report.

Material: Mass Timber Option



Mass Timber Structural Bay

ASSEMBLY: CLT FLOOR

2-INCH GYPCRETE TOPPING LAYER
Tally Definition: Self-leveling cementitious underlayment or fiber cement underlayment board.

3/4-INCH ACOUSTIC MAT
Tally Definition: Polycarbonate cellular plastic, sheet, solid sheet stock.
The weight of the material was taken from USG SAM-N75 Sound Attenuation Mat (28 lbs. per 125 sq. Ft. Roll). *

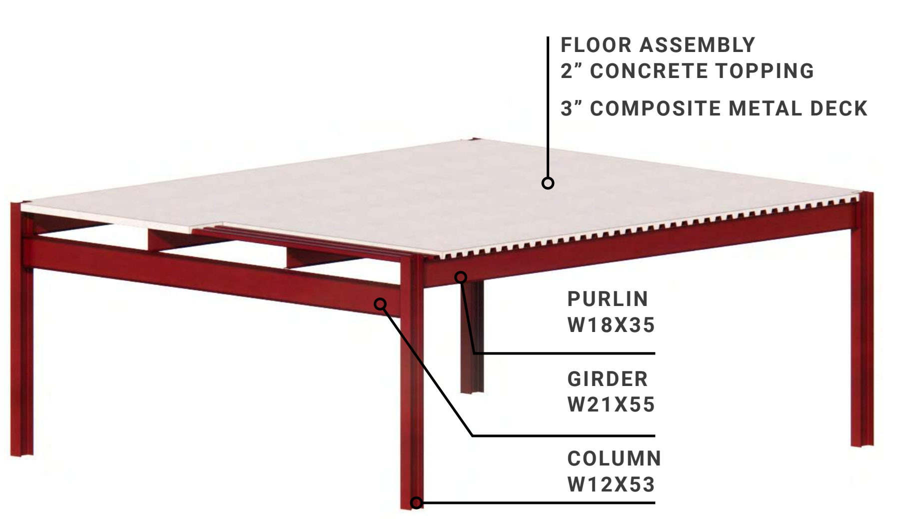
3-PLY CLT FLOOR PANEL (4-1/8-INCH THICK)
Tally Definition: Cross-laminated timber (generic) beams inclusive of adhesive and wood finish.

STRUCTURAL LOAD-BEARING FRAME: GLT POST & BEAM

GLUED LAMINATED TIMBER COLUMNS, PURLINS AND BEAMS
Tally Definition: Glue laminated timber (Glulam) Architectural-grade structural glue-laminated timber (AWC EPD), composed of softwood which has been end-joined, laminated, and planed. Entry inclusive of factory-applied sealer.

** Because an acoustical underlayment material was not available in Tally at the time of conducting this study, a proxy material was used instead. In email correspondence, Tally recommended using either the polycarbonate cellular plastic, polyester solid surface, or the unreinforced polypropylene panel as a proxy material and manually entering density of the polymer. All three options were investigated, and because polycarbonate cellular plastic had the largest LCA impacts, this material was chosen as the most conservative option.*

Material: Steel Option



Steel Structural Bay

ASSEMBLY: STEEL FLOOR

COMPOSITE METAL DECK AND CONCRETE FILL
Tally Definition: Structural Concrete 2-inch concrete topping plus volume of concrete filling flutes. Structural concrete (4000 psi) with 30% slag and low rebar reinforcement.

30% of the concrete volume (5-inch total slab depth including deck) was subtracted to account for flutes in the composite steel deck.

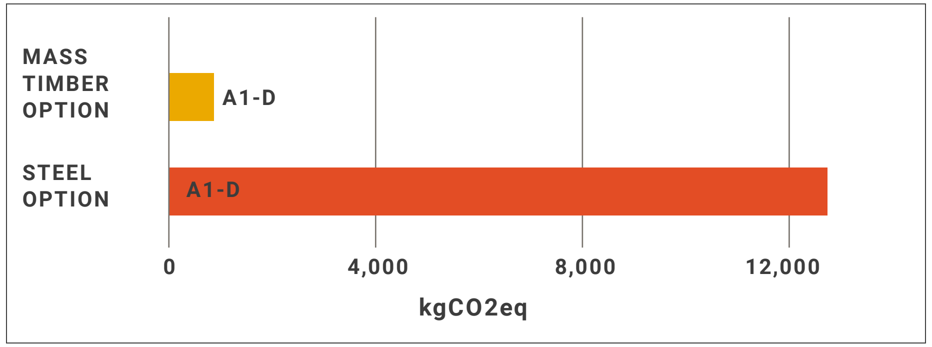
Tally Definition: Steel Deck
3-inch, 18-gauge composite galvanized steel decking with no fireproofing or finish.

STRUCTURAL LOAD-BEARING FRAME: STEEL POST & BEAM FRAME

WIDE FLANGE COLUMNS AND BEAMS
Tally Definition: Hot rolled steel, wide flange W shape with no fireproofing or finish.

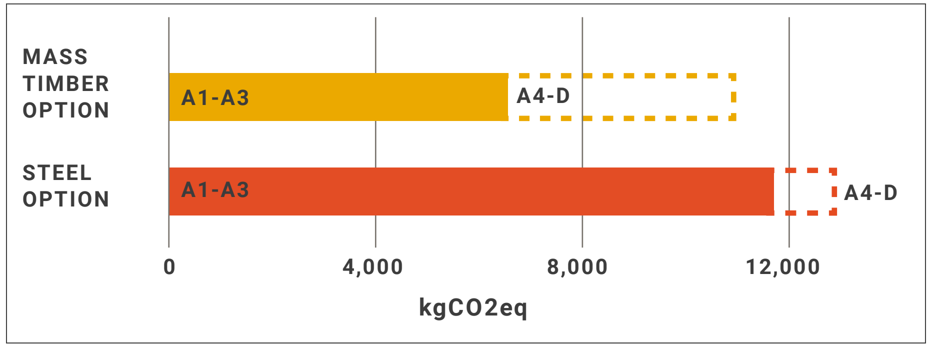
BELOW:
Tally Life Cycle Global Warming Potential [GWP] Modules A1-D (*Includes* Biogenic Carbon)

While not all working forests in the U.S. are part of a sustainable certification system, annual national reporting in accordance with the United Nations Framework Convention of Climate Change (UNFCCC) indicates increasing and/or stable forest carbon stocks in the U.S. Because of this, project teams may choose to include biogenic carbon in their LCA studies.



BELOW:
Tally Life Cycle Global Warming Potential [GWP] Modules A1-D (*Excludes* Biogenic Carbon)

If project teams know their wood is coming from non-sustainably managed forests, or if they wish to take a conservative approach, biogenic carbon can be excluded from the LCA study. Even without biogenic carbon, the mass timber scheme still represents a significant reduction in greenhouse gas emissions.



TALLY RESULTS: GWP

The results of this study indicate that the mass timber option represents more than a 90% reduction in Global Warming Potential (GWP or kgCO2eq) when biogenic carbon is accounted for (modules A-D).

When biogenic carbon is excluded from the study, the mass timber option reduces GWP by approximately 15% compared to the steel option (modules A-D). However, a large amount of the GWP impact for the mass timber option comes from end-of-life assumptions for wood discussed earlier. Because mass timber elements are unlikely to be land-filled at the end of a building's life, comparing just emissions from material manufacturing (Modules A1-A3) may give a better picture of GWP impacts between mass timber and steel when biogenic carbon is excluded. In this case, the mass timber option reduces GWP by approximately 45% compared to the steel option. The mass timber option also uses less energy than the steel option regardless of whether biogenic carbon is included.

TALLY RESULTS: OTHER IMPACT CATEGORIES

When comparing just LCA modules A1-A3 (cradle-to-gate), the impacts from acidification, eutrophication and smog are very similar between the mass timber and steel options (see bar charts on the following page). However, if end-of-life impacts (modules C2-C4) are included, Tally results indicate the mass timber bay increases acidification, eutrophication and smog formation.

For the mass timber option, including modules C2-C4 roughly doubles the acidification impact and increases eutrophication by almost seven times. Smog potential also increases for the mass timber option when Transportation (A4) and End-of-Life (C2-C4) are included. In this case smog increases by about 1.5 times above the total cradle to gate impact.

Interestingly, Tally indicates that Transportation (A4) smog emissions are more than double for the mass timber option over the steel option. These results indicate that transportation and end-of-life treatments are incredibly important for reducing environmental impacts.

IMPACT AT LOCAL VS. GLOBAL SCALE

Impacts from building materials and the locality of environmental measures vary from a small scale (local), to large scale (global) depending on the LCA category. Global Warming Potential, as the name suggests, is a global impact, whereas acidification is regional and smog formation and eutrophication are local. Local issues are controlled by the local rules and regulations. Regulations on fertilizer use could reduce eutrophication and regulations on manufacturing emissions or transportation could reduce smog formation, for example. Forestry regulations in Washington State are used to mitigate local and regional impacts as well (see Sustainable Sourcing for more discussion). Smog can create local health issues, and, while short term and local, it is of concern as it impacts local communities.

HARMONIZATION OF TIMBER + STEEL

The increase of certain impact categories outlined above for the Tally mass timber option may be related to harmonization of underlying data between steel and timber. The wood industry is based on Ecoinvent data for electricity inputs whereas the steel industry data is based on the GaBi database. The incongruence between the two databases is known to cause some differences in reporting.[19] Harmonization is an important issue that the LCA community is working hard on.

LCA Impact Categories

ACIDIFICATION

Combustion related to energy production and transportation, as well as ammonia production from agriculture, can release sulfur oxides (SOx), nitrous oxides (NOx), and NH_3 into the environment. These chemicals can change the pH of water and soil, which can lead to a decline in plant and animal life, as well as ocean health.

EUTROPHICATION

Nutrient run-off, particularly from storm-water, fertilizers and fossil fuel combustion, can lead to excessive amounts of Nitrogen (N) and Phosphorous (P) in water bodes, depleting oxygen levels and leading to algae blooms and aquatic dead zones.

GLOBAL WARMING POTENTIAL (GWP)

A metric used to compare the impact of greenhouse gases on local, regional and global surface temperatures based on how much heat they trap (greenhouse effect) and how long they remain in the atmosphere. GWP is measured relative to carbon dioxide, which is assigned a value of 1. Gases, such as methane and nitrous oxide, have a higher warming potential by factors of 25 and 298 respectively. GWP is the metric that quantifies embodied carbon.

SMOG

A major source of smog is from combustion of fossil fuels which release sulfur oxides (SOx) and nitrous oxides (NOx), creating an excess of ozone in the lower stratosphere. Smog can lead to respiratory problems, inflammation and even permanent lung damage.

ABOVE:
Mahlum Architects reused existing wood structure and repurposed other wood elements for their new office in Portland, Oregon – which is the city's first Living Building Certified project.

OTHER QUANTIFYING IMPACT RESOURCES

In addition to Tally, the team also used EPDs and material take-offs from Revit as a second approach to quantifying impacts (for modules A1-A3 only) between the mass timber and steel options.

When using EPDs from local mass timber suppliers, the impacts from acidification and smog were decreased for the mass timber option compared to Tally results. However, eutrophication impacts were larger for both the steel and mass timber options.

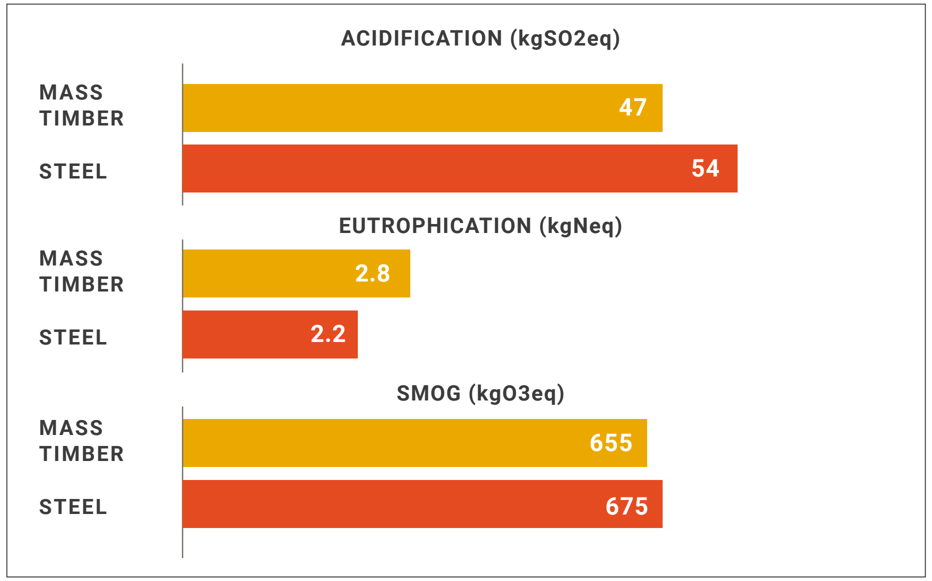
Using EPDs in lieu of Tally resulted in greater acidification and smog formation impacts for the steel option over the mass timber option. Only eutrophication was higher in the mass timber option, but the increase is relatively small overall. However, it should be noted that this method of comparing EPDs has uncertainty due to different LCA data sources, different background sources, differing levels of specificity, etc., between EPDs.

UNDERSTANDING IMPACTS

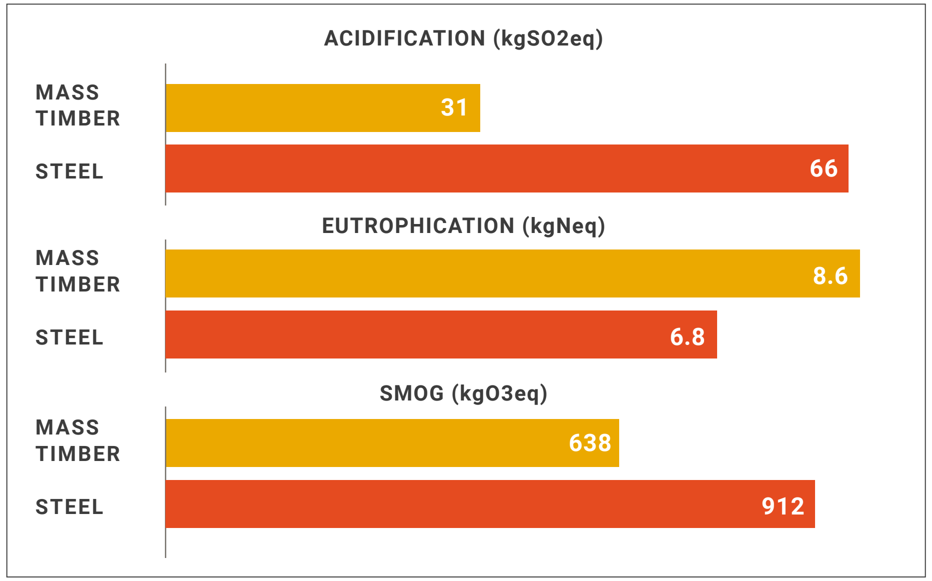
Wide flange hot rolled structural steel shapes can be continually recycled and are typically composed of over 90% recycled content. Corrugated steel decking, on the other hand, is typically produced using steel coils from both the Basic Oxygen Furnaces (BOF) and EAF process, using much less scrap, meaning that this material has a larger environmental footprint. Furthermore, recycling composite concrete and steel floor decks is typically not possible due to the complexities of separating the two materials.

The cementitious underlayment for the mass timber option has a large environmental impact for the overall volume. Finding an optimized or alternate product or floor assembly to reduce these impacts is important for future study.

Both the steel and concrete industries are actively seeking to reduce the environmental impacts of the materials they manufacture. For example, future steel production could be powered by renewable energy and concrete could be used to sequester carbon from the atmosphere. These are just two possible paths being actively developed to green these products. As material production advances and new materials come on-line, reassessing material choices for reduced environmental impacts will be essential.



ABOVE: Impact Comparisons Using Tally (Modules A1-A3)



ABOVE: Impact Comparison Using EPDs* (Modules A1-A3)

**The following EPDs were utilized for the study above:*

Mass Timber EPDs

CROSS-LAMINATED TIMBER (CLT)
Vaagen Timbers dated April 15, 2021

GLUED-LAMINATED TIMBER (GLT)
Structurlam GlulamPlus dated January 13, 2020

ACOUSTIC MAT UNDERLAYMENT
Regupol SonusWave 25mm dated July 6, 2017

CEMENTITIOUS TOPPING LAYER
USG LevelRock 3500 dated April 17, 2020

Structural Steel EPDs

WIDE FLANGE STEEL
AISC Fabricated Hot-Rolled Structural Sections dated March 31, 2016

CORRUGATED STEEL DECKING
Steel Deck Institute Steel Deck dated December 15, 2015

CONCRETE TOPPING
CalPortland EPD from Mahlum's Kellogg Middle School project, dated June 18, 2019

The use of mass timber to draw down carbon emissions is an aggressive, yet short-term strategy for pushing toward carbon neutrality by 2050.

CARBON IN CONCLUSION

The use of mass timber to draw down carbon emissions is an aggressive, yet short term strategy for pushing toward carbon neutrality by 2050. Forest management practices, design for disassembly and reuse are critically important to the viability of mass timber as a lower-carbon building material. As mass timber buildings constructed today reach their end-of-life, these wood-based building elements must be reused, refurbished and repurposed. If they are simply thrown-away, then carbon is released back into the atmosphere and more material production must fill the gap, negating (at least a portion of) the original benefit.

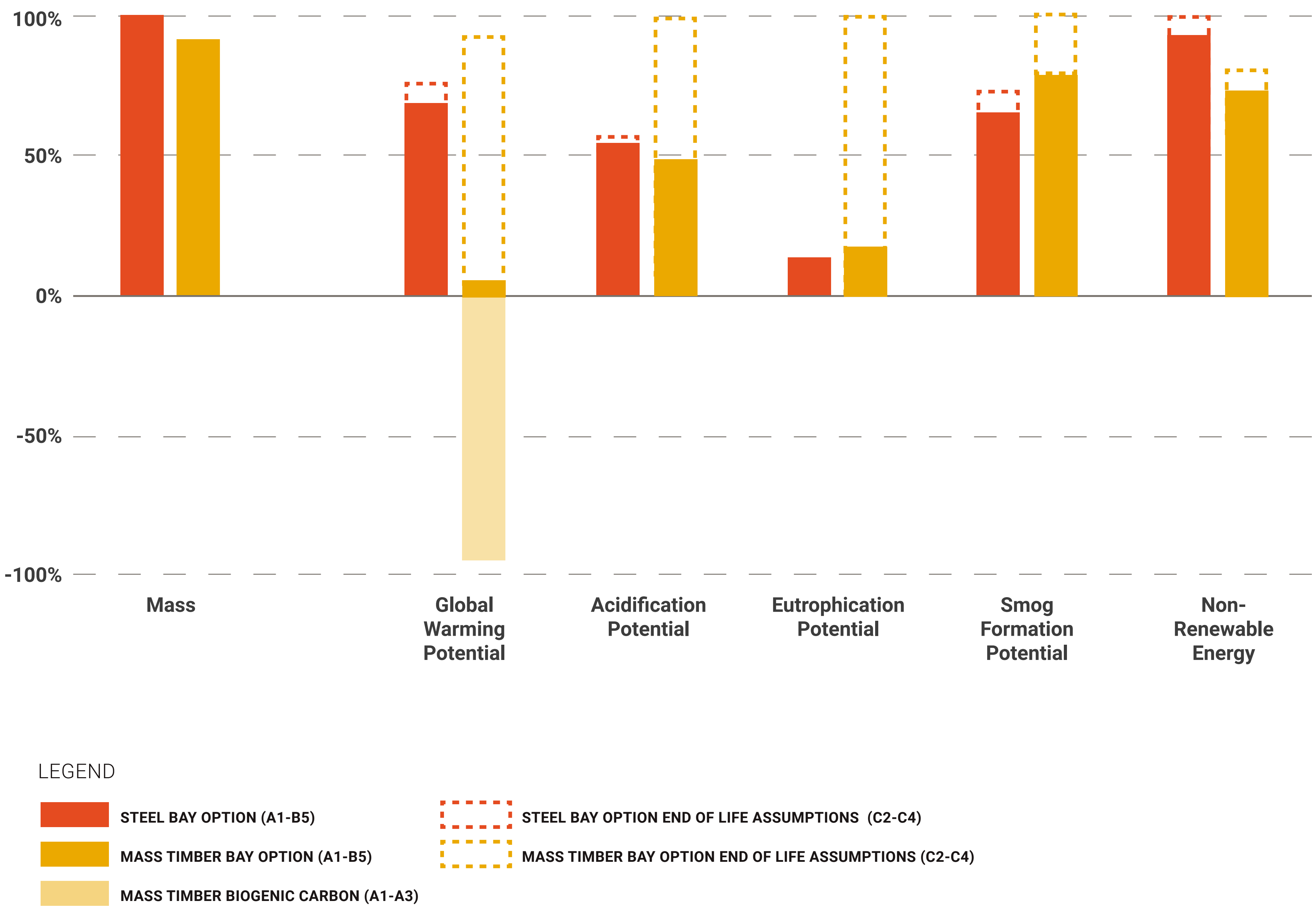
All construction materials have an environmental impact but finding and using the lowest impact materials is more imperative than it ever has been. Timber and other biogenic building materials can play a role in greening new construction.

RIGHT:
Tally Life-cycle impact (LCA) results (includes biogenic carbon), comparing the Steel Bay Option to the Mass Timber Bay Option.

Tally only accounts for 14.5% of timber elements recovered after the building's life, with the majority of wood being landfilled (63.5%) and the rest being incinerated (22%).

As the chart illustrates, a large portion of mass timber's impact is the result of these assumed end of life scenarios. However, if mass timber elements are continually reused, these negative impacts are postponed. Even if land-filled, the American Wood Council EPD for glulam notes that 84% of embodied carbon is permanently sequestered when land-filled, reducing end of life impacts shown here.

Tally also assumes that 98% of steel decking is recycled. However, this level of recycling is likely not possible using composite steel and concrete decks. Consequently, the end of life impacts for steel deck are likely higher than reported here.



SECTION 03B FOOTNOTES

FOOTNOTES

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5. http://www.carbonleadershipforum.org/2017/02/09/the-time-value-of-carbon, pg. 2
6. Bruce King, The New Carbon Architecture: Building to Cool the Climate (New Society Publishers; 2017), pg. 13
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18. Tall Wood Institute, Cross-Laminated Timber Info Fact Sheets, 2019, http://tallwoodinstitute.org/sites/twi/files/Info%20Sheets_Final_200616.pdf, pg. 31-32
19. Email exchange with Athena Institute; message titled "LCA impacts of multi-story mass timber school" to Joe Mayo, dated October 19, 2020

LIFE CYCLE ASSESSMENT MODULES (PAGE 38)

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B. Kwok, A. G., Zalusky, H., Rasmussen, L., & McKay, H. (2019). (rep.). CROSS-LAMINATED TIMBER BUILDINGS: A WBLCA CASE STUDY SERIES. Tallwood Design Institute & NetZED. Retrieved January 2021, from http://tallwoodinstitute.org/sites/twi/files/Case_Studies_Final_2.pdf

C. Note on comparing EPDs: Even if you have EPDs for two functionally equivalent products, they have likely been developed using different Product Category Rules (PCRs), using different LCAs. Direct comparison of EPDs for different products is generally not accurate or encouraged.

D. Kathrina Simonen, Life Cycle Assessment (Routledge, 2014), pg. 20-21

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SECTION 03B FOOTNOTES (CONTINUED)

BIOGENIC CARBON (PAGE 40)

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SECTION 03B IMAGE CREDITS

Page 36: Photo by **Mahlum Architects**

Page 37: Photo by **Mahlum Architects**

Page 38: Graphic adapted from **Tally LCA** reporting

Page 39: Graphics adapted from the **American Wood Council's** EPD for North American Glulam, dated April 16, 2013

Page 40: Diagram adapted with permission from **Bruce King and Frances Yang;** Photo by **Michael Gaida**

Page 41: Photo by **Benjamin Benschneider**

Page 43: Photo by **Lincoln Barbour**

Page 45: Graphic adapted from **Tally LCA** reporting

SECTION 03C

Indoor Environmental Quality

We are drawn to – and seek out – connections to nature, and our emotional wellbeing is genetically linked to the level at which we can sustain an intimate connection with the natural world. In fact, studies have shown that views into nature and natural materials can improve student performance, exemplified in the design of Riverdale Grade School.

Riverdale Grade School, Riverdale School District, Riverdale, Oregon
(Designed by Mahlum Architects)

By the time a child has graduated high school, they will have spent approximately 15,000 hours in schools and classrooms.[1]

A broad range of issues from light, temperature, air quality, ownership, flexibility, complexity, color, and access to nature all impact learning outcomes.[2] How can we improve on the quality of this time and create spaces that are optimal for learning, cognition, development, and creative thinking?

WORKING WITH NATURE

We have all experienced long, unbroken hours in the same setting. When the environment is bland and without other stimuli or activity, it is not surprising that our concentration slips away. This state is known as mental fatigue, where attention, thinking, interaction, and higher cognitive functioning is diminished. When students experience this in a classroom setting, they can mentally 'check-out'. How can design help prevent this?

HOW SPACES CAN BE RESTORATIVE AND ALSO PROMOTE LEARNING

Attention Restoration Theory (ART) holds that nature and natural objects can combat mental fatigue. For example, the rustling of leaves or flowing of water creates what has been termed "soft fascinations" that tap into a different part of the mind. Attention to the movement of clouds is effortless, allowing the mind freedom to wander and expand in different directions and with different associations. This freedom is calming and restorative. As the mind relaxes it can again gain focus and switch back to direct attention.

The presence of biophilic elements, especially in learning environments, are essential in our ability to maintain elevated levels of cognition over time.

Large windows flush with natural light, a cool breeze, the smell of pine, the patterns of wood grain, or views of trees gently bending in the distance can all provide this type of respite. The spatial environment can profoundly affect our psychological, physiological, and behavioral state.

Biophilia posits that because humans evolved with a close connection with nature – much closer than most of us have today – we are not only attracted to it, but the presence of nature sustains us physically and mentally.

Scientific experiments have demonstrated that nature can unburden the mind, reduce depression, increase healing, and excite the senses, including cognitive function.

IMAGE:
Trees harvested from the building's site were salvaged and turned into structural columns at Lakeridge Middle School, Lake Oswego School District, Lake Oswego, Oregon (Designed by Mahlum Architects)

The following section illustrates how working with nature can have a profound impact on indoor and outdoor learning environments.

BIOPHILIA AND BIOPHILIC SCHOOLS

Schools can be stressful places where social, academic, and environmental pressure influence learning. A growing body of research suggests that incorporation of biophilia into learning spaces can have dramatic effect on educational outcomes.

A recent study found biophilic elements in a classroom setting can reduce perceived stress by nearly 65 percent and boost test scores by more than three times.[3]

Well-designed classrooms have been shown to boost learning by 16 percent per year according to one study.[4] Rather than a sterile institutional feel, the use of wood and other biophilic elements can promote a more comfortable, home-like feeling where occupants are able to focus on learning.

Terrapin Bright Green recognizes fourteen patterns of Biophilic design, ranging from views to nature to natural patterns and materials or indoor-outdoor connections.[5] The presence of natural materials like wood have been shown to decrease blood pressure and improve creative performance and comfort.[6] Student stimulation through complexity, color, smells and naturalness of a space also influences learning.

Overall, incorporation of biophilic elements can lead to better test scores, learning rates, reduced stress and greater satisfaction and retention of teachers.[7]

Links between exposed wood and creativity have also been uncovered.[7] A rhythm of exposed beams, purlins and columns can create pleasing patterns and repetition in space. Tangential evidence suggests that use of wood as a finish material is less prone to damage and vandalism than other more institutional materials. While more research is needed, it may be due to our inherent attraction to exposed wood finishes and attachment we form with these materials.

Large windows with low windowsills provide direct visual connection to the outdoors and operable windows can allow seasonal scents from plants to enter. Vistas in the distance allow tired eyes focused on reading or screens to readjust to more distant objects, keeping them healthy.

DAYLIGHT

Access to daylight has been shown to support both mental and physical health. In schools, daylight assists cognitive performance, thereby boosting test scores as well as increased alertness. Daylight can also reduce absenteeism, boost our mood, and reduce energy use due to electrical lighting.[8] Too much daylighting, however, can have negative effects. Balanced daylight is critical in learning environments, reducing potential for glare and direct sunlight can be uncomfortable and negatively impact mental performance.

North glazing is optimal as it requires no shading and offers true color rendering. South glazing also offers good daylighting, but often should be shaded to reduce direct sun and thermal heat gain, which can be especially problematic in summer months, as well as periods of fall and spring. Sun shading, such as louvers or fins, can mitigate the impacts of direct sun on south, east and west building facades.

Recent studies have shown that more glazing is not always better for learning spaces. Too much glass can cause discomfort among occupants, create problems for viewing lessons and is not useful for lighting the space. One study found that classroom occupants preferred a 28 percent window-to-wall ratio to a 52 percent window-wall ratio.[9]

The Washington State Energy Code has a prescriptive limit of 30 percent window-to-wall ratio, which is the ratio utilized for this project – creating a balance between windows, daylight, views, and opaque high-performance walls for reduced energy use. Because the design of this project utilizes non-bearing exterior walls, there is great freedom in locating windows and adjusting their size so they will have the best impact. Tall widows deliver light deeper into classroom spaces and windows adjacent to walls can help bounce light for more even distribution of daylighting within the space.

Ultimately, biophilic design should promote more meaningful balance, interaction, and restoration of nature. Establishing a love of nature early will not only assist learning but establish principles of environmental stewardship that can last a lifetime.

INDOOR AIR QUALITY

With many of us spending around 90 percent of our time inside, indoor air quality is extremely important and has a direct impact on health and well-being. Providing adequate ventilation reduces carbon dioxide (CO2) concentrations and volatile organic compounds (VOCs) in interior spaces. This can be done through mechanical ventilation, passive ventilation with operable windows, or a combination of both. Research has shown that cognitive function is impaired at CO2 concentrations above 600ppm, yet many schools routinely test with higher concentrations than this. Increasing ventilation while also choosing interior products and finishes that are low or no emitting of VOCs improves indoor air quality. Improved indoor air quality fosters better academic performance, reduces absenteeism, and can make users generally happier.[10] A growing body of research is also discovering that delivering fresh, outdoor air can provide beneficial microorganisms that promote health.[11]

ABOVE: Biophilic elements in a classroom at Riverdale Grade School by Mahlum. Views to nature and presence of biolphilic patterns can benefit concentration and learning.

Wood also has hypoallergenic properties that make it ideal for schools. Research has demonstrated that wood possesses natural antimicrobial properties and is comparable hygienically to plastic, glass, and steel. Wood surfaces, due to the natural porosity of the material, can desiccate harmful microorganisms and suck them into the wood's pores and deprive them of oxygen. Natural extractives in the wood, which protect living trees from microbial, fungal and insect attack, can also kill unwanted microbes.

The porous structure of wood makes it a natural anti-microbial surface. A recent study found that virus and bacterial landing on pine surfaces were rendered inactive much quicker than other surfaces like plastic and metal.[12]

Counter to popular perception, wood does not lead to more transfer of bacteria than other surfaces[13], and in fact may lead to less.

VOCs + Formaldehyde

Volatile Organic Compounds (VOCs) are a family of chemical compounds that vaporize or become a gas at room temperature. VOCs have come under increased scrutiny for building products used in interior environments as they can lead to poor indoor air quality and potential negative reactions in occupants.

As a result, architects, designers and building owners now seek low-VOC or zero VOC products to ensure optimal interior air quality. Children are especially susceptible to VOC because their lungs are still in development. Therefore, focusing on VOC for schools is critical to a student's long-term development and success.

Formaldehyde is a well-known VOC present naturally in wood and found in certain adhesives used in structural engineered timber components. The use of formaldehyde in engineered wood products have been a studied at least since the 1960s and 70s but came under increasing scrutiny for health and occupational safety in the 1980s when elevated levels were detected in pressed wood products like particle board (PB) and medium density fiberboard (MDF). The undesirable off-gassing of these wood products lead to the creation of voluntary standards regarding formaldehyde.

Formaldehyde is a colorless, reactive, strong-smelling gas at room temperature. It is present in the natural environment at low levels -- typically less than 0.03 parts per million (ppm) -- and found in fruits, vegetables, human breath, and generated by combustion of fossil fuels, smoking and cooking. Naturally occurring in wood, formaldehyde can be formed from the main components of wood -- cellulose, hemicellulose, and lignin -- as well as from its extractives.[A] The human body readily breaks-down low levels of formaldehyde found in everyday environments.[B] Elevated exposures, however, could lead to adverse health effects.

IMAGE: Lacamas Lake Elementary School by Mahlum. The presence of wood creates a calming and healthy environment for both quiet learning and group activities.

In the past, concern for formaldehyde-related problems was largely associated with urea formaldehyde (UF) adhesives used in cores for interior casework items. UF adhesives are not water resistant, so they are only applicable for interior, non-structural use. Prior to air quality standards, extra formaldehyde was often used to produce fast-setting adhesives. This use of excess adhesive, however, led to unreacted formaldehyde during curing and resulted in significant, problematic emissions.[C] UF adhesives can continue to release significant levels of formaldehyde after the resin has cured, especially under high heat and humidity conditions.

Unlike UF adhesives, phenol-based adhesives, due to their low formaldehyde emission levels, have been of less concern. PF, PRF and MF are examples of adhesives that do not chemically break-down, thus little to no formaldehyde is detectable once the products are cured and in-service.[D] These are the types of adhesives used in structural, engineered wood components, like CLT and glued laminated timber. In additional, many mass timber manufacturers use formaldehyde-free adhesives, such as polyurethane (PUR) adhesives.

Due to the low levels of formaldehyde present in these elements, engineered wood products are often not covered or are specifically exempt from regulations. **Structural engineered wood products, like GLT and CLT, are exempt from California Air Resources Board (CARB) and the Environmental Protection Agency's (EPA's) TSCA Title IV standards because of the historical low levels of tested formaldehyde emissions.** CARB began regulating formaldehyde levels in 2007, and under Phase II levels range from 0.05 ppm to 0.11 ppm for interior, non-structural use items, depending on the product. Formaldehyde levels (and acetaldehyde) in engineered wood products naturally decrease over time.

The CLT Handbook outlines VOC testing of five samples of CLT of varying thicknesses that were manufactured using polyurethane (PUR) adhesive. The amount of formaldehyde found in the samples of CLT varied from 5 to 16 parts per billion (ppb); 0.005 ppm to 0.016 ppm.[E] These levels are far lower than the most stringent CARB requirements for composite wood products.

FORMALDEHYDE EMISSIONS

PRODUCT	CARB EMISSIONS STANDARD
Hardwood Plywood (non-structural)	0.05 ppm
	EMISSION TEST RESULTS[B]
Structural Plywood	0.01-0.04 ppm

NOTE: Structural engineered wood products are typically exempt from formaldehyde testing due to their historic low emission rates. However, testing validates that these products are very low emitters. CARB stands for California Air Resources Board and is referenced by LEED as a standard for VOC limits in composite wood products.

In addition, wood can buffer interior humidity – taking in moisture when humidity is high and breathing moisture out when humidity is low. This type of moisture buffering also contributes to a healthy interior environment. Wood will maintain its hygienic properties until moisture saturation, which will not occur in conditioned indoor environments, even at pools or other structures with high ambient moisture.

THERMAL COMFORT

The air temperature, as well as radiant temperature, air speed and humidity, can have a profound impact on an occupant's psychological state. Temperatures that are too high can cause metal fatigue, anxiety and decreased performance as attention spans deteriorate due to physical discomfort.[14]

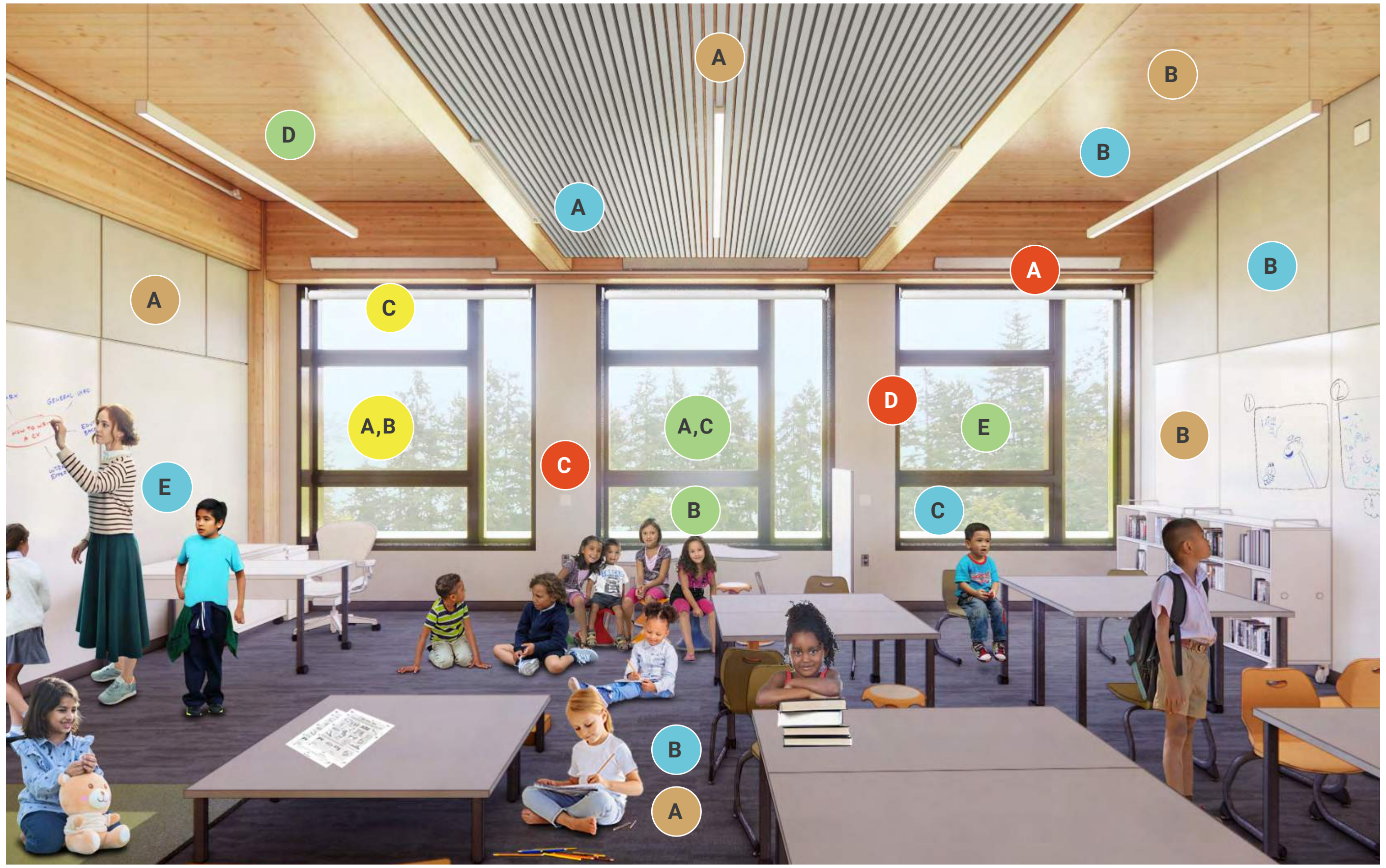
High performance learning spaces can maintain comfortable interior environment through several different strategies employed in this design. Providing partial cooling through the mechanical system can keep interior temperatures comfortable for most of the year. Incorporating natural ventilation and ceiling fans extend the wider range of thermal comfort for occupants while minimizing energy use. Thermally efficient exterior windows, walls and roofs greatly reduce the need for heating in the winter, while proper orientation and solar shading minimizes the effects of thermal gain in the summer. Harnessing natural stack ventilation for passive cooling assists thermal comfort while again reducing energy use.

Finally, providing individual thermostat controls and operable windows in each classroom afford teachers and students control over their environment to maintain optimal learning conditions. See the Mechanical Approach section for more information on passive ventilation and cooling.

Cold or hot surfaces, like poorly performing exterior windows and walls, radiate temperature extremes and can be uncomfortable to occupants near them. Consequently, occupants can feel chilled or overheated and this discomfort negatively impacts metal performance and productivity. Utilizing thermally efficient walls with high levels of insulation and air sealing can eliminate this issue. The use of double or triple pane windows that have thermal breaks and utilize non-conductive framing (like wood or fiberglass) will also improve thermal comfort while lowering energy usage at the same time.

A post and beam structural system removes the need of load-bearing walls at the perimeter of the building, thereby allowing placement of large operable windows virtually anywhere. Keeping a narrow footprint also improves natural ventilation and generous floor to floor heights allows easy routing of ventilation ducting and can mitigate against stale air in the short term.[15]

The use of wood, in combination with the other strategies discussed in this section, can create an ideal environment for exploration, learning and growth.



ABOVE: Design of a typical classroom window wall showing strategies for improved indoor environmental quality.

4. INDOOR AIR QUALITY*

A. Increased Mechanical Ventilation
B. Low-To-No VOC Emitting Materials
C. Natural Ventilation
E. User Controls

> Lower CO2 and VOCs
> Decrease in asthma, allergies and irritants
> Reduced Communicable Disease
> Improved Cognitive Function
> Improved Concentration and Focus
> Reduced Communicable Disease
> Improved academic performance

*See Mechanical Approach Section for more information

1. BIOPHILIA

A. Visual Connection with Nature
B. Thermal & Airflow Variability
C. Dynamic & Diffuse Light
D. Material Connection with Nature
E. Prospect

> Improved Concentration
> Attentions restoration
> Reduced Stress
> Improved academic performance

2. DAYLIGHT

A. Balanced light
B. Windows/Shading Adapted to Orientation
C. User Controls

> Alertness
> Circadian Rhythms
> Improved Concentration and Focus
> Improved academic performance

3. THERMAL COMFORT

A. Cove Heaters
B. Ceiling Fans (not in view)
C. User Controls
D. Hi-Performance Windows and Exterior Walls

> Concentration
> Attentions restoration
> Reduced Stress
> Improved academic performance

5. ACOUSTICAL CONTROL*

A. Sound absorbing surfaces
B. Acoustic Privacy Between Spaces

> Improved Hearing and Comprehension
> Improved Memory
> Reduced Stress
> Improved academic performance

*See Acoustics Section for more information

SECTION 03C FOOTNOTES

FOOTNOTES

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SECTION 03C FOOTNOTES (CONTINUED)

VOCS + FORMALDEHYDE (PAGE 51)

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SECTION 03C IMAGE CREDITS

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SECTION 03D

Acoustics

Designed to stringent acoustical standards, the K-12 prototype design demonstrates how exemplary acoustical performance and exposed CLT can co-exist.

K-12 Mass Timber Prototype
(Designed by Mahlum Architects)

Acoustics are critical – teachers and students need to be able to understand each other without straining voices or ears.

Space	Adjacency	Minimum STC Rating Required for Single or Composite Wall and Floor-Ceiling Assemblies	Minimum IIC Rating Required for Floor-Ceiling Assemblies Separating a Core Learning Space (below) from an Adjacent Space (above)
Core Learning Space	Core Learning Space	50	45 (Applies without carpeting)
	Restroom	53	45 (Applies without carpeting)
	Office, Conference Room	45 (50 if "acoustic privacy" required)	45 (Applies without carpeting)
	Corridor, Stairs	45	45 (Applies without carpeting)
	Music Room, Music Performance Space, Auditorium, Mechanical Room, Cafeteria, Gymnasium, Indoor Pool	60	45 (Applies without carpeting)
	Spaces with High-Impact Activity (e.g. Gym, Dance Studio)	60	65-70 (Applies without carpeting)

Schools need an acoustic environment that promotes focus and learning by providing clear intelligible speech communication and minimizing distraction from noise intrusion (both from the exterior environment and adjacent interior spaces).

Studies have shown that acoustics impact children's cognition. Poor acoustic environments such as poorly isolated spaces (increased auditory distraction) or highly reverberant spaces (decreased speech intelligibility) are likely to impair focus and communication, frustrating both teachers and students alike.[1]

Complex tasks that require dedicated focus are known to suffer more than simple tasks, making activities like math and writing more challenging.[2] Additionally, as students age, they are more likely to be impacted by poor acoustics; children aged around 11 years and older have been found to be more sensitive to acoustic distraction than younger children.[3]

For acoustic performance of educational K-12 spaces, sound control is defined by the following two standards: **Washington State Sustainable Schools Protocol (WSSP)** which references Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools (ANSI S12.60-2010), and **Washington Administrative Code WAC** 246-366-110 'Sound Control.'

Larger schools that receive public funding in Washington State are required to meet WSSP requirements and all new classroom construction must conform to WAC standards. If LEED certification is pursued, acoustic credits also align with the ANSI S12.60-2010 standard.

The above standards define acoustic criteria for two distinct types of spaces:

> Core learning spaces, in which the primary functions of the space are teaching/learning, (i.e. enclosed or open plan classrooms, instructional pods, libraries, instructional or practice music rooms)

> Auxiliary/Ancillary learning spaces, in which the primary functions of the space are informal learning or social interactions (i.e. common areas, break-out spaces corridors, cafeterias, gyms)

Note that the standards do not apply to modular/temporary classrooms, auditoria, teleconferencing, or special education spaces.

Key requirements to control the acoustic environment within core learning spaces per the standards include:

> Background noise levels generated from HVAC or other mechanical noise sources cannot exceed NC 35 in unoccupied core learning spaces.

> Overall noise levels from all sources of environmental, interior, and ventilation equipment noise cannot exceed 45 dB(A) at any student location within an unoccupied core learning space.

> Maximum reverberation time (RT) of 0.6-seconds for core learning spaces 10,000 cubic feet or less.

> Maximum reverberation time (RT) of 0.7-seconds for core learning spaces greater than 10,000 but less than 20,000 cubic feet.

It is recommended based on experience and best practices that in addition to the guidance above, core learning spaces and auxiliary/ancillary learning spaces should aim to achieve a background noise level no higher than NC 30 and NC 35 respectively.

Learning spaces for this project have been designed to meet these more stringent NC levels.

In addition to controlling the background and reverberance within core learning spaces, the standards reference the following minimum STC and IIC performance to ensure acoustic isolation between learning spaces (*see chart above*).

ACOUSTICS AND MASS TIMBER

When using mass timber there is typically a strong desire to leave the structural timber elements exposed. The wood surfaces can be attractive and biophilic. Leaving them exposed is also efficient since the elements can function as both structure and architectural finish. This strategy can eliminate interior finish materials, reduce costs, and save time. However, **leaving a fully exposed mass timber structure can create challenges for interior acoustics since the ceiling plane is the primary surface for sound absorbing finishes required to meet the reverberation time criteria.**

Wood surfaces are hard, so they reflect sound rather than absorbing it. As sound bounces-off hard surfaces in a room, late reflections reduce speech intelligibility and can lead to annoyance or even performance and cognition problems. Providing sound absorbing materials on walls and ceilings, such as acoustical panels, lowers reverberation time and improves speech intelligibility when compared to solid wood surfaces alone. Materials with a high Noise Reduction Coefficient (NRC) can absorb sound, reduce reverberation time (RT), and thereby contribute to better room acoustics. Studies indicate that both teachers and students perform better in classrooms with short reverberation times than in classrooms with long reverberation times.[4]

How sound is reflected or absorbed within a room is one measure of acoustic performance. Another key consideration is how easily sound is transferred through walls and floors. The acoustic performance of floor and wall assemblies is typically measured by two metrics: Sound Transmission Class (STC) and Impact Insulation Class (IIC) - see *Acoustic Terminology* on page 60.

Mass timber elements are lighter weight (ie. less mass) than concrete construction. A paper published by WoodWorks notes how a 6-inch concrete slab weighs approximately 80 pounds per square foot while a nearly 7-inch (5-ply) thick CLT panel weighs about 18 pounds per square foot.[5] While lighter weight construction has advantages for lifting, construction speed, reduced foundations and lower embodied carbon, it does not perform as well acoustically. A common solution to improve airborne sound separation (STC) is to add mass to lighter weight assemblies, which can be accomplished by increasing the thickness of a partition buildup by installing extra layers of materials. For walls this might mean additional layers of gypsum wall board, whereas for floors this might mean a cementitious topping layer.

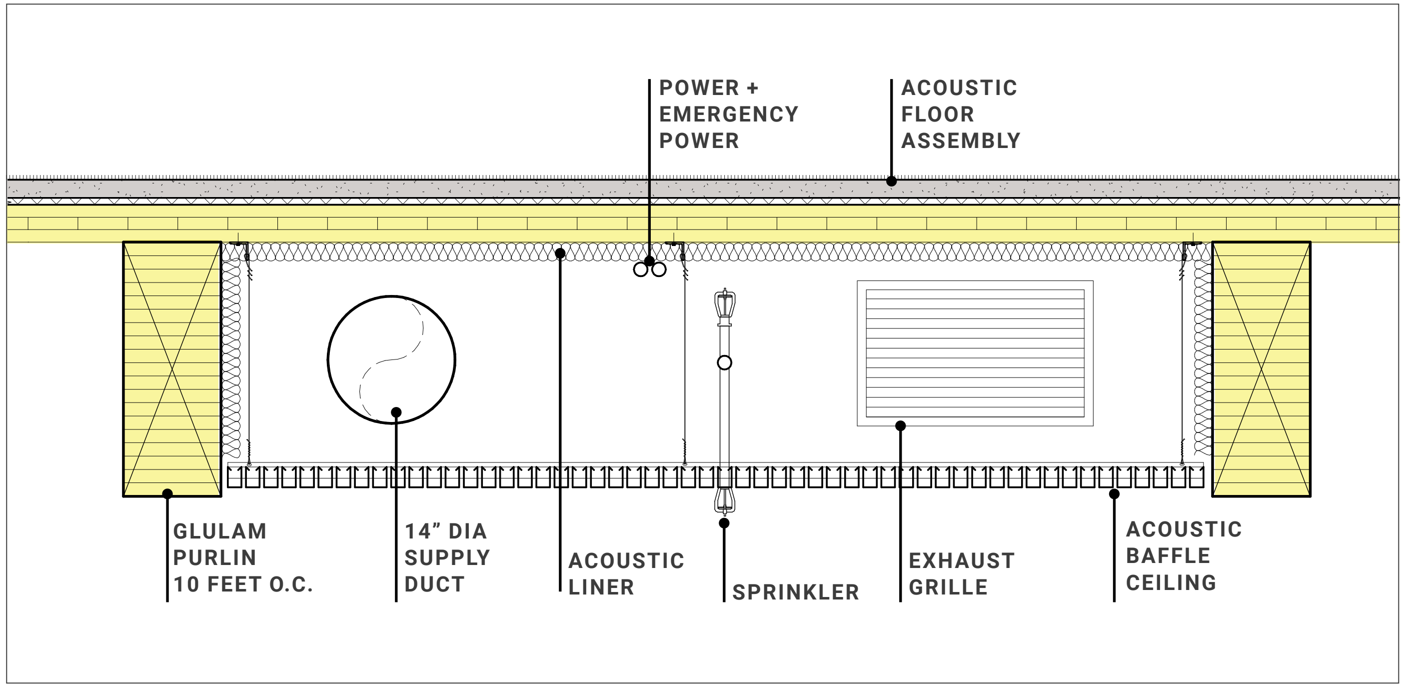
In order to improve impact sound separation (IIC), floor-ceiling assemblies must strategically decouple the sound isolating layers. One common approach is to use an acoustic underlayment, soft floor finishes such as carpet, or resilient channels for wall and ceiling assemblies that contain gypsum wall board.

From a design, cost and constructability standpoint, there are several considerations to be balanced. Generally speaking, utilizing acoustic assemblies that have the fewest number of low-cost-high-impact components result in lower cost, faster construction and reduced embodied carbon impacts. Below is a discussion of the acoustic assemblies selected for this project.

ACOUSTICAL DESIGN FOR MASS TIMBER LEARNING ENVIRONMENTS

A primary goal of this project is to expose as much mass timber as possible, while maintaining the acoustic performance requirements. To meet acoustic performance criteria, learning spaces utilize sound-absorbing finishes such as acoustical wall paneling, ceiling treatments and carpeting.

In the project typical classroom (900 – 999 sf), a minimum of 660sf of absorptive treatment is required to meet the requisite 0.6-second RT for core learning spaces, excluding carpeting. Per ANSI standards, the maximum permitted RT of 0.6s must be achieved at each midband frequency (500, 1kHz, and 2kHz) which align with typical speech frequencies. Adding absorptive flooring (i.e. carpeting) will improve room acoustics in the typical classroom at the 1kHz and 2kHz octave bands, but is not expected to provide sufficient absorption in lower frequencies (including 500Hz). Due to anticipated learning surfaces (i.e. whiteboards/screens), glazing areas, and a desire to protect low-hanging absorptive paneling from damage, there is limited available wall surface in the typical classroom.



ABOVE: Section through acoustical suspended ceiling assembly

ABOVE: Typical classroom showing distribution of acoustical finishes

For acoustic wall paneling, a 1” thick FSorb panel (NRC 0.70) is assumed as the basis of design. For reference, a 2” thick FSorb panel (NRC 1.00) type provides a similar level of absorption as a typical ACT ceiling in the critical frequency bands.

Due to the space constraints, the remaining area of sound absorbing finishes must be applied on the ceiling plane. As the design team’s primary goal was to highlight and expose the mass timber construction, the acoustic ceiling treatment was consolidated into a space-efficient approach of a suspended acoustic baffle system (Basis of Design: Heartfelt, NRC 0.67), with the ceiling area above lined with a 2” 5pcf black acoustic insulation (see detail section drawing on page 57).

With this approach, a typical 3-bay classroom requires only one bay (approx. 1/3 of ceiling area) of absorptive treatment, leaving two bays of the CLT ceiling exposed to view. Some classrooms have a portion of ACT ceiling (NRC 0.8, see reflected ceiling plan on following page), and these rooms required less additional treatment using the acoustic baffle and liner approach.

DOWEL-LAMINATED TIMBER (DLT)

Dowel-Laminated Timber (DLT) is a proprietary product that was also studied. When DLT is manufactured with integral inset sound absorbing material it can perform as both a sound absorbing material and structure. In this case, use of acoustic DLT eliminated the need for any additional sound absorbing finishes in classrooms.

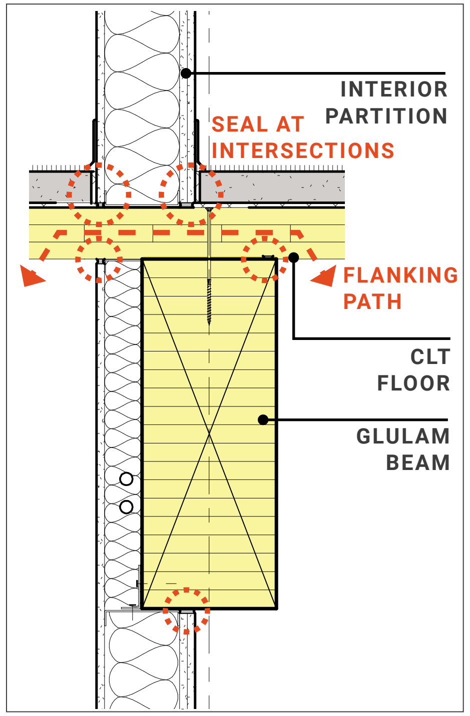
An exposed DLT ceiling alone can provide all the necessary acoustic mitigation needed to meet State requirements. However, DLT performance as a partition element has lower STC and IIC performance, so additional layers or layer thickness would need to be added for floor-to-floor sound transfer. DLT was not chosen as the primary horizontal material for the project because CLT has performance benefits structurally in large, open space designs (see DLT informational box below).

DROPPED ACT CEILING

In small meeting rooms and conference rooms a dropped ACT ceiling (minimum NRC 0.8) is recommended. If wall absorption is also used over the equivalent of one wall area, the ceiling ACT may be reduced to NRC 0.7.

Note that there is risk of flanking transmission between classroom demising walls (through CLT) given that the classroom ceiling design does not include a continuous dropped ceiling. A continuous dropped ceiling covers the top intersection between wall and floor/ceiling, thereby providing additional acoustic sound separation protections at the weak point where sound is more prone to transfer over the top of wall (i.e. flanking path).

Adequate sealing is recommended between the top of wall and ceiling, and likely mass timber panel joint/spline to mitigate this sound flanking path. Additional research is needed to better understand how much “flanking sound” is propagated over the demising partition through the relatively lightweight CLT (even with a properly sealed head track condition).



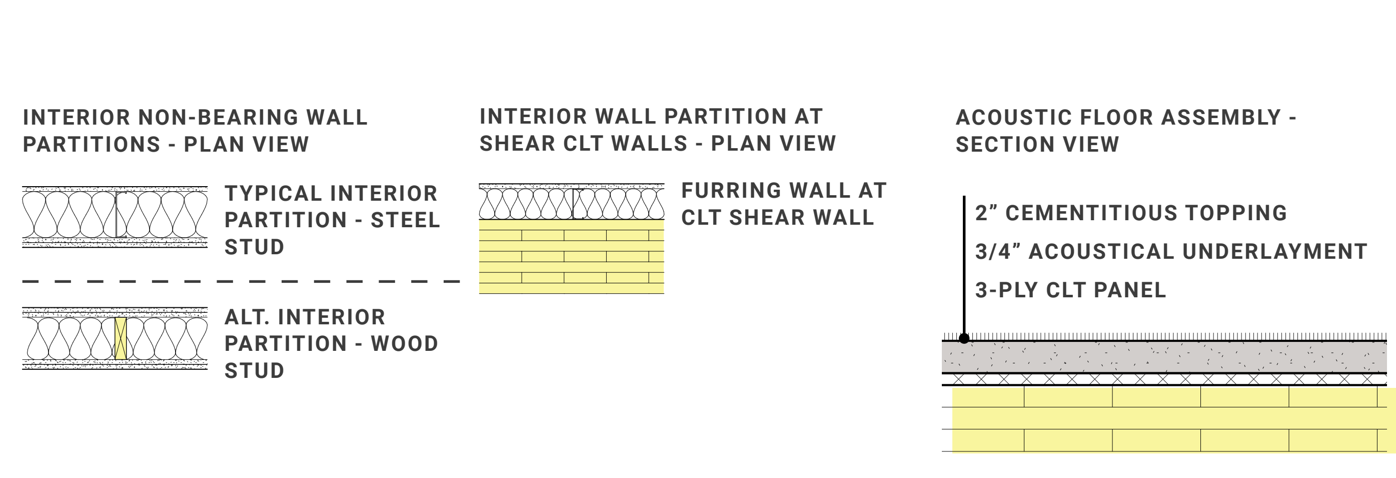
LEFT:
Section detail at CLT floor and interior partition. Sealing at intersections between mass timber and other elements is critical to prevent flanking transmission. A better understanding flanking transmission in mass timber buildings with exposed structural elements is needed.

IMAGE: Acoustic DLT at the manufacturing facility for Kellogg Middle School, Shoreline School District, Shoreline, Washington (Designed by Mahlum Architects)

Acoustic Dowel-Laminated Timber (DLT)

Some mass timber elements can be used for both structure and acoustical surface.

Existing dowel-laminated timber test reports indicate the material is capable of achieving up to NRC 0.7, which is significantly more absorptive than CLT or similar wood finishes. During manufacturing the exposed DLT surface can have narrow channels routed through the wood structure. These channels are then filled with an acoustical insulation that serves to absorb sound. Structurally, DLT spans in a single direction with good span characteristics. DLT does not have inherent shear strength and depends on a layer of structural sheathing, such as plywood or OSB, to transfer diaphragm forces to shear walls or other lateral elements. Thin layers of sheathing do not have the same structural capacity as CLT, which can limit the use of DLT in wide-open spaces with few interior walls. At the time of this report, there is only one manufacturer of DLT, making competitive bids on this product challenging. Nevertheless, DLT is an important mass timber structural element that should be studied during design to determine if it meets project needs.



ABOVE: Reflected ceiling plan showing extent of exposed CLT ceilings

ACOUSTICAL PARTITION WALLS

A primary goal of the Wood Innovation Grants is to find new markets for wood products. With this in mind, the design team first assumed non-bearing interior acoustic partitions walls would be 2x6 wood framed. Per ANSI/ASA S12.60, walls separating core learning spaces should have a minimum Sound Transmission Class (STC) of 50.

To meet STC 50, two possible assemblies were optioned:

> Light wood framed interior partitions framed on 6" studs, 24-inches on-center with two layers of gypsum wall board on both sides (total 4 layers of GWB), with 3.5". (2-3psf) mineral wool insulation.

> Steel stud (3-5/8") framed interior partitions framed 24in. on-center with two layers of gypsum wall board on one side, one layer on opposite side (total 3 layers of GWB), with 3.5". (2-3psf) mineral wool insulation.

A staggered stud light wood framed wall with 2x4 studs on a 2x6 plate could be another option, but was not studied for this report.

24" stud spacing provides better acoustic performance than studs spaced 16" on-center. Because interior walls are non-load bearing, increasing the stud spacing to 24-inches is not expected to be an issue.

The steel framing strategy which requires less gypsum wall board than wood framing, represents a large time and cost savings. In addition, the design team used Tally to analyze the embodied carbon impacts between the wood and steel STC-50 assemblies and found that the steel acoustic wall assembly was slightly superior to wood, even when accounting for biogenic carbon in the wood framed assembly. This is primarily due to less gypsum board in the steel wall assembly. Light framed steel walls have other advantages in that they are lighter than wood walls, often straighter and come with perforated tabs to easily run conduit through the framing. With these considerations in mind, the design team selected light gauge steel framing (25 gauge) for all non-load bearing interior partition walls.

At areas where an acoustic CLT wall partition is required, an additional furred wall is added to one side of the CLT wall panel. The assembly is based on testing conducted by Maxxon and SmartLam.[6] The tested wall assembly used a 5-ply (6.875") CLT wall panel with 2 x 4 furring, batt insulation and 5/8" gypsum wall board finish. This assembly is expected to meet STC 49 per test reports. The assembly used for this project is a 7-ply CLT wall panel with 4" light gauge steel furring, acoustic batt insulation and 5/8" gypsum wall board cladding. Because the proposed assembly has more mass and utilizes steel instead of wood framing, it is predicted to meet STC 50. The use of a furred wall also allows space for conduit and wall boxes to be located.

As noted previously regarding flanking issues, the intersection of different materials (i.e. framed wall intersecting a column or beam) should be acoustically sealed (using airtight and non-hardening sealant) to prevent sound transmission and flanking potential.

FLOOR/CEILING ASSEMBLY

To meet WA state acoustic requirements for acoustic transmission between vertically adjacent core learning spaces, vertical assemblies (i.e. floors and ceilings) must meet STC 50 and IIC 45. A common approach to provide this level of acoustic performance while allowing the underside of the CLT deck to remain exposed is adding additional layers on the top side of the CLT floor deck; this approach has been tested in multiple configurations with a wide variety of acoustic mat underlayment and cementitious topping layers. The following assemblies were identified to meet acoustic performance requirements:

> 3-ply CLT panel (4.125" thick, 9.7 psf) + 3/8" resilient underlayment (Pliteq FF10 Geniemat as basis of design) + 2.5" gypsum-based topping (21.8 psf) + carpet tile

> **3-ply CLT panel (4.125" thick, 9.7 psf) + 3/4" resilient underlayment (Pliteq FF20 Geniemat as basis of design) + 2" gypsum-based topping (17.5 psf) + carpet tile**

A 2" gypsum-based topping layer is a more typical installation than a 2.5" topping layer and the former also dries faster, speeding up construction times. The two assemblies are comparable in cost. **Because of the reasons above, the design team opted for the second option using a 2" gypsum-based topping over a 3/4" acoustic mat underlayment.**

At entries, corridors and other locations, a resilient flooring (such as linoleum) is often more desirable than carpet for easy cleaning and maintenance. In this case the carpet layer in the floor assembly noted above can be changed to resilient flooring (a ~2mm thick product) as long as the flooring has a minimum 3.5mm thick foam backing (such as Marmoleum Decibel resilient flooring with foam backing). If a resilient product with a foam backing cannot be specified, then the acoustical underlayment should be increased to 1" thick in lieu of 3/4" thick.

In this project, the gypsum-based topping layers noted above may alternatively consist of concrete of the same thickness. Regardless of whether gypsum-based topping or concrete topping is used, the buildups will still require an acoustical underlayment of the same thickness noted previously. Email correspondence with the USG Corp. indicated that use of gypsum-based topping in lieu concrete could reduce embodied carbon emissions for identical thickness.[7]

ABOVE: Example of acoustic wall paneling at Capitol Childcare Center in Olympia, Washington (Designed by Mahlum Architects)

An early design concept to maximize the visibility of mass timber ceiling elements was to recess conduit/power into the floor's cementitious topping layer in order to avoid exposed conduits at the CLT ceilings. However, installed precedents of this approach are limited and the possibility of recessed electrical boxes short circuiting the acoustical assembly (as flanking path) could not be practically addressed. Additionally, recessing conduit would reduce opportunities for future flexibility. As such, the design team chose not to pursue this option. See the Electrical Approach section for additional information on power and data distribution.

Steel runner tracks for the base of interior acoustic wall partitions require special attention. To allow easy renovation and movement of interior walls, having the base runner track installed directly above the floor's cementitious topping layer is preferred. From an acoustic perspective, however, this track introduces a horizontal flanking if there is no acoustic break/ discontinuity at the partition between spaces. To limit this flanking risk, an acoustic break at the front side of the runner track is strongly recommended, especially if utilizing a light-weight gypsum-based topping. Additionally, fastening a runner track though the gypsum-based topping layer could create cracking and short circuit the underlayment layer, decreasing the acoustical performance of the assembly, and is not recommended.

A more common approach is to install the runner track directly above the CLT deck. This approach does not permit walls to be moved as easily and requires wall framing and gypsum wall board to be installed prior to pouring the gypsum-based topping. Heavy equipment is known to crack these types of topping layers, so typically it would be installed after overhead work is completed and heavy equipment will no longer be moved over top. Utilizing concrete in lieu of a gypsum-based topping allows less concern for attaching runner tracks directly to the slab. Cracking from heavy equipment is also less of a concern with concrete than with gypsum-based topping.

Common Acoustic Terminology

Decibel (dB)
A measurement of the intensity of sound. The ratio of sound pressures which we can hear is a ratio of 106:1 (one million:one). For convenience, therefore, a logarithmic measurement scale is used. The resulting parameter is called the 'sound pressure level' (Lp) and the associated measurement unit is the decibel (dB). As the decibel is a logarithmic ratio, the laws of logarithmic addition and subtraction apply.

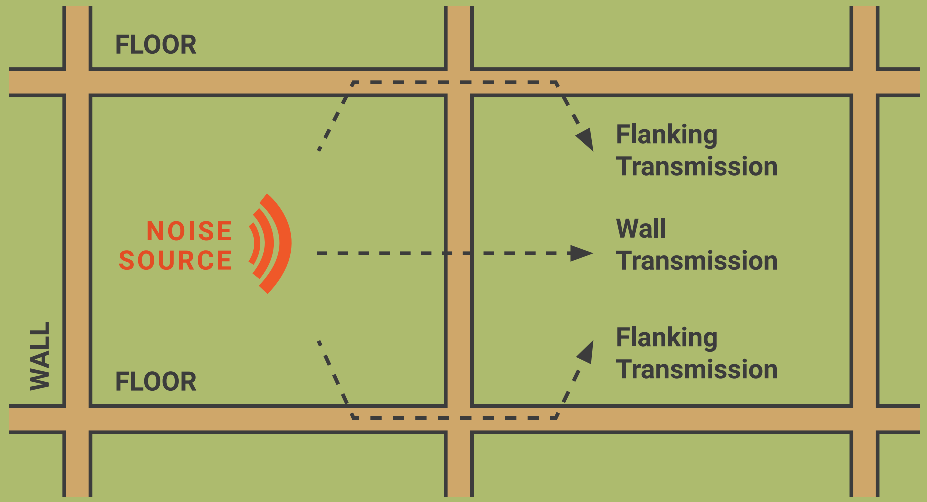
Flanking Transmission
Any sound transmission path passing around, over or under partitions separating two spaces, causing a partition to have a lower sound transmission class (STC) than the partition structure.

Impact Insulation Class (IIC)
The impact sound insulation of floors is evaluated by measuring the sound pressure level in the receiving room resulting from a standard tapping machine placed on the floor of the source room. The measured values, in each of the third-octave bands from 100Hz to 3150Hz, are adjusted to allow for the acoustic of the receiving room and compared with a standard reference curve, in accordance with the procedure defined in ASTM E989 to obtain the single figure weighted standardized impact isolation class, IIC.

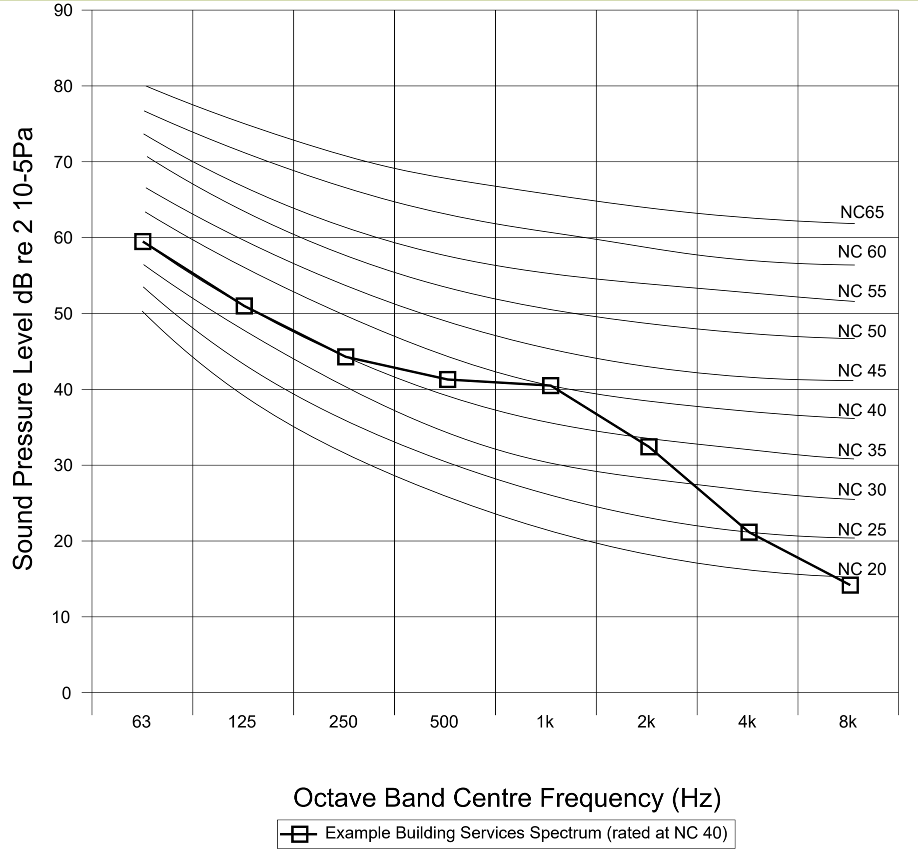
Room Reverberation Time (RT) –
he time in seconds taken for a sound within a space to decay by 60dB after the sound source has stopped. The RT is an important indicator of the subjective acoustic within a space.

Sound Transmission Class (STC)
The sound reduction index, or transmission loss, of a building element is a measure of the loss of sound through the material (i.e. its attenuation properties). It is a property of the component, unlike the sound level difference which is affected by the common area between the rooms and the acoustic of the receiving room. The weighted sound transmission class, STC, is a single figure description which is defined in ASTM E413. The STC is calculated from measurements in an acoustic laboratory.

Noise Criteria (NC)
NC is a curve defined by sound pressure level (dB) along a set of octave bands (Hz). The curves are commonly used to define building services noise limits. The NC value of a noise is obtained by plotting the octave band spectrum on the set of standard curves. The highest value curve which is reached by the spectrum is the NC value. Shown below is an example plant noise spectrum that is equivalent to NC40.



ABOVE: Section diagram showing examples of noise transmission paths



ABOVE: Noise Criterion (NC) Curves with example noise level spectrum

OCCUPIED ROOF AND PENTHOUSE ASSEMBLIES

An occupied roof is proposed above core learning spaces in this design. From an acoustic standpoint, there is a lack of available test data to accurately predict sound transfer through the raised access paver system above the insulated CLT roof deck assembly to interior spaces below. If occupied, the roof assembly is interpreted to require the same STC and IIC performance as the typical core learning space floor-ceiling assembly. As in the floor assembly, the roof then also requires the addition of extra mass and decoupling layer to meet performance standards.

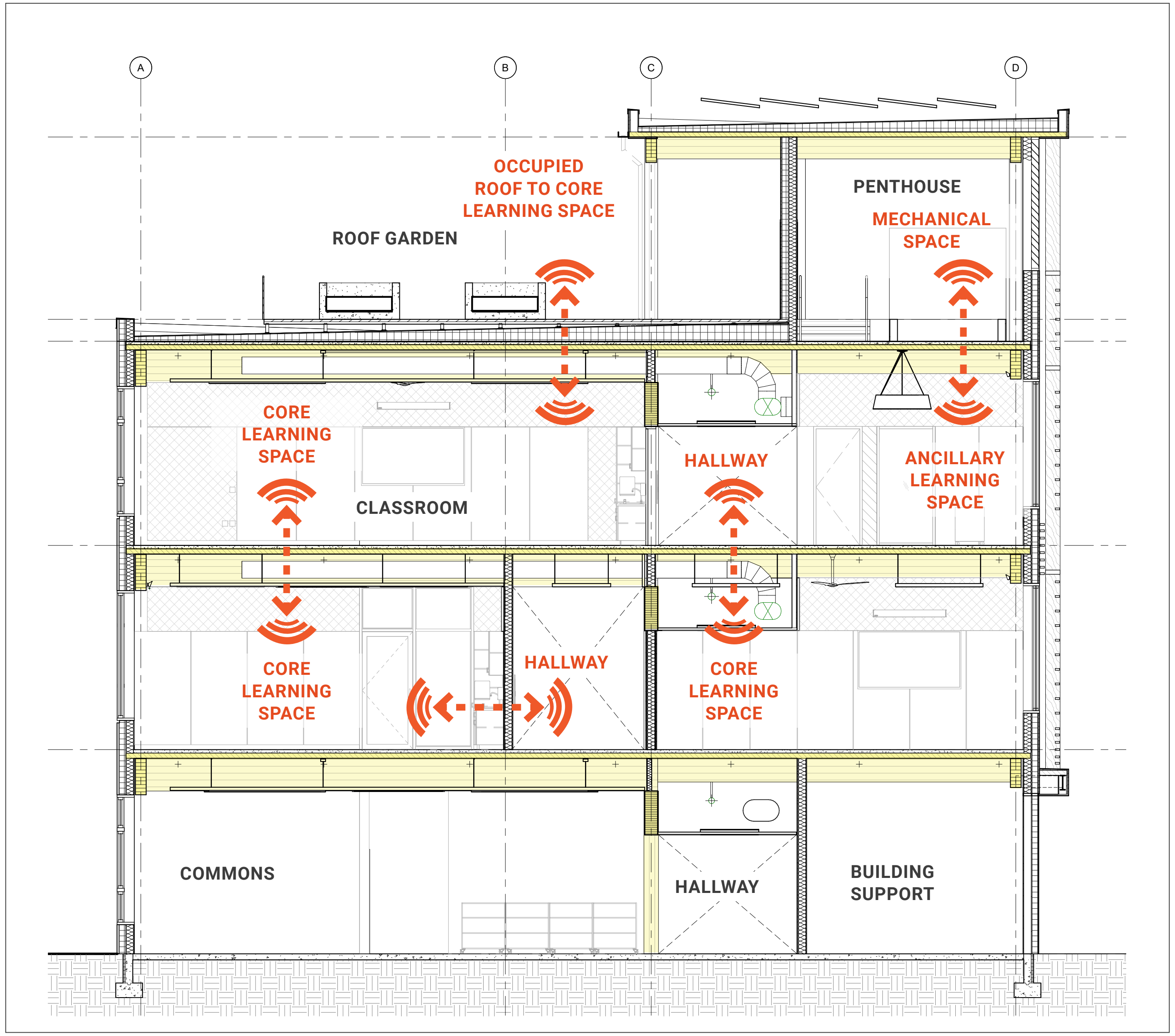
Noise produced from mechanical equipment within the rooftop penthouse should also be carefully considered. The proposed DOAS ventilation units are not expected to produce enough noise to require a different floor assembly than used throughout the rest of the building. In fact, because it is unlikely that there will be foot traffic in these spaces during regular school hours, IIC performance is not critical. Therefore, the acoustic underlayment can be eliminated under the DOAS units and still meet performance criteria given that the DOAS units have vibration isolated as part of the equipment design and specification. The DOAS units do need to be lifted off the ground to allow for condensate drainage. A site-built curb can be used for this purpose.

Acoustically, the proposed condensing units for this project are more problematic as they are specified to generate a higher level of noise. These units should not be located directly above core learning spaces. Currently, these condensing units are located over the restrooms which act as a buffer space to the core learning spaces below.

MECHANICAL IMPLICATIONS

Ductwork, ventilation and exhaust need to be considered for acoustic performance in order to meet the WA state requirements. The design documented here can utilize either fully ducted return/exhaust air or exhaust air can be transferred through grilles from enclosed spaces to the corridor where return air is then exhausted out of the building. The latter approach can reduce costs but does create an acoustic weak point between enclosed spaces and corridors. To solve this, an acoustic “Z,” “U,” or “L” boot is often used to prevent noise transfer.

To move approximately 1,000 CFM from a typical classroom, a 28-inch by 18-inch (outside dimension) opening with an “L” shaped acoustic lined boot with each boot leg running 4’-6” long is proposed. Supply grilles should have an NC rating at least 5 points below the background noise criteria of the rooms it serves (for reference, Core Learning Spaces have a background noise criteria of NC 35 per state standards).



ABOVE: Building section showing key acoustic partition types

SECTION 03D FOOTNOTES

FOOTNOTES

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SECTION 03D IMAGE CREDITS

Page 55: Rendering by **Mahlum Architects**

Page 57: Rendering by **Mahlum Architects**

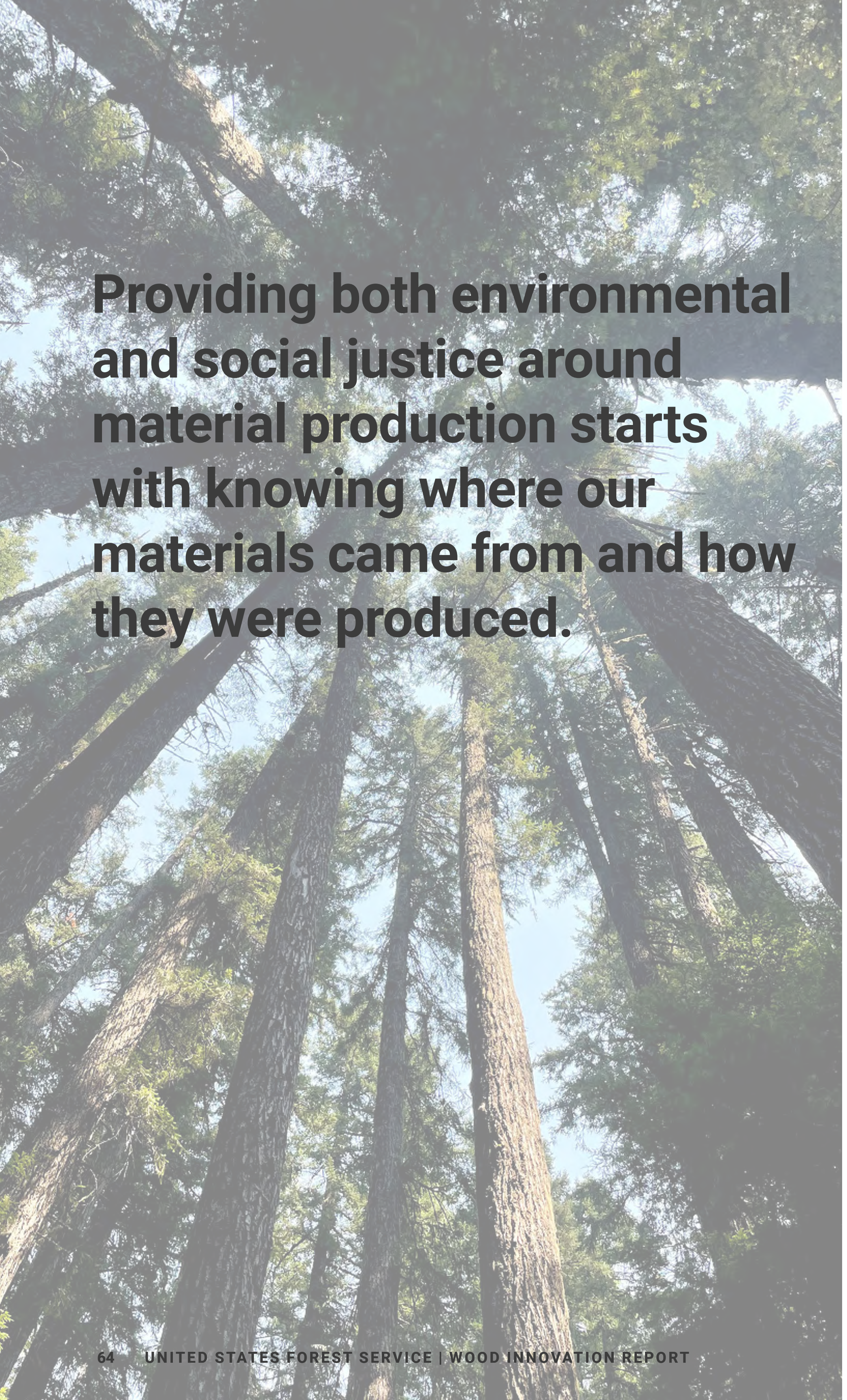
Page 58: Photo by **StructureCraft**

Page 60: Photo courtesy **Walsh Construction**

SECTION 03E

Sustainable Sourcing

Small diameter logs can be sustainably harvested and used to manufacture mass timber products like CLT.



Providing both environmental and social justice around material production starts with knowing where our materials came from and how they were produced.

Unfortunately, our current industrialized material manufacturing and procurement process effectively anonymizes most building elements and strips component parts of their identity and origin.

Supply chains are often so complex that manufacturers do not know all the ingredients, much less ingredient sourcing, that goes into the final end product of a building component. Manufacturing taking place outside of the U.S. may have less scrutiny on the production processes, leading to excessive carbon emissions from dirty energy or exposure of workers and communities to toxins during production. Wood harvesting from certain countries may be illegal, thwarting rights of indigenous peoples and communities and failing to meet sustainable environmental practices.

THE LACEY ACT

North American wood is an exception in many ways. The Lacey Act in the U.S. makes it illegal to import forest products that have been harvested or processed in violation of foreign and domestic laws. Domestic mass timber sources softwood lumber grown in North America and is not known to use illicit wood. Unlike so many modern materials, wood is not an anonymous material, especially when we can follow its supply chain. Its characteristics differ between tree species, and environment in which it grew. Certain tree and wood species can define a region or culture. Wood harvested in Washington State meets some of the most stringent environmental regulations.[1]

Throughout this section we will explore forestry practices and how Washington's forest economy can support schools, sustainability, jobs, and our natural environments.

WASHINGTON'S WOODS

Parts of Washington State, with its mild climate and ample precipitation, grow trees faster than almost anywhere else on the planet. The rain-soaked Olympic Peninsula hosts the largest Western Red Cedars and Sitka Spruce trees known in the world. Outside Mount Rainier, a nearly 400-foot-tall Douglas Fir was documented with annual growth rings numbering 1,020.

Trees are central to the identity of Washingtonians. While tree species and habitat fluctuate as we move from the coastal rainforests in the west, across the Cascade Mountains to drier east side forest zones, around half of the state is forested. In 2016 the USDA estimated 9.4 billion trees across the state.[2] Two-thirds of forested land is public, and one-third is privately held.

The amount of forest in Washington is larger than the entire country of Austria, a world leader in mass timber.

A report published in 2019 indicated that Washington's forests are a net carbon sink, with growth greatly exceeding mortality and harvest on a yearly basis. Above ground biomass of trees is estimated to store 853.3 million Mg of carbon, or 1.9e+12 pounds of carbon.[3] Climate change and the climate crisis, however, is a substantial threat to forests in Washington and across the West. Research already suggests that forests in British Columbia could now be a net emission source due to wildfires and climate change.[3]

Drier summers, higher temperatures and a history of fire suppression have led to increasingly intense wildfires, with over 700,000 acres burned in Washington during 2020 alone.

WORKING TOGETHER

Active management techniques like thinning (while leaving the largest trees uncut), prescribed burns and other indigenous practices can help reduce the risk. While there has long been tension between forestry operations and environmental groups, increasingly an understanding has emerged that collaboration between the two can protect our iconic landscapes, support rural economies, and generate sustainable building materials that lock-in carbon for lengthy periods of time.

The Northeast Washington Forestry Coalition (NEWFC), for example, is an alliance of timber companies, conservationists, business owners, and forestry professionals working together to create healthier forests through forest restoration practices. This is just one of several forest collaboration groups across the state.

Russ Vaagen, of Vaagen Timbers, has promoted the NEWFC's work, citing how forest thinning can make forests in Eastern Washington more resilient to wildfires while also providing small-diameter logs to manufacture forest products like cross-laminated timber.

Decades of suppression of naturally occurring wildfire, coupled with restrictions on forest management on second and third growth forests (where larger fire-resistant trees have been previously harvested) has led to dramatically increased wildfire risk on public lands throughout the West. Thinning and controlled burns during the rainy season can help these forests return to a more natural composition, supports forest health and provides a useful by-product to build buildings. Russ gives a more complete picture in his 2018 Ted Talk, "Creating Abundance through Collaboration."

There will be continued debate about best practices, but a consensus is emerging in drier regions of the West that we can leave a substantial number of trees in the forest (including dead trees and larger trees more resistant to wildfire) while removing smaller trees that serve as fuel ladders for fire. The remaining trees continue sequestering carbon and providing other ecological benefits, while the thinning process promotes forest health, fosters good rural jobs and creates sustainable building materials to grow our urban centers.[4, 5, 6] Working with nature and with each other will bring the broadest benefits.

The threat of wildfires is real and increasing, yet a study from 2017 found that converting forests to non-forest uses has three times greater carbon impacts across the state than wildfires.[7] Keeping forests as forests is an imperative for Washington's cultural identity, economy, climate, biodiversity, watersheds and ways of life.

QUANTIFYING IMPACTS

Forests provide an incredible array of services and benefits which Life Cycle Analysis (LCA) does not fully capture (for more information on LCA, see Embodied Carbon section). Biodiversity, preservation of old-growth, water quality and soil stability, flood prevention, and cultural connection, for example, are important metrics not covered by LCAs.

Erosion and water quality issues may occur on steep slope logging (depending on the local geology), but LCAs do not differentiate between steep and flat logging, or high-intensity logging to low-impact logging. Other social impacts, such as Indigenous rights, are also missing. Washington State's forestry regulations address many of these issues, such as riparian protection, replanting, road construction and minimizing risks of erosion and landslides (see the next page for more information on Washington State forest regulations).

FOREST CERTIFICATION SYSTEMS

In addition to State regulations, there are also a variety of forest certification systems that address land use impacts to varying degrees. Some of the most common forest certification systems include Forest Stewardship Council (FSC), Sustainable Forestry Initiative (SFI), and the Programme for the Endorsement of Forest Certification (PEFC). There are important differences between these certification systems. Certification systems can promote forest health, which is important because there is a direct correlation between forest health and biodiversity, water quality, soil quality and other environmental metrics. Some forest certification systems are prescriptive, and performance based, while others are not.

In some systems highly hazardous chemicals are banned, for example, while other certification systems may allow their use, even within a certain distance of fish-bearing streams. When considering different forest management certifications, pay close attention to impacts that could have long-term consequences on the land, such as clear-cut size, use of chemicals, riparian protection, and human rights. While some certification systems still allow it, logging old growth should never be allowed. Washington State requires all forests to be replanted after harvest and the State's forestry regulations exceed SFI standards.

Land use practices can vary widely from forest owner to forest owner. Therefore, even if a forest is not certified, or certified to a lower standard, that does not necessarily mean that rigorous forest management is not taking place. If possible, learn where your wood comes from and choose sources that value environmental sustainability. In addition, forestry regulations vary from place to place. Some local, regional or national standards may promote sustainability more than other locations and, depending on transportation distances, these locations could be prioritized for sourcing. Using wood harvested in Washington for Washington projects can reduce transportation emissions, support strong forestry practices, and connect building occupants more directly to place.

FORESTRY PRACTICES

After harvest and manufacturing, a significant portion of carbon stored in the trees is transfered to building products. New trees are planted and the cycle of carbon sequestration at a forest level begins again. If widely implemented in urban areas, mid-rise mass timber buildings could actually store more carbon than forests.[8]

Different forestry practices will also impact the embodied carbon balance of wood products. Studies have found that leaving more trees standing during harvest, having a mix of tree species and ages, and utilizing longer rotations are methods that could store more carbon, build resiliency and create additional environmental benefits.[9, 10]

ABOVE: Densely planted forest landscape after a wildfire in Eastern Washington

ABOVE: Treated versus untreated forest in the Colville National Forest

ABOVE: Small diameter logs harvested from forest restoration projects, as shown here, can be used to manufacture products like CLT

Sustainable Forestry in Washington: A Brief History

Washington State's 1946 Forest Practice Act mandated the replanting of sites after they were logged.[A] While a contentious issue among many forest landowners at the time, Weyerhaeuser had already begun the first efforts of replanting trees in 1940 in Montesano, Washington.[B] With its roots in Montesano, the American Tree Farm system was an early precursor of sustainable forestry in the country.

In 1974, the Washington State Legislature adopted the Forest Practices Act, replacing the previous version. The act provided better mechanisms for rulemaking to protect natural resources while also maintaining jobs in the forest products industry. The Forest Practice Act regulates planting, growing and harvesting trees, as well as use of fertilizers and pesticides and creating and maintenance of forest roads. It is intended to protect soils, water quality, fish, and wildlife. Also in 1974, the Boldt decision upheld tribal rights from the State's Treaties made during the 1850s, entitling 50% of off-reservation fish harvest. The ruling recognized tribal rights in land management and implications of forestry practices on water quality and fish bearing waterways.[C]

In 1987, the Timber Fish Wildlife (TFW) Agreement provided a path for more diverse set of stakeholders, including tribes, loggers, environmentalists, and government agencies, to develop regulations surrounding logging practices. The agreement amended the Forest Practices Act and provided additional protections to riparian zones and upland watersheds.[D]

In the mid 1990s, participants in the TFW agreement reconvened to study issues surrounding water quality compliance at logging sites, better mapping of fish bearing areas and protection of endangered species, like the Chinook salmon. Participants looked to restore riparian areas and fish stocks, meet requirements from the Endangered Species and Clean Water Acts and keep the forestry industry economically viable. The resulting Forest and Fish Report, now known as the Forest and Fish Law, was adopted by the State Legislature in 1999 as part of the Statewide Strategy to Recovery Salmon.[E, F] The Forest and Fish Law became the basis for the federal Forest Practices Habitat Conservation Plan (FPHCP).[G] The FPHCP is a 50-year agreement that protects 60,000 miles of streams on 9.3M acres (about twice the area of New Jersey) of forestland and ensures forestry practices meet the Endangered Species Act (ESA).[H] It is the largest Habitat Conservation Plan (HCP) in the country and uses the Department of Natural Resources (DNR) Adaptive Management (AMP) and Compliance Monitoring Program (CMP) to ensure landowners and forestry operators meet forest practices rules.[I]

Today, about 1.2% of Washington's forests are harvested on an annual basis, and harvests require extensive planning. A Forest Practices Application that outlines proposed activities must be completed prior to each harvest and submitted to DNR.[J] DNR then notifies the public and submits the application to the Department of Ecology (for water quality compliance), the Department of Fish and Wildlife (for wildlife protection), the Affected Treaty Tribes (who are in a formal agreement with the State) and Federal Agencies (for water protection and endangered species).[K] Each group can then raise concerns or request amendments. This application is reviewed for adherence to current rules adopted by the Forest Practices Board and site visits are conducted if additional questions need to be addressed.[D, K] Since 1975 Washington State has amended and strengthened its forestry practices rules 13 times.[L] While trailing California, Washington nevertheless does have some of the most stringent environmental forestry regulations of anywhere in the country.

This photo shows a long-rotation commercial forest in Western Washington after thinning cycles.

60-80 year rotations can maximize carbon sequestration per acre in a coastal Douglas Fir stand. Port Blakley's Winston Creek Carbon Forest practices longer rotations and has partnered with WholeTrees to supply Structural Round Timber (SRT) and Sawn Heavy Timber (SHT) products. These products are easy to trace back to the forest from where they were grown. They also offer the benefit of minimal processing, shorter supply chains, lower embodied energy and less waste.

Forest Economy & Schools

With 1,700 forest products’ businesses, Washington State’s entire forestry industry provides some 101,000 jobs, many of them in rural communities.[11, 12]

Washington’s K-12 schools also benefit from the state’s forest industry and products. The state's Department of Natural Resources, for example, manages 3 million acres of state trust that provide financial support to public kindergarten through Grade 12 schools through timber sales.[13] Forest harvesters on public and private lands in Washington also pay a Forest Harvest Excise Tax (FET). The FET is distributed to schools and other taxing districts in the county in which the timber was harvested.[14] Keeping forests healthy and resilient will be key to maintaining this source of funding for public school construction. The ecological health of forests and school funding should be complementary and support both goals.[15] Through long-term management, the State’s trust lands can utilize Washington wood for mass timber construction, while demonstrating a synergy between education, forestry and the health of our children and landscapes.

ABOVE:
The interior of a CLT Classroom Pilot project in Seattle, Washington (Designed by Mahlum Architects)

WASTE-FREE MANUFACTURING

Harvest techniques today can influence future yields, so there is a strong awareness of sustainability and efficiency. Foresters, especially in light of climate change, are focused on ensuring forests maintain growth in the long-term – a key aspect of sustainability.

Once trees arrive at a mill to be processed, this is again marked by efficiency. A report from Dovetail.org found that waste at sawmills “is largely obsolete in the context of today’s North American forest products industry.” [16] All parts of the tree are used, and any bits left over and not turned into a product are converted to energy to power the mill, offsetting reliance on fossil fuels.

DESIGN & MANUFACTURING INTEGRATION

Manufacturers that produce mass timber elements have adopted new technology in grading, assembling, pressing and cutting these components. They are now integrated into project teams, providing valuable design assist services, shop drawings and just-in-time delivery to job sites. The production of mass timber elements can be characterized by advanced technology, high-tech equipment, precision, collaboration, and speed.

This is the type of industry that can provide livable wages to rural workers, produce sustainable building materials for our rapidly growing state population, and play an integral part in fighting climate change.

FROM PINE TO PANEL AND FOREST TO SCHOOLS

Tree harvesting in Washington State today is far less impactful on the land than the early industrial era here. While techniques and technology must continue to evolve and improve, harvesting equipment today can remove trees with a lighter touch and, with proper planning and execution, minimal effect on soil and water quality or surrounding vegetation.

For mass timber to be a viable option in school construction, the lumber must be sourced from healthy, sustainable forests. Forest regulations, best practices and certification systems are an important part of this so that designers, contractors and ultimately the building users can feel good about the decision to use wood and know it was the right choice.

Mass timber has created renewed attention to forestry practices, material production and sustainability. This attention is a positive development because these are incredibly complex and evolving issues that compel us to deeply examine our relationship to this material. Can we see the forest as more than just trees, but a deeply intertwined and interconnected system? Having a deeper understanding of these systems will inform how we on an individual and collective level approach the use of wood in light of sustainability, resiliency, forestry, conservation, carbon, economics and jobs.

ABOVE: Glued-laminated timber production at Vaagen Timbers

ABOVE: Integrating connection hardware into mass timber elements at Vaagen Timber’s manufacturing facility

ABOVE:
Bootleg Fire restoration work marked by Klamath Tribes Crews

Forest Restoration: Building for Positive Impact

Wood products offer an opportunity to build positive relationship between the built environment and forest health. Ecological based forest practices, including thinning and prescribed fire, allow us to protect forests and high conservation values through active management. Markets for wood products created from small diameter timber are important; providing vital revenue to pay for non-commercial thinning, prescribed fire, stream and road improvements.

Tens of thousands of acres of forest are being restored each year on federal, state, tribal, and private lands in NE Washington. Small diameter mills like Vaagen Brothers Lumber provide critical ecological forestry infrastructure to make projects feasible.

On average, projects on the Colville National Forest have produced 5,000 board feet (BF) of round wood per acre of commercial thinning treatment area. Wood used in the simulated K-12 school building presented in this report represents 616 MBF (thousand board feet) of CLT and 349 MBF of glue laminated beams and columns. Based on the volume of fiber used in each building, the average round wood produced per-acre, and manufacturing conversions, each school of similar scale will directly support the restoration of 185 acres of forest.[M]

Forest restoration projects on the Colville National Forest include the 54,000 acre South and Middle Fork Mill Creek A to Z[N], 26,892 acre Kettle Face North and South[F], 43,692 acre East Wedge project.[G] These projects are all supported by the NEWFC forest collaborative and represent a radical middle ground where community and conservation values are achieved, rural jobs are maintained, and fiber is produced for sustainable building.

One of the main goals of the restoration projects is to improve fire outcomes. All four restoration projects have experienced wildfire in the last ten years including the Reneer, Boyds, and Horns Mountain Fires. Post fire tours and monitoring show that restoration projects successfully reduced extreme fire behavior, tree mortality, crown level fire, and soil loss. In the Boyds fire restoration areas also enabled the fire crew to hold a fire line and protect the community of Barneys Junction.

Projects created heterogeneous forest structure through thinning and prescribed understory burning. Treatments improved habitat for the Endangered Canadian Lynx, increased forage and protected Goshawk nesting areas, protected large late successional trees, improved fish passage, and decommissioned roads in harmful riparian areas.

ABOVE: Legacy Trees protected by restoration thinning at the Fremont-Winema National Forest

SECTION 03E FOOTNOTES

FOOTNOTES

1. Generally, Washington has more stringent forestry standards than Oregon, but less than California.
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SECTION 03E FOOTNOTES CONTINUED

SUSTAINABLE FORESTRY IN WASHINGTON (PAGE 66)

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SECTION 03E IMAGE CREDITS

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Photo by **Steve Rondeau, the Klamath Tribes Natural Resources Director**
Photo courtesy **Sustainable NW**

FOREST RESTORATION, BUILDING A POSITIVE IMPACT (PAGE 68)

Text by Paul Vanderford, Sustainable NW

M. Project BF use / (BF of roundwood per acre X roundwood lumber conversion) X (total acres of restoration project / acres of commercial thinning).

N. https://www.fs.usda.gov/nfs/11558/www/nepa/102248_FSPLT3_2552580.pdf

F. https://www.fs.usda.gov/nfs/11558/www/nepa/52419_FSPLT2_047787.pdf

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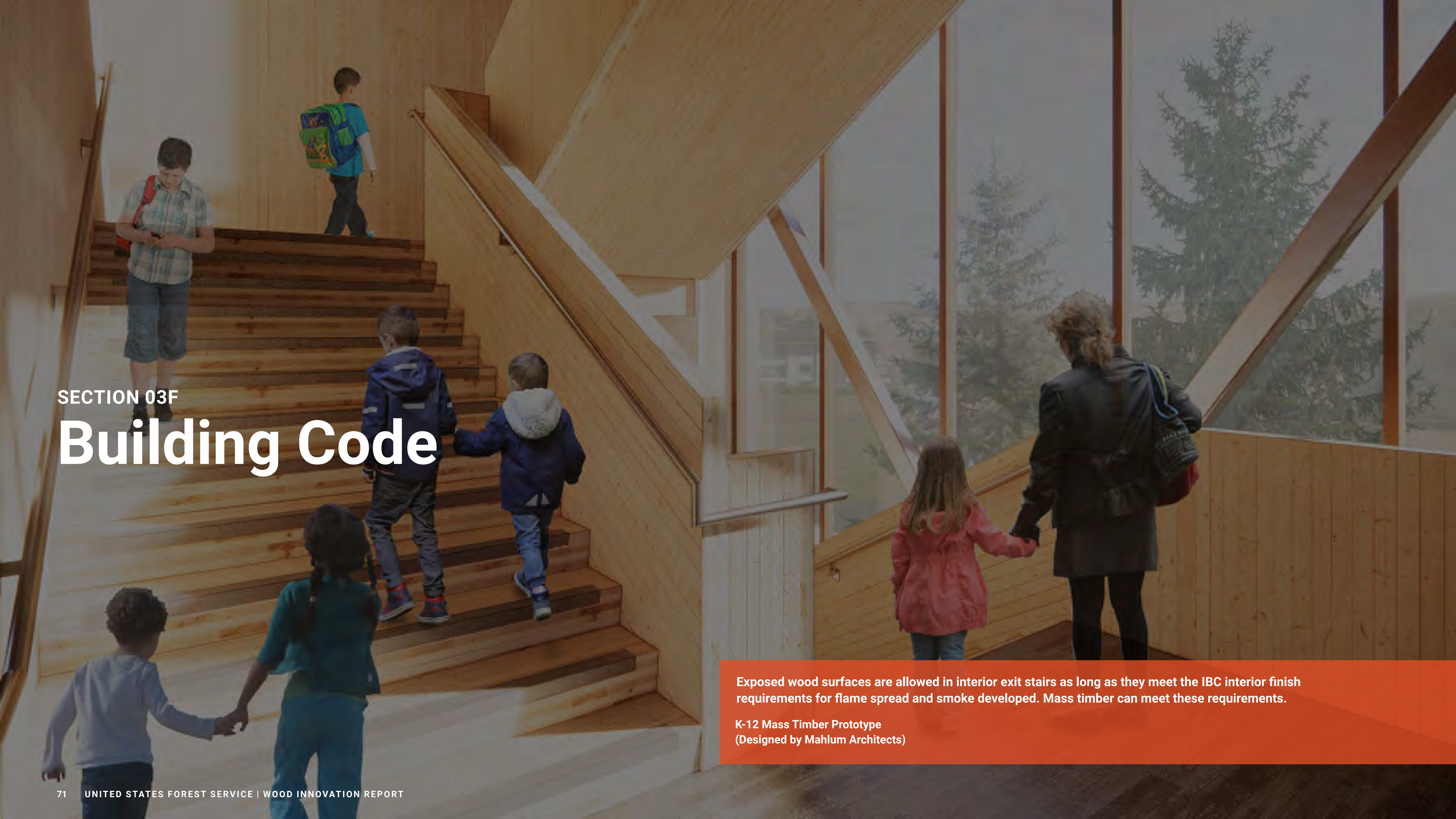
Example Mass Timber Wood Products Sourced from Forest Restoration: https://www.futureforestsnorthwest.org/restorationwood-storymap

SECTION 03F

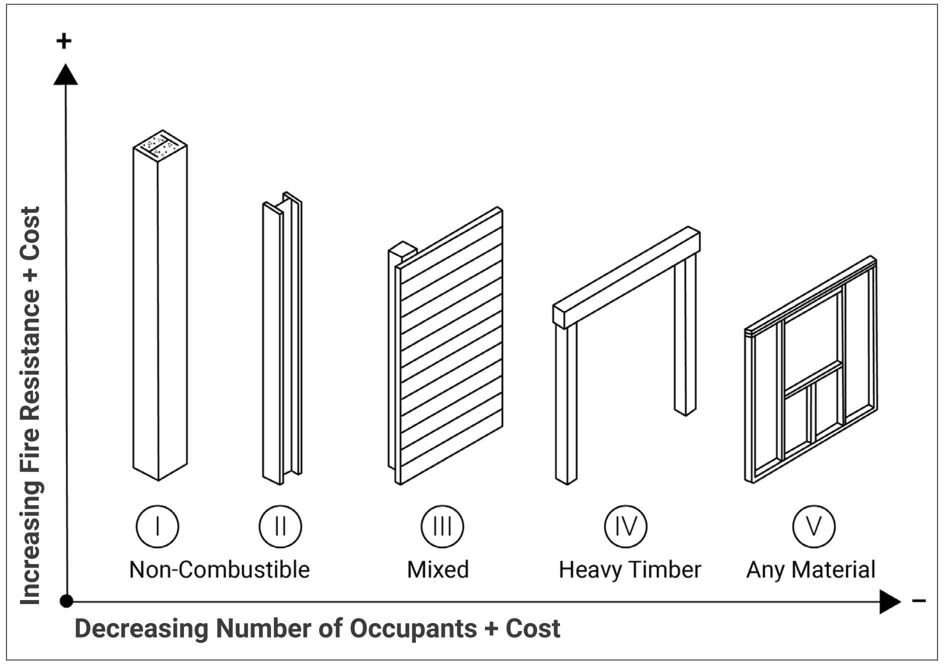
Building Code



Exposed wood surfaces are allowed in interior exit stairs as long as they meet the IBC interior finish requirements for flame spread and smoke developed. Mass timber can meet these requirements.

K-12 Mass Timber Prototype
(Designed by Mahlum Architects)

Understanding building code implications for mass timber design can help reduce cost, risk, and time.



LEFT:
Construction types are distinguished between combustible and non-combustible construction. Mass timber can be readily used in Types III, IV and V

The scope of this study involves using mass timber construction for multi-story K-12 schools 2-3 stories tall and comparing this to standard structural steel construction.

The building height, number of stories and type of structural material is regulated by the International Building Code (IBC), which has been adopted in all 50 states, including Washington.

This chapter explores the construction types included in the 2018 Washington State amended IBC that can be used for multi-story timber schools, and the applicable building code considerations for planning and constructing such buildings.

For the purposes of this study, the team has selected Type III-B as the construction type to be used for 3-story mass timber schools. To conduct cost, constructability and embodied carbon comparisons, the steel baseline building uses Type II-B construction. The discussion below goes into further detail for what these construction types are and why they were selected.

CONSTRUCTION TYPES

The International Building Code (IBC) defines buildings by their Construction Type, of which there are five different classifications: Types I, II, III, IV and V. The construction type correlates to its level of fire protection, with Type I being the most fire resistive and Type V being the least. Construction types that have been observed or perceived to perform better during fire events can be taller and with greater area than others. With a few exceptions, Type I and Type II construction are required to be built from non-combustible elements, such as concrete or steel. Therefore, mass timber elements are not allowed in Type I buildings, and only allowed as roof elements in Type IB and II construction. The remaining construction types allow mass timber elements, except in exterior walls in certain cases. Type III, Type IV and Type V can be built from combustible or non-combustible elements. Construction types have additional letter signifiers of A, B, and C. The letter A indicates a higher level of fire protection than the letter B. Similarly, the letter B indicates a higher level of fire protection than the letter C. Due to increased levels of protection, A construction allows additional building height and area as compared to B or C.

Mass timber elements can only be extensively used in Types III, IV and V.

Construction types that allow mass timber can be characterized by the following:

> Type III: non-combustible exterior walls with interior construction of any type permitted by the code, including mass timber.

> Type IV: non-combustible exterior walls, or CLT exterior walls, with Heavy Timber (HT) or mass timber interior construction. In Type IV-HT, 1-hour fire-resistance rated interior partitions of any construction are allowed, but in Type IV-A, B and C, no light wood framing is permitted.

> Type V: combustible construction is allowed throughout this construction type and any material permitted by the code is allowed. While beyond the scope of this study, a 1-story Type IA concrete podium with 2-stories of Type V construction above is allowed per IBC section 510.

Schools are considered a Group E occupancy per Chapter 3 of the IBC. The chart on the following page illustrates key differences between combustible and non-combustible construction for Group E occupancies. The Washington State Amended IBC requires all Group E occupancies to be fully sprinklered when there is an occupant load of 51 or more, regardless of construction type.

Because Type V construction restricts the building height to 2 stories for schools, this construction type does not meet the minimum scope defined for this study.

Only Type III and Type IV construction allows 3-story (or taller for Type IV) educational buildings constructed from mass timber.

For a 3-story school, the most likely construction types to use that allow combustible materials are either Type III-B or Type IV-HT. Type III-A and Type IV-A, B, and C require higher levels of fire protection and would not likely be chosen unless the project needs to be taller than 3 stories. Higher levels of fire protection can be generally equated to higher costs, due to additional material and methods needed to meet the required resistance times. Because of that, construction types with the lowest required fire resistance rating should be selected that meet the required height and areas of the program.

Buildings with less fire rated construction often leads to shorter building permit review times and fewer comments and corrections during the permitting process. This can also save time and resources for design and build teams.

CONSIDERATIONS BETWEEN TYPE III OR TYPE IV CONSTRUCTION

A key difference between Type III-B and Type IV-HT is that Type-IV HT allows CLT in the exterior walls where Type III requires non-combustible construction or fire-resistant treated (FRT) lumber used for exterior walls. Interior load bearing elements and partitions have additional fire protection requirements in Type IV-HT that are not required in Type III. Type IV-HT interior elements must meet minimum sectional size requirements for timber elements and hourly requirements for wood framed elements. These minimum sectional dimensions are not required for Type III. Exposed primary steel structure in Type IV-HT may also need to be fire protected, whereas it would not in Type III-B.

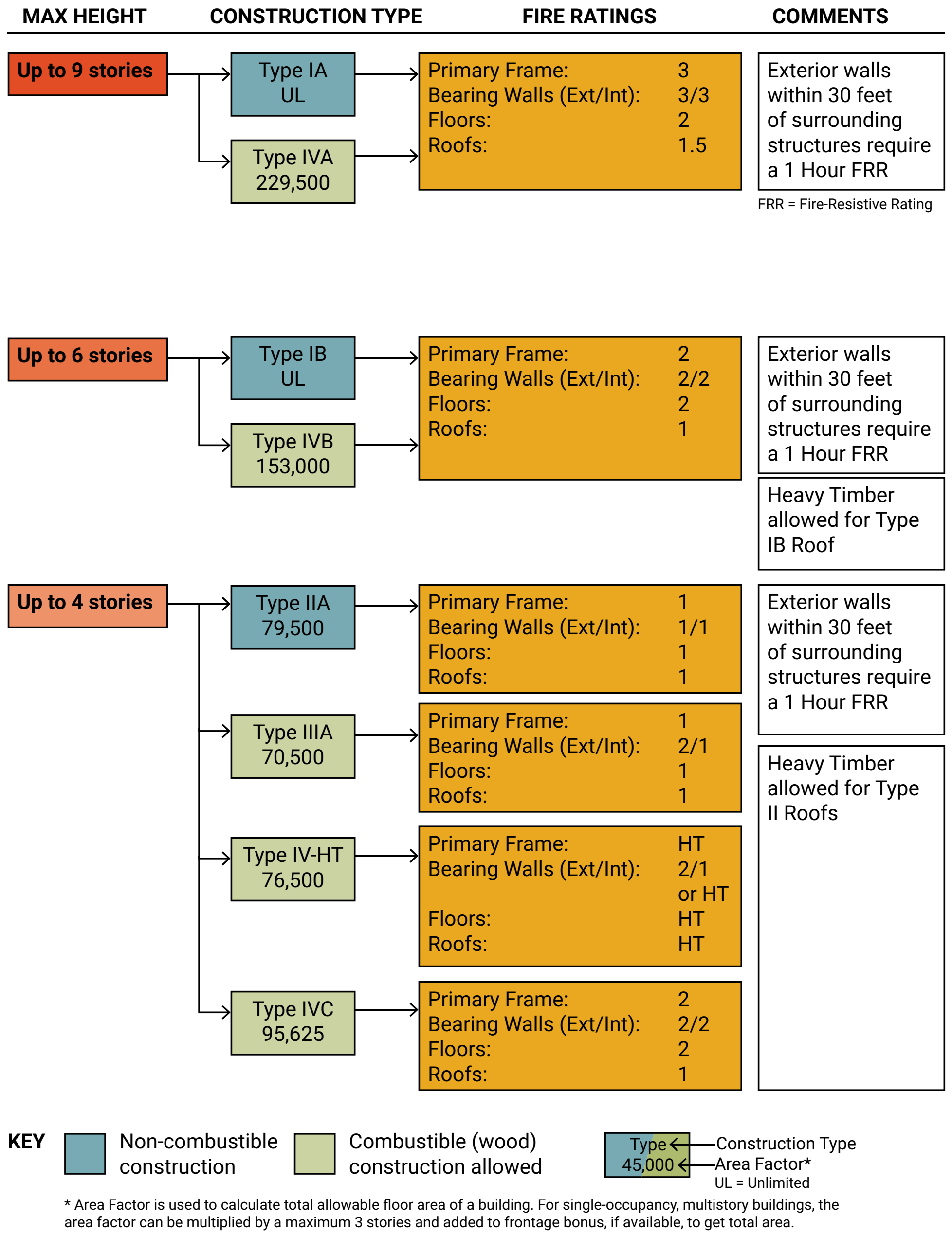
Because Type III-B allows for a 3-story school (a requirement from the grant proposal) and has the least amount of required fire-rated construction, this study has identified Type III-B as the preferred construction type.

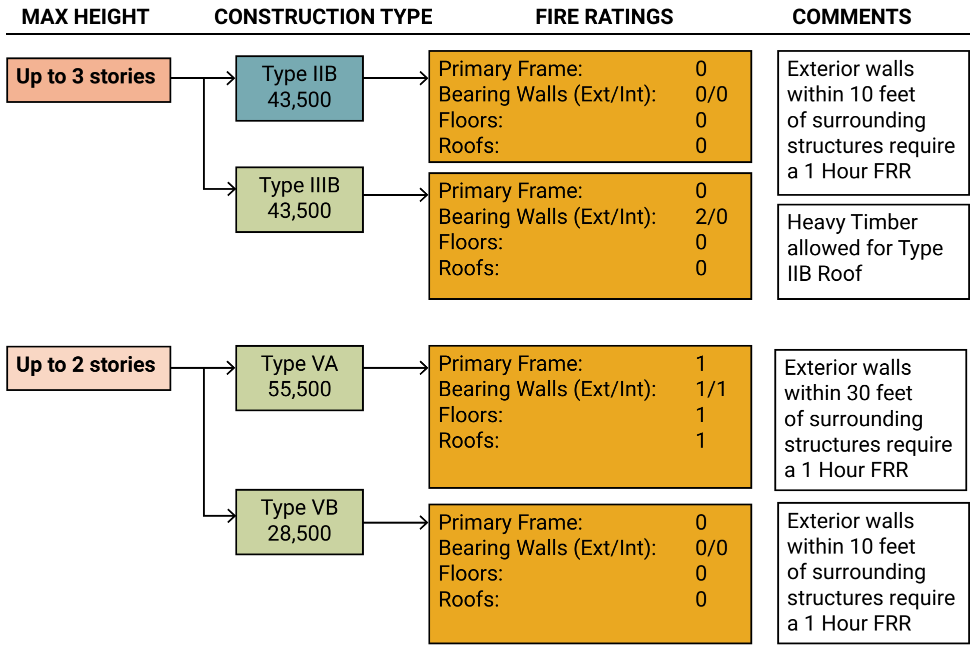
For projects that want to use CLT for exterior walls, Type IV construction is required at this time.

One further distinguishing factor between Type III and Type IV-HT construction involves concealed spaces.

Type IV-HT does not allow for concealed spaces, which typically involve cavities found in floor and/or ceiling construction. These concealed areas are places where fire could spread and grow unseen and are thereby regulated by the building code. While traditionally concealed spaces have been restricted from Heavy Timber

BELOW: Building Height, Area, and Fire Rating Requirements for Educational Occupancies (Group E, Fully Sprinkled)





INTERIOR WALL AND CEILING FINISH REQUIREMENTS (TABLE 803.11)

GROUP	SPRINKLERED		
	Interior exit stairways	Corridors and enclosure for exit access stairways	Rooms and enclosed spaces
E	B	C	C

Class B: = Flame spread index 26-75; smoke developed index of 0-450
Class C: = Flame spread index 76-200; smoke developed index 0-350
* Type IV-HT exempt from finish requirements (803.3)

NOTES:

- Code analysis is per Washington State Amended 2018 IBC
- For all Construction Types here, non-load bearing interior walls do not require a fire-resistive rating, except Type IV-HT where non-bearing partitions (steel or wood) require a 1-hour rating.
- Type IVA, B & C not available in all jurisdictions until adoption of 2021BC or pre-adoption
- Type IVA and B have restrictions on exposed wood structure
- Additional high-rise provisions apply for buildings over 75’
- Type IV-HT requires minimum sectional dimensions for timber load bearing elements
- Type IV buildings with exposed steel structure that is part of load bearing system must be fire protected
- Common path of travel for sprinklered Group E buildings is 75 feet (Table 1006.2.1)
- Exit access travel distance for sprinklered Group E buildings is 250 feet (Table 1017.2)

Mass Timber and Fire-Rated Construction

Mass timber can be used for fire-resistance rated construction.

IBC section 703.3 defines methods for determining fire resistance. The most common methods for mass timber involve either a full-scale fire test to validate performance, or use of the U.S. National Design Specification (NDS) for Wood Construction. The NDS allows a calculated fire-resistance of up to two hours for solid wood and engineered wood products.

The capacity of the timber member is calculated using the actual mechanical and physical properties of wood for a given period of time and effective charring rate. The effective char depth accounts for the heated portion of wood (zero-strength layer) which is assumed to be 20% of the char depth. The longer a solid wood element is exposed to fire, the deeper the char layer penetrates. The combination of char layer and heated portion of wood determines the residual structural capacity of the element. Working with a structural engineer, wood elements can be sized to meet a given period of fire exposure and still have structural capacity to maintain building loads based on the reduced section of the element. Sometimes this will lead to oversizing structural elements to account for char, but timber components may not need to be oversized and can meet fire resistance times based on their size for structural loading. The current PRG 320 product standard for CLT requires heat-resistant adhesives to be used, which greatly improves performance in the unlikely event of an extended duration fire by eliminating char fall-off due to delamination at the glue-line.

During a fire, the outer layer of char is insulative and delays heat and resultant thermal degradation from penetrating deeper into the section of wood. The char and heated zone of wood are considered to have no structural strength, but the cold, unheated wood behind these zones continues to maintain structural capacity. Because wood is an excellent insulator, the spread of heat deeper into the section of wood is slow. As a fire continues, the char layer grows, creating more insulation, and delaying the penetration of heat deeper into the section.

Through testing, the development of char during a fire is predictable, constant and well understood, allowing it to be calculated for a structural fire assessment.[2] Such predictability is crucial for fire departments to have confidence that mass timber buildings can maintain integrity for long periods of time to prevent the loss of life and property. Consequently, using mass timber elements for fire rated elements, like shaft walls for this project, is allowed in Type IIIB Construction, as well as other construction types.

construction, the 2021 IBC provides new provisions for concealed spaces in Type IV-HT construction. Per the 2021 IBC, to have concealed spaces in Type IV-HT construction, one or more of the following provisions must be met:

> Sprinkler concealed spaces

> Fill concealed spaces with non-combustible insulation

> Wrap all concealed timber surfaces with a minimum one layer of 5/8” thick Type-X gypsum board

Type II and III construction does not have additional code provisions for concealed spaces per the IBC, however, the applicable sprinkler standard such as NFPA 13 may carry additional requirements for protection in combustible concealed spaces.

This again makes Type III construction more flexible to use for design and potentially reduces costs and permit review times. However, Type IV-HT construction does allow for one additional story and additional gross floor area.

One additional key consideration when choosing construction type is requirements for fire protection of structural connections. Because Type III-B does not require fire-resistance rated construction for interior building elements, connections for timber elements do not require protection. However, shafts two or more stories and/or occupancy/building separations do require fire-resistance rated construction for both II-B and III-B construction. Supporting construction for these elements must also be rated to the same hourly requirement.

Attention should be given to connections and smoke and gas sealing within these rated assemblies. Type IV-A, B and C construction requires sealing of abutting edges between mass timber elements as part of fire rated assemblies, but there is no similar provision for Type III or IV-HT construction. Connections are most often fabricated steel elements. Because steel does not maintain its strength at elevated temperatures, these connections may fail during a fire and collapse. Fire protection of connections requires additional materials, as well as design and review time, thereby increasing construction costs and complexities.

For timber post and beam construction, Type III buildings can likely be reclassified as Type IV-HT construction with limited design changes if an additional story or greater floor area is required. For multi-story timber post and beam construction, the primary timber structural frame will most likely meet minimum sectional dimensions required by Type IV construction because of structural sizing demands.

The major considerations in choosing between Type IIIB and Type IV-HT include requirements for concealed spaces, options for exterior walls and fire ratings on interior partitions, as discussed above.

STEEL BASELINE CONSTRUCTION TYPE

For comparing costs and constructability between mass timber and steel, the most comparable steel Construction Type is II-B. Like Type III-B, Type II-B does not require any interior fire rated construction, except for shafts over 2-stories or occupancy and building separations.

Type II-B requires non-combustible construction, with exceptions for the roof, furring and finishes. Besides requiring non-combustible construction, the major difference between Type II-B and III-B is that the later allows combustible construction in all areas except the exterior wall construction, which must be non-combustible or fire-retardant treated lumber (FRT). Both construction types allow 3-story Group E buildings of the same floor area, making them ideal for cost comparison.

Both Type II-B and III-B have an allowable area factor for sprinklered, multi-story Group E buildings of 43,500 square feet (sf). To find the total allowable area for single-occupancy, multi-story buildings, the code permits the allowable area factor to be multiplied by a maximum of 3-stories, resulting in a total allowable square footage of 130,500 SF. Additional area is allowed by frontage bonus if no surrounding buildings are less than 20 feet away. Because schools are often located on campuses, frontage bonuses can often be taken. 130,500 sf can accommodate elementary shcools, middle schools and even large high schools. If additional area is needed, fire-resistance rated building separation assemblies can be added to effectively create separate buildings on the same site.

ABOVE: DR Johnson CLT floor panel after passing 2-hour fire test.[4]

FIRE

A key difference between timber and steel is that timber provides inherent fire resistiveness whereas steel does not. Steel can lose approximately half of its strength at temperatures around 900 degrees F. Temperatures during the early phases of a fire can be twice this hot, leaving unprotected steel structure vulnerable to reduced strength and event the threat of collapse.

Timber elements, on the other hand, do not lose their strength at elevated temperatures, but instead form a layer of protective char. As a fire continues, the cross-sectional area of timber elements is slowly diminished due to charring, but the wood beyond the heated char zone maintains its full strength.

The National Design Specifications (NDS) for Wood Construction allows calculations of up to 2-hour fire-resistance for timber components. For timber elements requiring more than 2-hour fire-resistive ratings, non-combustible components like gypsum wall board must be used. In contrast, steel must always be encased in a non-combustible enclosure, such as gypsum-wall board or concrete to achieve the required fire-rating. Because timber is inherently fire-resistive, dimensionally stable at high temperatures, and an excellent thermal insulator, mass timber provides surprisingly good passive fire-safety performance attributes.

Fire rated construction is limited in this study as neither Type III-B nor Type II-B construction require extensive fire-resistance rated assemblies per Chapter 6 of the IBC. For structures over 3-stories in height, the considerations for fire-rated construction increase. Type IV-HT allows up to 4-story Group E schools. Columns and beams for this construction type are not required to be fire-resistance rated, but they must meet the minimum heavy timber (HT) dimensions specified in Chapter 23 of the International Building Code. The American Wood Council (AWC) notes that "connections of [Type IV-HT] heavy timber members that are not fire-resistance rated are not required to be [fire] protected."[1] However, if other sections of the code besides Table 601 require fire-resistance rating, than these timber elements would need to be fire protected. Taller mass timber schools that use Construction Types IV-A, B or C do require fire-resistance rating for structural elements. In this case, connections need to be protected. Procedures for fire protecting connections can be found in AWC's Technical Report No. 10 (TR10). WoodWorks also has a public listing of fire tested mass timber connections.[3] Many connections are available today, and more under development that can meet 1- and 2-hour fire-resistive rating requirements by encapsulating the steel hardware with timber.

One final consideration for fire is interior finish requirements, which govern flame spread and smoke developed indexes of interior elements and surfaces. Exposed structural elements that meet the code's definition of Heavy Timber are exempt from interior finish requirements, except for exit stairways, exit ramps and exit passageways. For sprinklered Group E buildings, these exit components must have a minimum Class B finish material. A Class B finish material must meet a flame spread index of 26-75 and smoke-developed index of 0-450. The AWC's Design for Code Acceptance 1 – Flame Spread Performance of Wood Products Used for Interior Finish (DCA-1) provides flame spread information for common species used in timber construction. DCA-1 indicates that mass timber components meet requirements for a Class B material, and likewise are permitted in exit stairways and passageways in schools. See chart at right for additional information.

Fire testing of mass timber elements have demonstrated that these components can even exceed the values found in DCA-1 and meet Class A requirements.[5] Heavy timber elements that meet dimensional requirements for Type IV construction but used in Type III construction are also exempt from wall and ceiling finish requirements.

CLT elements have undergone extensive fire testing over the past several years, demonstrating that even unprotected CLT can meet 1 and 2-hout fire ratings. The design presented in this report assumes a minimum 5-ply CLT panel used for vertical fire-rated stair shafts. WoodWorks hosts an extensive list of fire-resistance tested mass timber assemblies.

PENTHOUSE AND ROOF

The International Building Code does not count mechanical penthouses as an additional story of the building if the penthouse is no more than one third the area of the supporting roof deck and is only used for mechanical, electrical, plumbing equipment, or vertical shafts.

Occupied roofs are also allowed by the building code. Any occupancy allowed on the floor below, is allowed at the roof. Rooftop occupancies do not count as an additional floor if the exterior spaces are not enclosed by a roof or walls taller than 48 inches.

PLUMBING FIXTURES

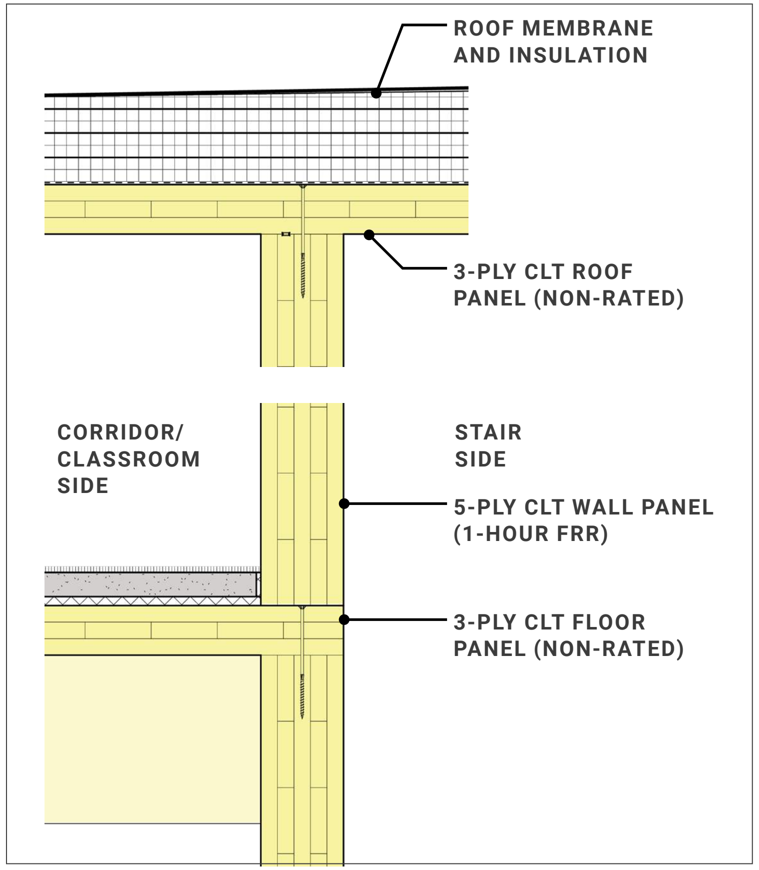
The Amended Washington State Building Code sets minimum plumbing fixtures counts, such as water closets and lavatories, by the building's overall gross floor area. The number of occupants for a Group E, Educational building to define plumbing counts is taken as the building's gross square footage divided by 100 SF per occupant.

Often, areas in a school could be used for assembly after hours, such as community meetings. In these instances, the plumbing fixture count should be determined by the Assembly occupancy (either 15 or 7 square feet per occupant) rather than Educational occupancy. Assembly occupancies will require additional toileting and handwashing facilities.

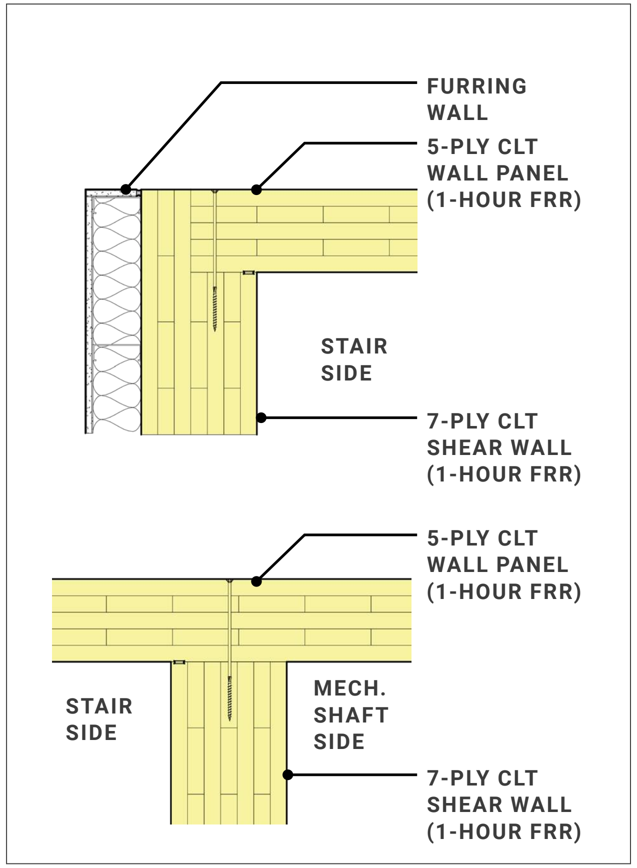
The 2018 Washington Building Code includes provisions for gender-neutral facilities, meaning that restrooms no longer need to be separated between male and female. Gender-neutral facilities require individual compartments with full height walls and a securable door for privacy. These facilities can be more equitable and reduce harassment that might occur in traditional separated facilities.

BELOW: The American Wood Council's document DCA-1 lists Flame Spread Performance of various wood species. The wood species above may be used in mass timber elements, and due to their Flame Spread Class, can be used in classrooms and egress components for K-12 schools.

TREE SPECIES	FLAME SPREAD INDEX	SMOKE DEVELOPED INDEX	FLAME SPREAD CLASS
Douglas-Fir	70	80	B
Hem-Fir	60	70	B
Southern Yellow Pine	70	165	B



ABOVE: Detail section drawing through stair shaft showing rated shaft wall and intersection of non-rated floor and non-rated roof (While this detail meets continuity requirements of building code, its acceptance should be confirmed by the Authority Having Jurisdiction)



ABOVE:
Plan details showing CLT intersections at stair shaft (FRR = Fire-Resistance Rated)

SECTION 03F FOOTNOTES

FOOTNOTES

1. American Wood Council (AWC). (n.d.). Are connections in type IV-HT construction required to be fire-resistance rated? FAQ > Fire. Retrieved January 2021, from https://awc.org/faqs/fire/fire/for-type-iv-construction-(heavy-timber)-are-the-heavy-timber-connections-required-to-be-fire-resistance-rated
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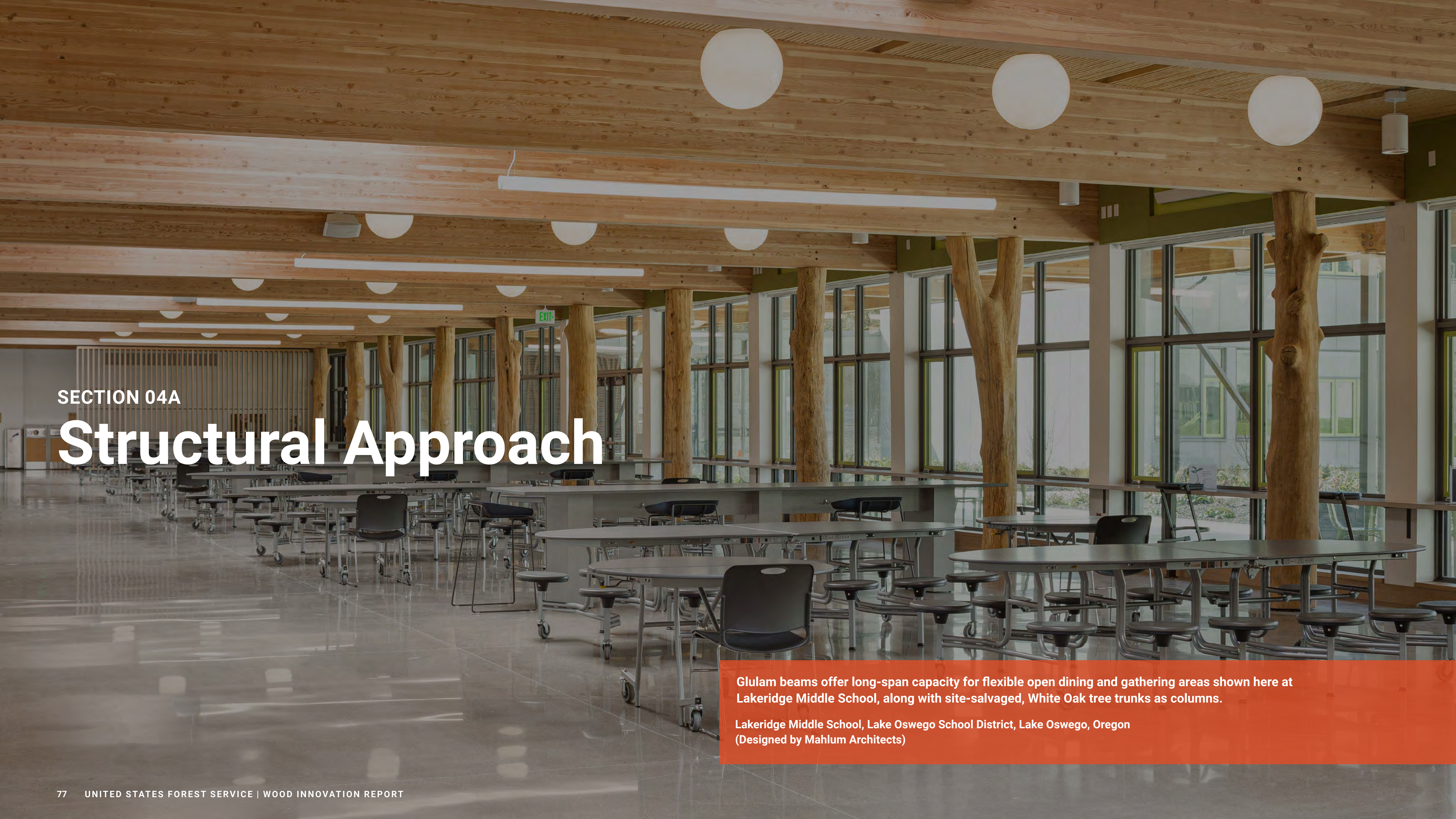
SECTION 03F IMAGE CREDITS

Page 71: Rendering by **Mahlum Architects**

Page 72: Diagram redrawn and adapted from **John Wiley & Sons, Building Code Illustrated**

Page 75: Photo by **D.R. Johnson Wood Innovations**



SECTION 04A

Structural Approach

Glulam beams offer long-span capacity for flexible open dining and gathering areas shown here at Lakeridge Middle School, along with site-salvaged, White Oak tree trunks as columns.

Lakeridge Middle School, Lake Oswego School District, Lake Oswego, Oregon (Designed by Mahlum Architects)

Cantilevering out of the ground and reaching for the sun, the forces that a tree resists in nature make it an ideal building material.

Raw wood is not widely considered a modern material in the same way as steel or concrete, yet it does exhibit many features that make it more advanced than some of our more common building blocks.

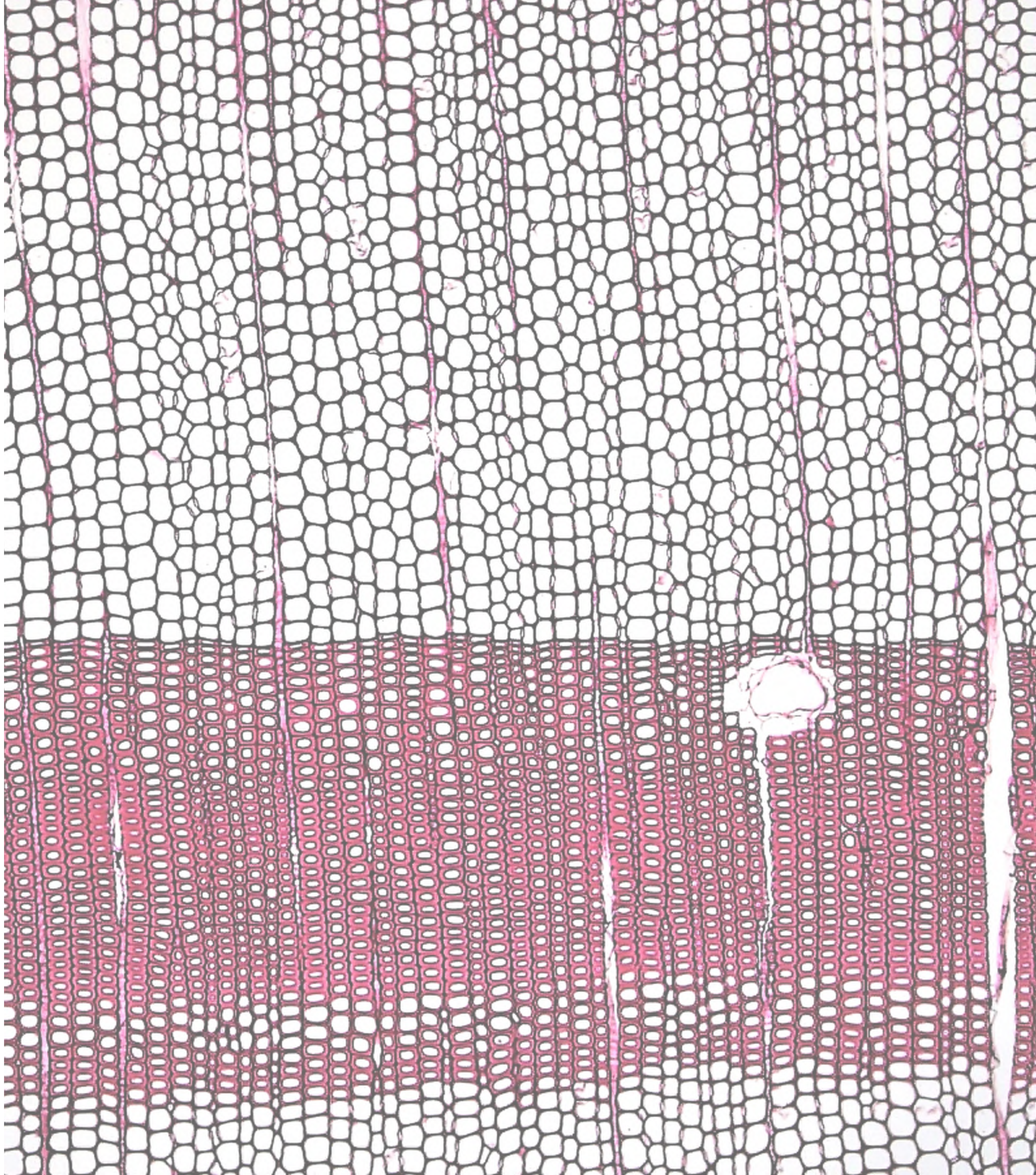
Raw wood possesses multiple levels of structure, from the scale of the whole tree, to branches, down to the macroscopic, cellular level; to the microscopic, cell wall level; and the molecular, polymeric level.[1]

Its cellular structure makes it light, yet flexible and able to localize damage and fracturing. The cellular structure is held together in a matrix of natural adhesive with fibers woven together and oriented in ways to provide strength.[2] This underlying structure of wood informs its strength properties.

Wood is in fact a technological marvel, an advanced material produced by the efficiencies of nature rather than the excess of humankind. Strength and stiffness are critical factors in a wood element's ability to resist loads without bending excessively or breaking.

This can be defined using bending strength and stiffness characteristics. Together, these two properties help describe a material's structural capabilities. **When compared to steel and concrete, wood has a high strength to weight ratio, lending itself as a useful building material for modern day buildings.**

IMAGE:
Transverse, cross-section of pinus stem magnification showing well defined rings of spring wood (larger diameter) and autumn wood (smaller diameter)

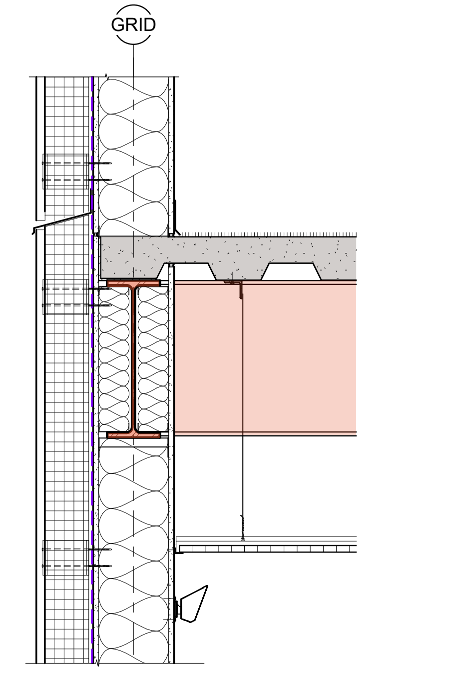


STRUCTURAL APPROACH (MASS TIMBER VS STEEL)

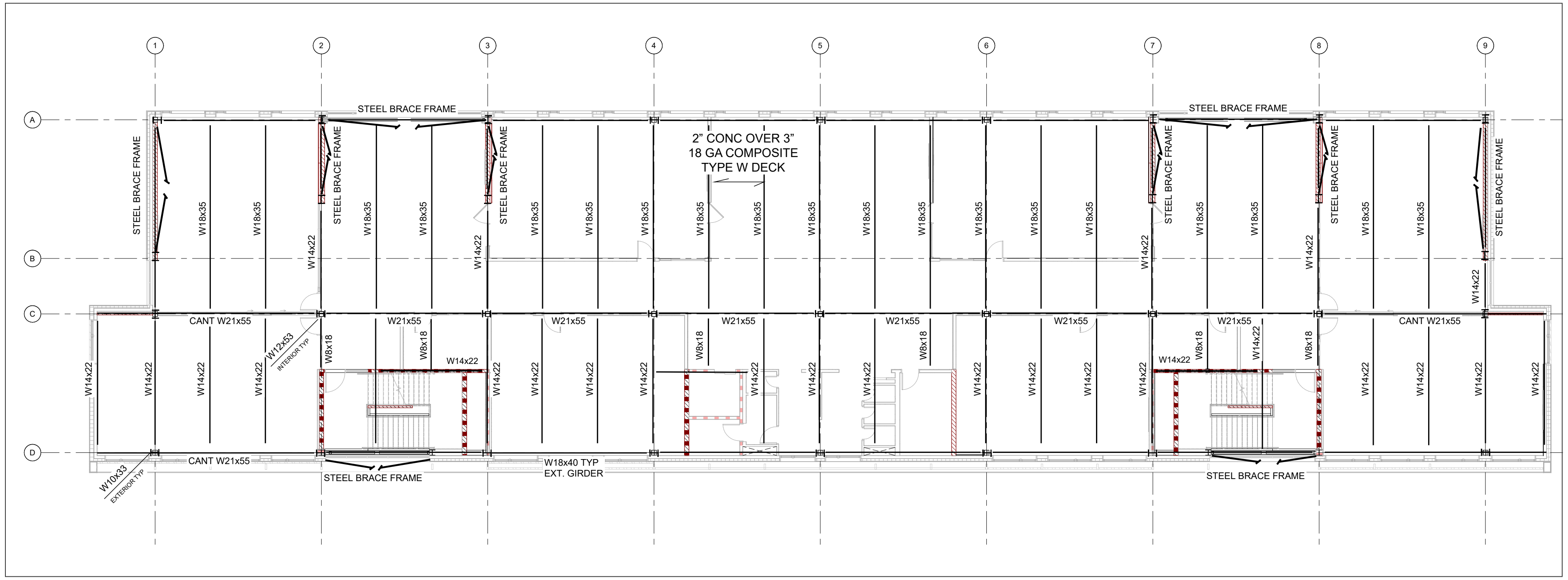
Our approach to the structural design of this school prototype is to provide an economic solution for a typical steel building and a mass timber building for comparison purposes. The steel baseline scheme consists of steel wide flange beams, steel columns, and distributed steel brace frames. The floor structure is a standard steel composite floor deck with concrete topping and steel deck at the roof. This is typical for many multi-story classroom buildings currently in Washington State, and as such will act as the baseline. (See drawings, top right, for a typical framing plan and a typical detail for the steel scheme.)

The baseline steel building was then compared to a multi-story classroom block of mass timber construction, with the primary building frame consisting of glulam beams and columns, with CLT floor and roof panels. This building has been modeled as a Type IIIB building, as outlined in Section 601 of the International Building Code (IBC), and was designed with Heavy Timber sizing in mind. The following sections describe this scheme in more detail. See drawings, bottom right, for a typical timber framing plan and section detail.

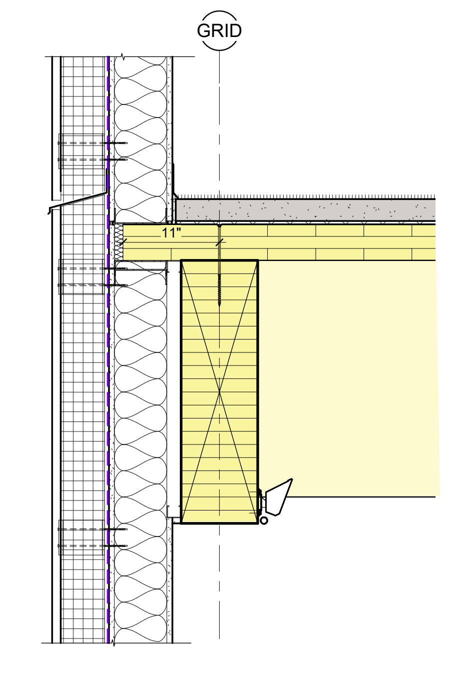
For both concepts, it was imperative that we provide an open floor plan, with minimal fixed walls and an adaptable column layout. This ensures that the design will meet the needs of schools with varying program needs and allows for maximum flexibility for future use. We have also provided an occupiable rooftop for outdoor learning and a rooftop garden. This roof structure has been designed to withstand the live load associated with an accessible roof as well as the weight of raised planting boxes distributed throughout the roof structure.



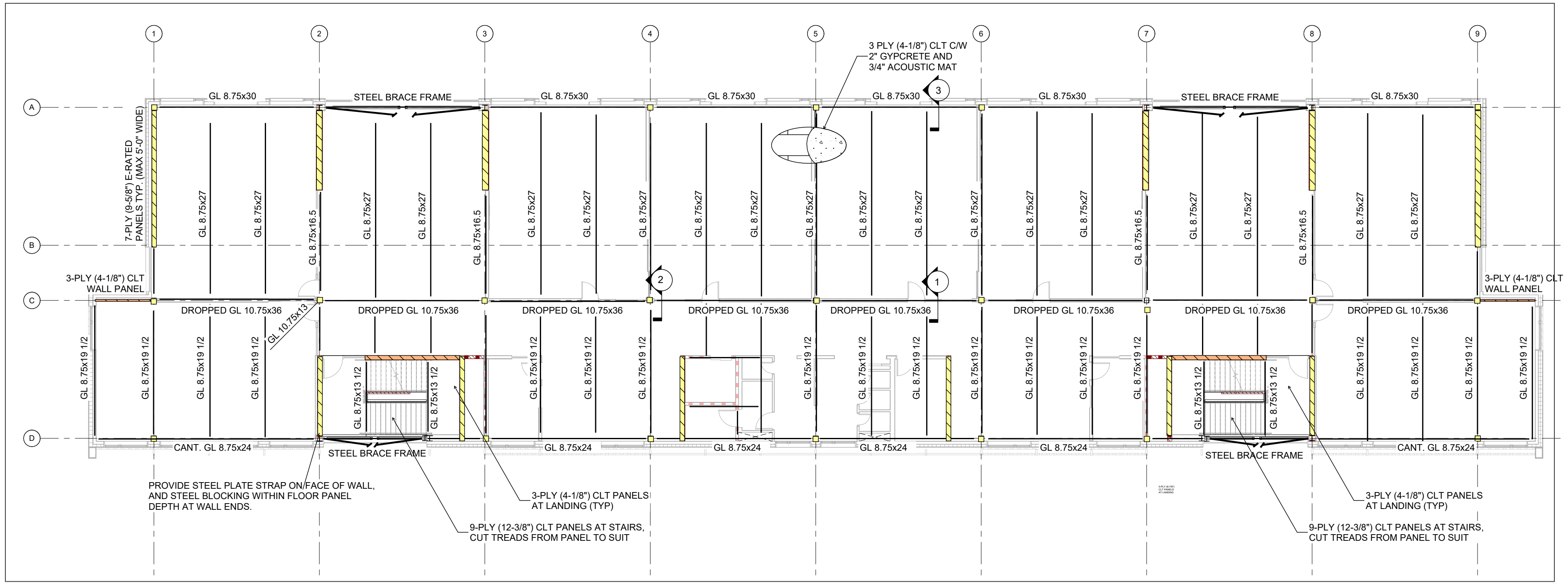
ABOVE: Exterior wall, steel construction detail.



ABOVE: Steel framing plan for typical upper floor.



ABOVE: Exterior wall, mass timber construction detail.



ABOVE: Mass timber flaming plan for typical upper floor. North-south walls highlighted yellow are CLT shear walls.

N

ECONOMIC DESIGN

Both the steel and mass timber schemes were designed with economy in mind, using stacked floor plans and a uniform grid layout. For the steel framed building, beam and column sizes were optimized to ensure a low cost as well as meeting performance objectives with respect to deflections, vibrations, and acoustics.

To compete with traditional construction methods, mass timber design must be efficient in its planning, layout and structural design. Many project types utilize a structural grid of columns and beams to frame the building. **Optimized mass timber grids and spacing of elements will often be different than steel or concrete design, but similar spans can be achieved.**

Understanding the dimensions of framing members, even at a schematic planning level, is essential for space layout and realistic integration of services.

Working with the structural attributes of the wood, aspects such as floor-to-floor heights, horizontal and vertical clearances, and spans can be adjusted and optimized. Adding several purlins between primary beams, for example, may allow for a more efficient floor system, but could create a problem for service integration. On the other hand, creating spans that are too large could necessitate using very deep beams, imposing head-height issues and problems with running services.

The structural properties of mass timber elements may also differ depending on the manufacturer and the wood species. The dimensions of a mass timber product will have a direct correlation to cost, and the more wood fiber in a mass timber building, the greater the cost. **Optimizing the amount of wood used in a project will also optimize the overall cost. This is known as fiber-optimized design.**

Larger spans and wider beam spacing results in fewer overall structural components in a building. This means fewer crane lifts and less time attaching elements during construction, which reduces the overall schedule. Finding the right balance between layout and number of structural components is critical for programming, schedule, and overall cost.

As a solid wood panel, CLT contains considerable wood fiber which translates to cost. Using a 3-ply CLT panel in lieu of a 5-ply CLT panel is an approach that can reduce costs and help make CLT cost competitive with more traditional forms of construction. A 3-ply panel, however, has reduced span capabilities than a 5-ply panel, so additional support structure is required.

For this design, purlins are spaced 10-feet on-center to support the 3-ply floor deck. Using a 5-ply panel, the purlins could be spaced at around 15-feet on-center. Considering the amount of wood fiber in purlins and CLT, the 3-ply approach reduces the amount of wood by approximately 10%-15% and reduces the assembly depth by around 8”-12” per floor due to shallower purlins and thinner floor thicknesses. This strategy also saves money in reduced envelope and cladding costs.

In the end, we concluded that reducing the wood volume for our building, even with more total building elements, results in less overall construction cost. To further reduce the relative cost of the mass timber building, we have exposed many of the CLT and glulam elements to limit the extent of finishes that need to be installed. This in turn reduces cost, as well as provides the added benefit of exposed timber. In some areas it is necessary to conceal ceilings or walls for acoustics or service routing, and in turn additional surface treatments may be installed to those surfaces to aid in acoustic performance.

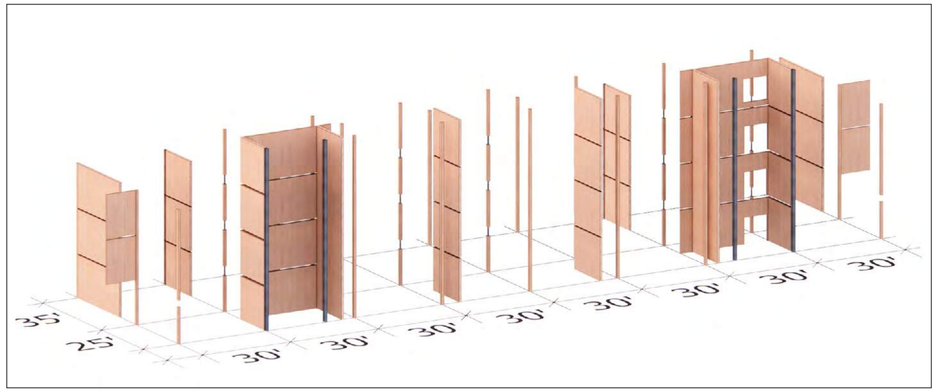
LATERAL FORCE-RESISTING SYSTEM (MASS TIMBER) HYBRID APPROACH

We have considered a hybrid system of CLT shearwalls and steel braces for the Lateral Force-Resisting System (LFRS). Along the length of the building, we have placed steel brace frames at the exterior walls to allow for as much an open floor plan as possible. In the perpendicular direction, we are using CLT shearwalls spaced strategically and aligning with our typical classroom. We have used a Seismic Response Modification Factor of R=3 for our CLT shearwalls based on current research, which limits the aspect ratio of CLT wall panels to be between 2 and 4. In our case, a 7-ply (9-5/8”) wall panel is used to transfer the lateral loads, and a maximum wall panel width of 5 ft will be specified to stay within the maximum aspect ratio requirement.

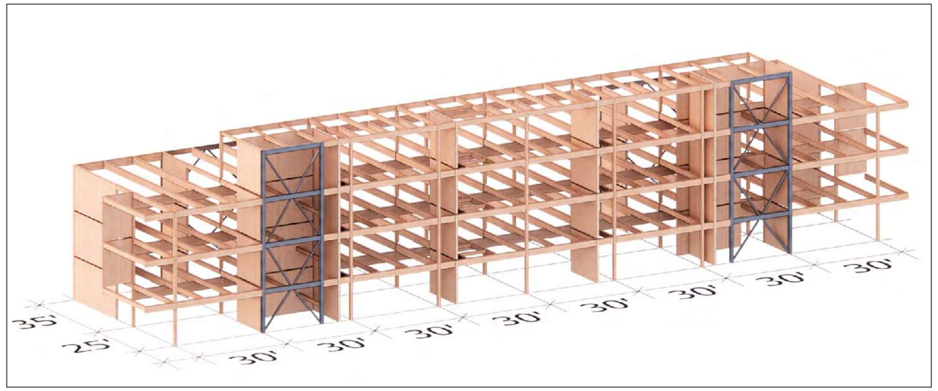
Multi-story mass timber lateral systems are not currently included in the prescriptive language of the 2018 International Building Code. As such, a school (Risk Category III) may require an Alternate Means & Methods request and discussions with the jurisdiction for how the project meets the design loads. Depending on the jurisdiction, a performance-based design in accordance with ASCE 7-16 Chapter 1 may be needed.[3] Starting this conversation early with jurisdictions is critical, and there is precedent in Washington State for use of CLT shear walls in a completed multi-story educational building.[4] Moreover, both ASCE 7-22 and SDPWS-21 have allowances for CLT shear walls which will be included shortly into the IBC.[5] As a final point, Fast + Epp has completed two multi-story schools in Vancouver, BC that utilize CLT shear walls.[6] Use of CLT shear walls is eminently possible, but because they are not yet codified, design teams may choose to use only steel brace frames in lieu of a hybrid system until code compliant lateral systems for CLT are advanced or additional funding is provided.

As such, only steel brace frames may be used along both the length and width of the building. In this case, fewer bracing elements are required compared to a hybrid steel and CLT shearwall system, provided the CLT floor diaphragm is designed for the increased spacing. This would allow a more open floor plan and added future flexibility for classroom layouts and programmatic needs.

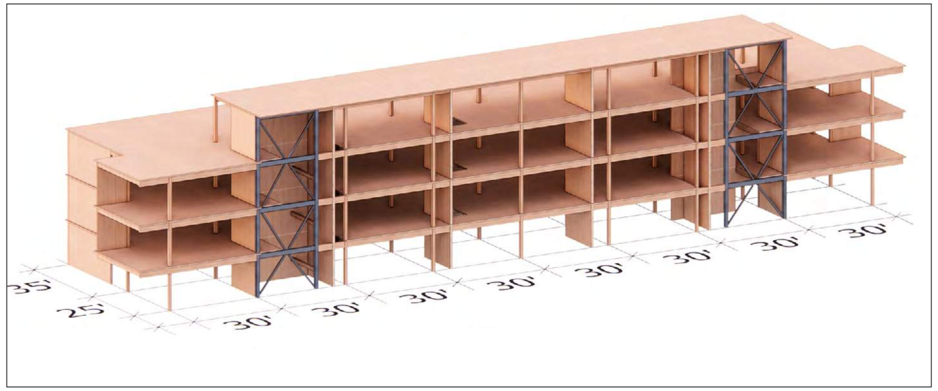
Whether all steel brace frames or a hybrid approach of steel brace frames and CLT shear walls are utilized as the LFRS, the amount of concrete and reinforcing steel in the building’s foundation is very similar. Therefore, the team did not approach foundation design as a cost or design differentiator between the different options.



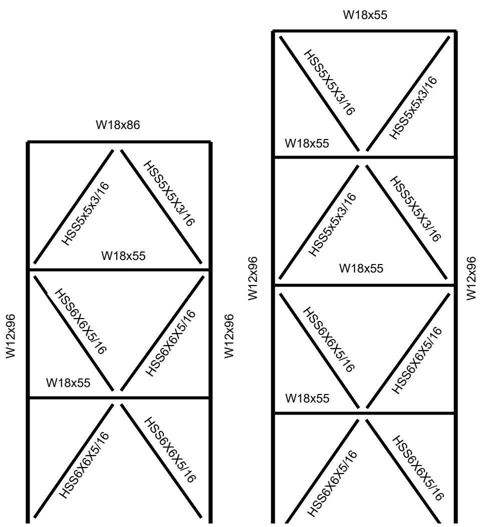
ABOVE: Vertical structure



ABOVE: Vertical, horizontal, and bracing structure



ABOVE: Vertical, horizontal, bracing, and CLT structure



ABOVE: Brace frame elevations for building's north side (left) and south side (right)

ALL TIMBER APPROACH

The feasibility of an all-timber lateral system was studied, using CLT shearwalls in both primary directions for our LFRS. We discovered, however, that in order to use CLT walls in the long direction, we would need to introduce central corridor walls or limit the window openings on the exterior walls in order to provide enough lateral wall restraint. The resulting solution both limited the daylight entering the building, as well as reduced the flexibility and open concept.

In addition, as window openings are introduced into the exterior CLT wall panels, there is significant material waste, which directly affects both the cost and sustainability of the project. Since cost, sustainability, and daylight are primary design parameters, a hybrid approach was chosen to meet the design intent and allow the flexibility that is needed for the school.

That said, for shorter buildings or schools located in areas of a lower Seismic Design Category, an all-timber approach would be more feasible.

IMAGE: CLT shear wall at Fast + Epp's Vancouver, BC office

Panelized or Volumetric?

Modular volumetric mass timber construction (top left image) is a burgeoning field and holds great potential for future developments that utilize repeating units, such as school classrooms, housing and hospitality.

While volumetric construction was considered for this study, the design team ultimately concluded panelization and prefabrication of individual components could better achieve long-term flexibility.

Structures that use longer spans can be challenging for modular construction due to maximum shipping dimensions. Long span grids are often better achieved using a post and beam structure rather than modular bearing wall systems, a common approach for volumetric boxes. The use of bearing walls can limit future flexibility of space. Without greater design thinking, volumetric boxes themselves may reinforce the traditional concept of classrooms, and provide little variability for creating larger shared learning communities that break-out from the teacher-centered learning approach.

While factory modular construction can be extremely efficient, volumetric systems traditionally use more materials than panelized systems. Doubling of structure at demising walls and floor/ceiling assemblies is common. While there are acoustic and construction time benefits, the additional materials can increase costs and carbon footprint. Multi-story mass timber modular construction in seismic zones is not common, and therefore could increase design, permitting and construction costs. Finally, there is not yet a mass timber modular fabrication pipeline in Washington State. With limited number of suppliers, school districts could be challenged to obtain multiple bids and construction times could be impacted due to manufacturer's limited capacity. While these challenges will be resolved in the future and warrant reappraisal, at this time panelized construction offers more competition, a wider pool of manufactures and contractors, and more standard design and details to achieve the project's goals for a large, multi-story building.

IMAGE, TOP LEFT:
Prototype modular CLT housing unit under construction by Forterra

IMAGE, TOP RIGHT:
Panelized CLT construction

CONNECTIONS AND STRUCTURAL DETAILING (MASS TIMBER)

The main objectives with respect to structural connections and detailing were to keep costs low, simplify installation, and to limit the amount of exposed steel.

In response, we have decided to install all CLT wall panels as single-story platform framed walls (also the basis of requirements in 2021 Special Design Provisions for Wind and Seismic, SDPWS, Appendix B for CLT shear walls), and considered three different types of connections for the beam-to-beam and beam-to-column connections, as follows:

> **Bearing plate**: These connectors are generally cost effective and simple to install. Many steel fabricators can manufacture them for specific project needs. In this system the bearing plate supports the beam and is screwed into the column face. Bearing plates can be exposed or can be covered with wood to conceal the steel and hardware.

> **Form-fitting:** Also known as concealed connectors, these are generally proprietary, but can be custom welded plates with inclined screws as well. Form-fitting connectors are generally more expensive, but with more U.S. manufacturing coming online, they are becoming much more cost competitive. They also require less installation labor and provide the cleanest architectural appearance and do not require additional labor from plugs. (See Wilson School of Design as an example)

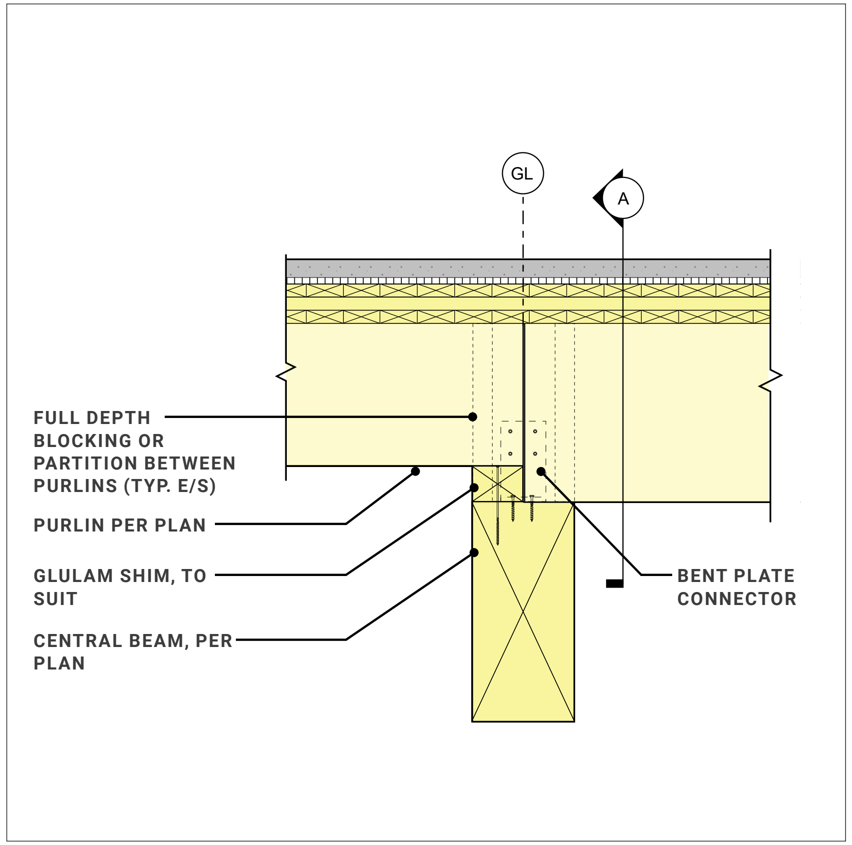
> **Knife plate and pin**: These connectors use welded knife plates attached to the column support. Beams are attached to the knife plate via bolts or pins which can be countersunk and plugged. (See Fast + Epp's new office as an example)

Along the center of the building, where connections are hidden from view, we decided to utilize a beam bearing connection. The purlins bear on the central glulam beam and are fastened in place with metal clips and wood blocking. This is simple to install, low cost, and is fully concealed.

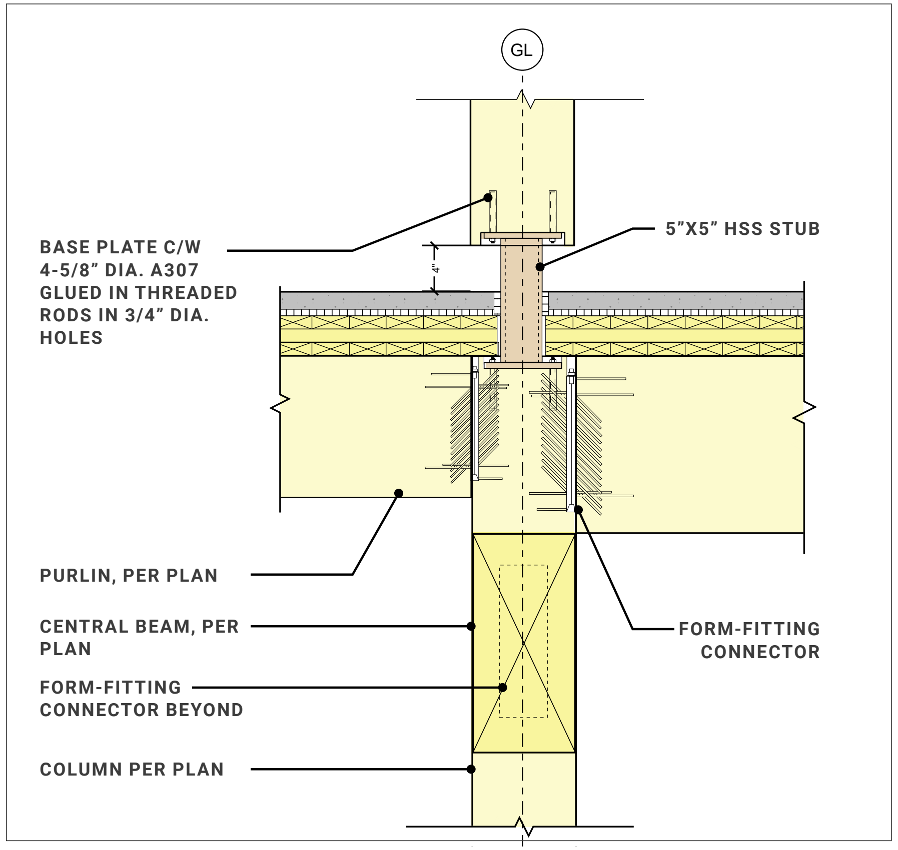
The second connection type is a concealed beam hanger for all beam-to-column connections as well as the flush framed beam-to-beam connections at the perimeter of the building. This detail allows for quick installation and maximizes daylighting into the classroom spaces by limiting the overall assembly depth. While not a focus of this study, these concealed beam-to-beam connectors can achieve fire-resistance ratings of at least 1 and 2-hours.[7]

The decision to install wall panels as single story walls was to allow maximum crane space while lifting CLT floor panels, as well as removing the need to carefully drop CLT panels down between upstanding walls.

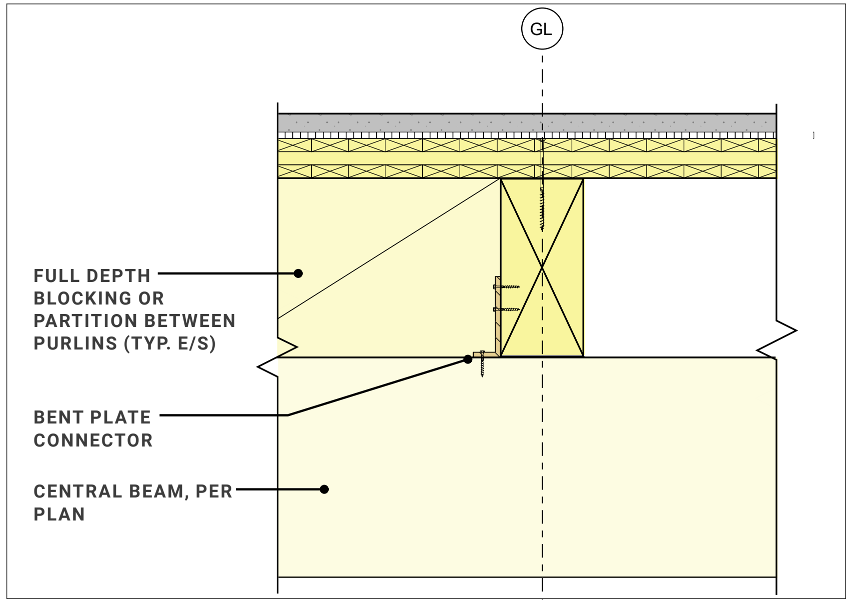
Column-to-column connections are achieved by a steel HSS stub with bearing plates. To promote cleaning and longevity, the columns are raised slightly off the floor plane. The HSS stub is typically concealed in partition walls and timber column exposed. If a fire-rated connection is needed, the exposed steel could use an intumescent coating, be encapsulated in a rated assembly, or potentially redesigned with a shorter stub so all steel is completely encapsulated by a minimum thickness of timber.



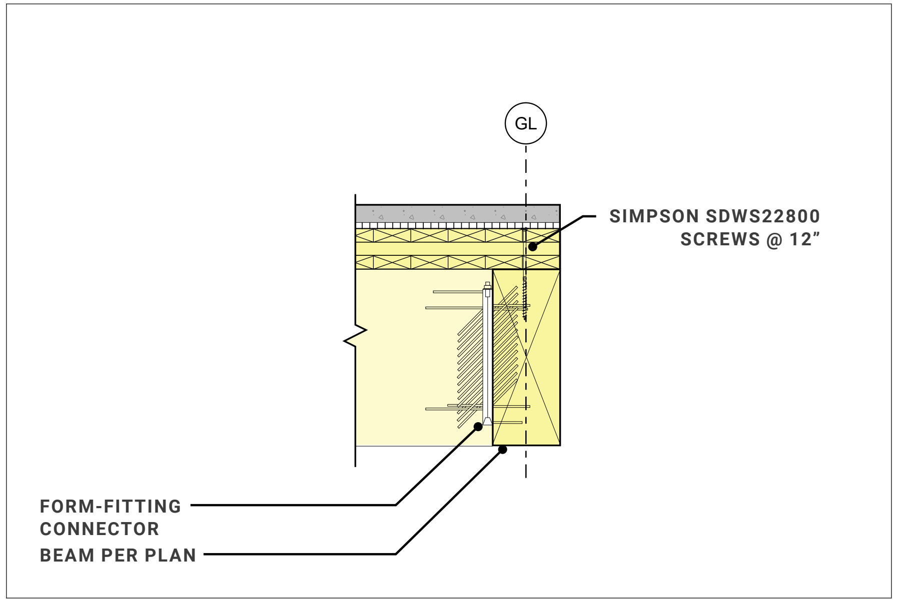
ABOVE: Typical Beam-to-Beam Bearing Detail (Detail 1)



ABOVE: Typical Beam-to-Column Connection Detail (Detail 2)



ABOVE: Section A



ABOVE: Typical Beam-to-Column Connection Detail (Detail 3)

The CLT walls are connected to the foundation wall by means of screws and a continuous steel angle, and floor to floor CLT connections are provided by a combination of steel angles, plates, and screw fasteners. All details allow for vertical shims or grout for tolerance, and will vary slightly depending on the timber species, supplier, and panel sizes provided by the chosen manufacturer.

See typical details on this page and the previous page.[8]

IMPLICATIONS FOR DIFFERENT BUILDING HEIGHTS AND LOCATIONS

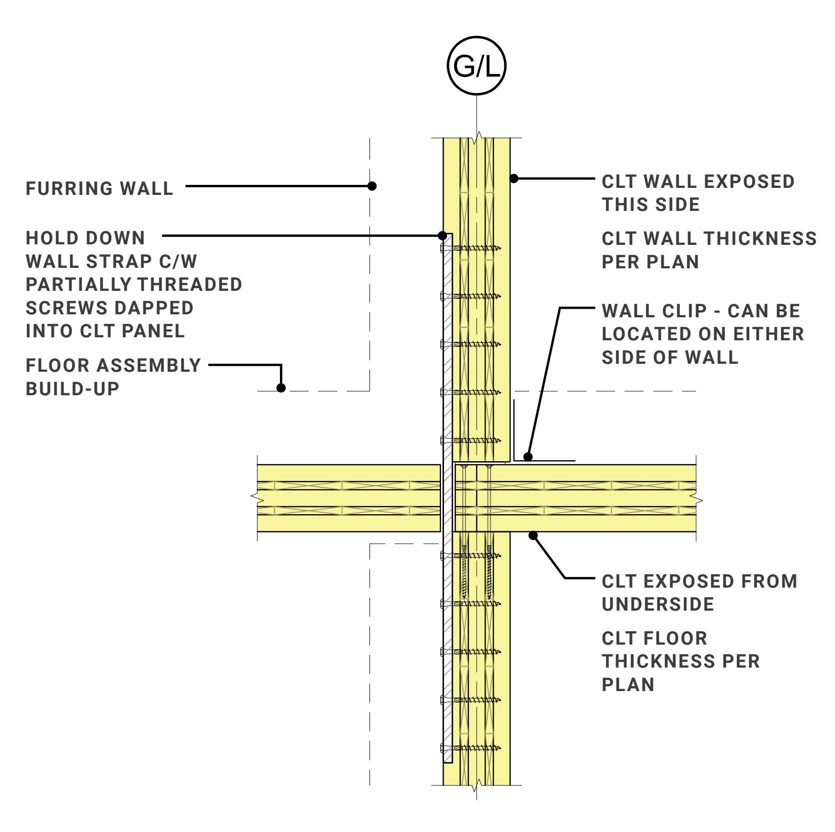
Shorter Wood Schools
If a school with fewer stories were constructed, there would be multiple benefits with respect to the building structure and design. Due to the reduced building weight and seismic load, the footings would decrease in size. As the seismic forces are reduced, there would also be a possibility to reduce the number of shear walls or allow more flexibility as to where shear walls are located.

In the case where seismic loads are significantly reduced, an all-timber approach would also be feasible as discussed previously. Further, there would be a reduced number of hold downs, fewer fasteners, and a reduction in miscellaneous steel required which results in a lower overall building cost.

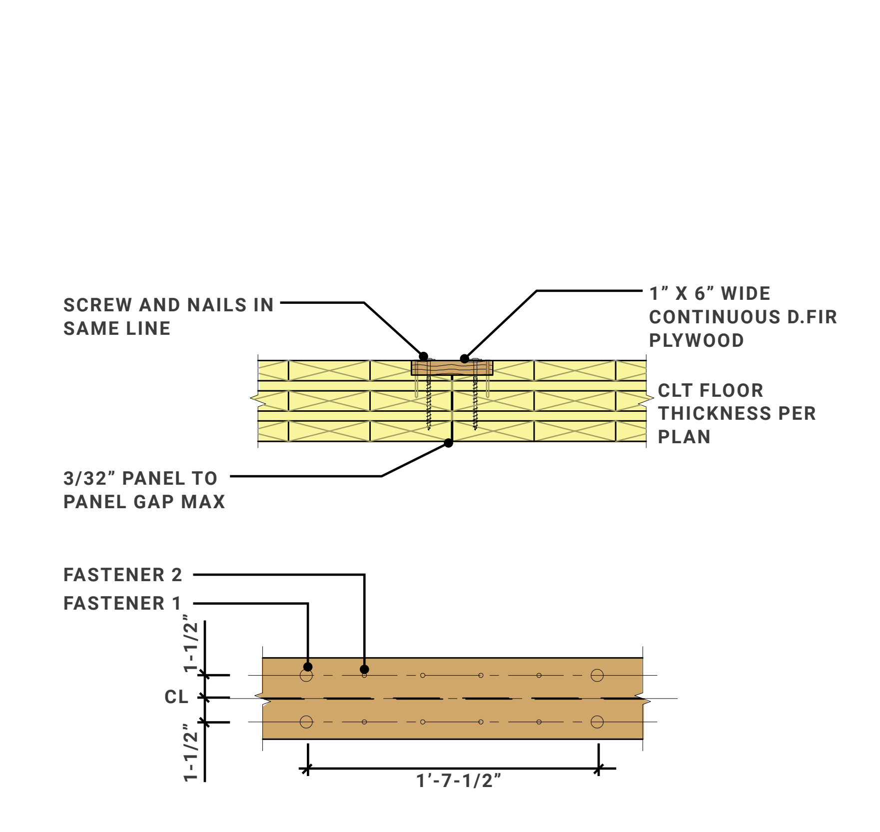
Taller Wood Schools
On the other hand, a school with more levels would require an increase in shear wall length, and likely an increase in hold down, spline, and foundation sizes. Depending on the area and height of the school, the construction type may also change to require a fire rated primary frame.

If a fire resistance rating of one-hour or greater is required, the primary frame may need to increase in size, including an increase in floor panels from a 3-ply to a 5-ply CLT system in order to withstand the required char rating, or fire-rated finishes would need to be applied, such as gypsum wall board. GLT columns and beams may be able to withstand a one-hour char without addition of extra material. However, if a two-hour or greater fire-rating is required, the cross-sectional area of the GLT elements would need to be increased, or encapsulation added, or both.

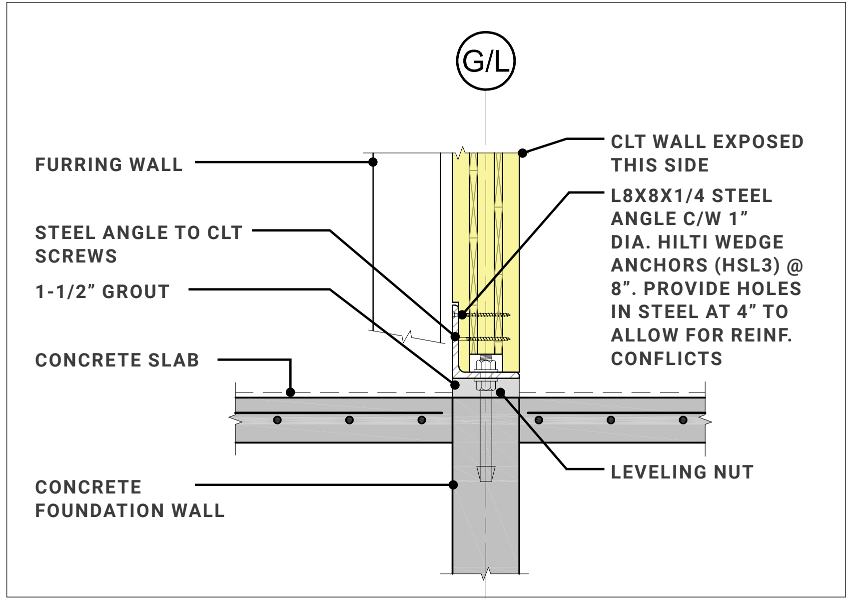
Different Locations
The implications for building a school in various regions throughout Washington State could have significant impacts on the structural system as well. For purposes of this report, we have assumed that the building is founded on Site Class C soils, and Seismic Design Category D has been used. This is a somewhat conservative approach, since there are locations within the State with a lower Seismic Design Category, which could result in significant benefits to the overall building structure as mentioned in the sections above.



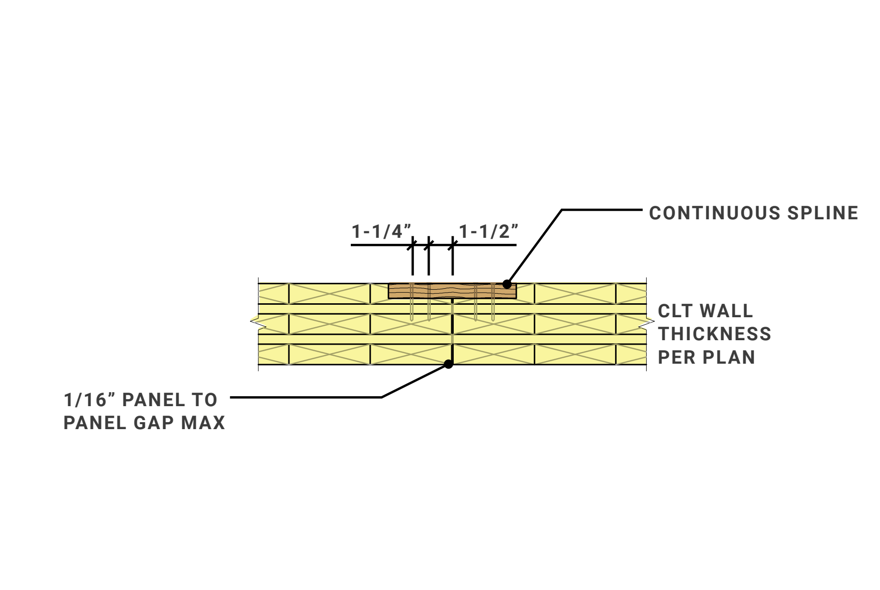
ABOVE: Typical Floor-to-Floor Hold Down Splice Section Detail



ABOVE: Typical CLT Panel-to-Panel Floor Joint Plywood Spline



ABOVE: Typical CLT-to-Foundation Wall Section Detail



ABOVE: Typical CLT Panel-to-Panel Floor Joint Plywood Spline

SECTION 04A FOOTNOTES

FOOTNOTES

1 Rowell, Roger, Handbook of Wood Chemistry and Wood Composites (Boca Raton, Florida: Taylor & Francis Group, 2005), pg. 317.

2. Gordon, J.E, The New Science of Strong Materials (Princeton, New Jersey: Princeton University Press, 1984), pg. 12n.

3. A performance-based design, if required, would require peer review and potential increased review and engineering time. ASCE 7-16 is a standard for minimum design loads and associated criteria for buildings and other structures references in the International Building Code (IBC).

4. CLT rocking shear walls have been permitted in Washington through a Code Alternate and had a non-linear analysis in a Seismic Design Category B region of the State. See the following paper for additional information:
Blomgren, Hans-Erik; McCutcheon, Jack; Sinha, Arijit; Zimmerman, Reid B. (2020). Catalyst - A Mass Timber Core Wall Building with High Ductility Hold-Downs in a Seismic Region. World Conference on Timber Engineering (WCTE) 2020, Santiago, Chile.

5. 2021 Special Design Provisions for Wind and Seismic (SDPWS) provides a Response Modification Coefficient ("R" factor) of 3 for CLT shear walls and 4 for CLT shear walls using high-aspect-ratio panels. These values align with the assumptions used in this report.

6. Fast + Epp designed Bayview Elementary and Begbie Elementary, two multi-story schools constructed using CLT shearwalls and CLT diaphragms.

7. CBH Concealed Beam Hanger Minimum Fire Char and Fastener Edge Distances. Simpson Strong-Tie Site. (2021, February 17). Retrieved July 10, 2021, from https://www.strongtie.com/miscconnectorsforengineeredwood_engineeredwood/cbh_hanger/p/cbh

8. Note: While not used for this study, WoodWorks has published an index of connections details for a wide variety of mass timber conditions. See:
KL&A Engineers & Builders, Oz Architecture, Swinerton Builders, & WoodWorks. (2021, August 21). Woodworks Index of mass timber connections. Retrieved November 4, 2021, from https://www.woodworks.org/wp-content/uploads/wood_solution_paper-Mass-Timber_CONNECTION_INDICES-Q.pdf

SECTION 04A IMAGE CREDITS

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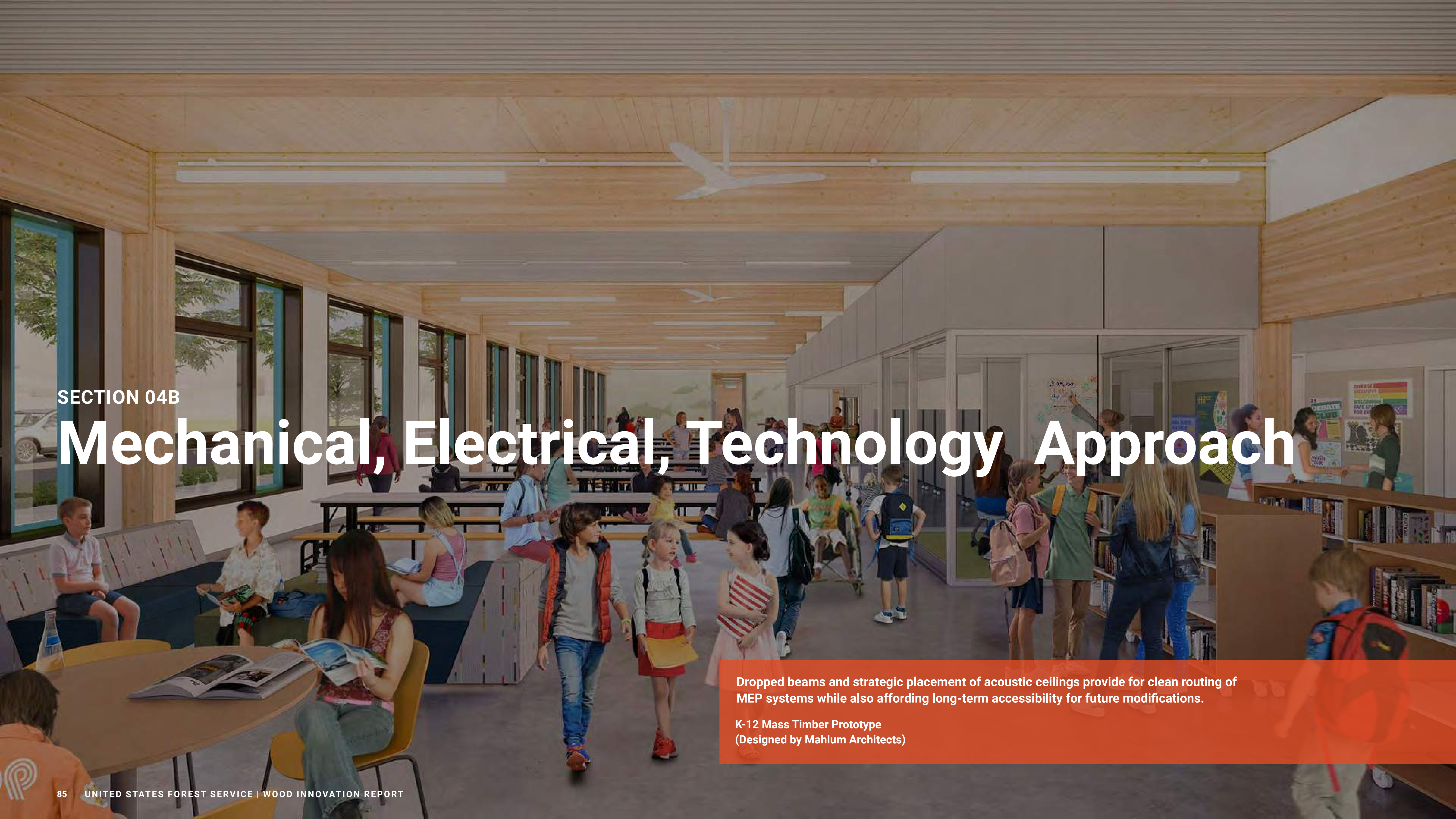


SECTION 04B

Mechanical, Electrical, Technology Approach

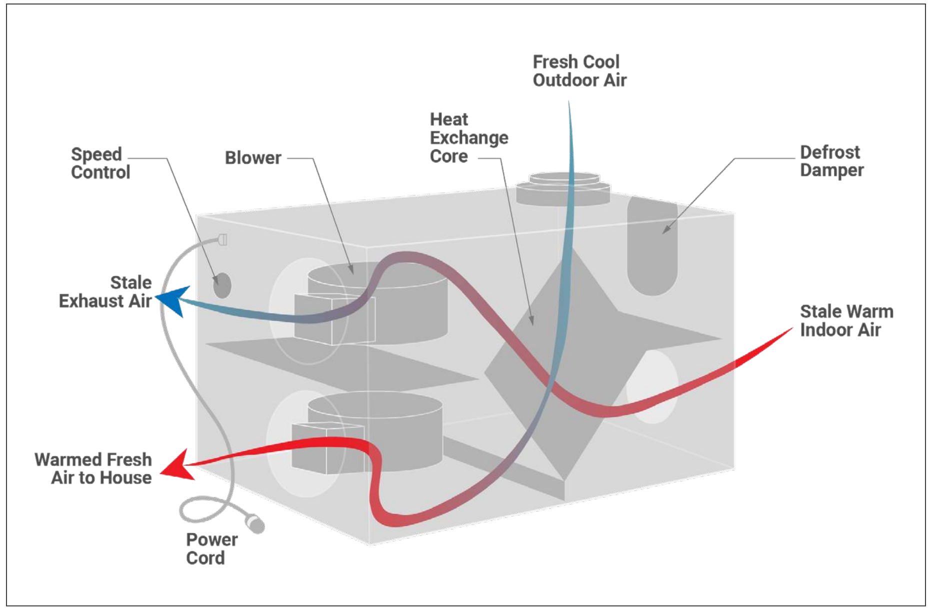
Dropped beams and strategic placement of acoustic ceilings provide for clean routing of MEP systems while also affording long-term accessibility for future modifications.

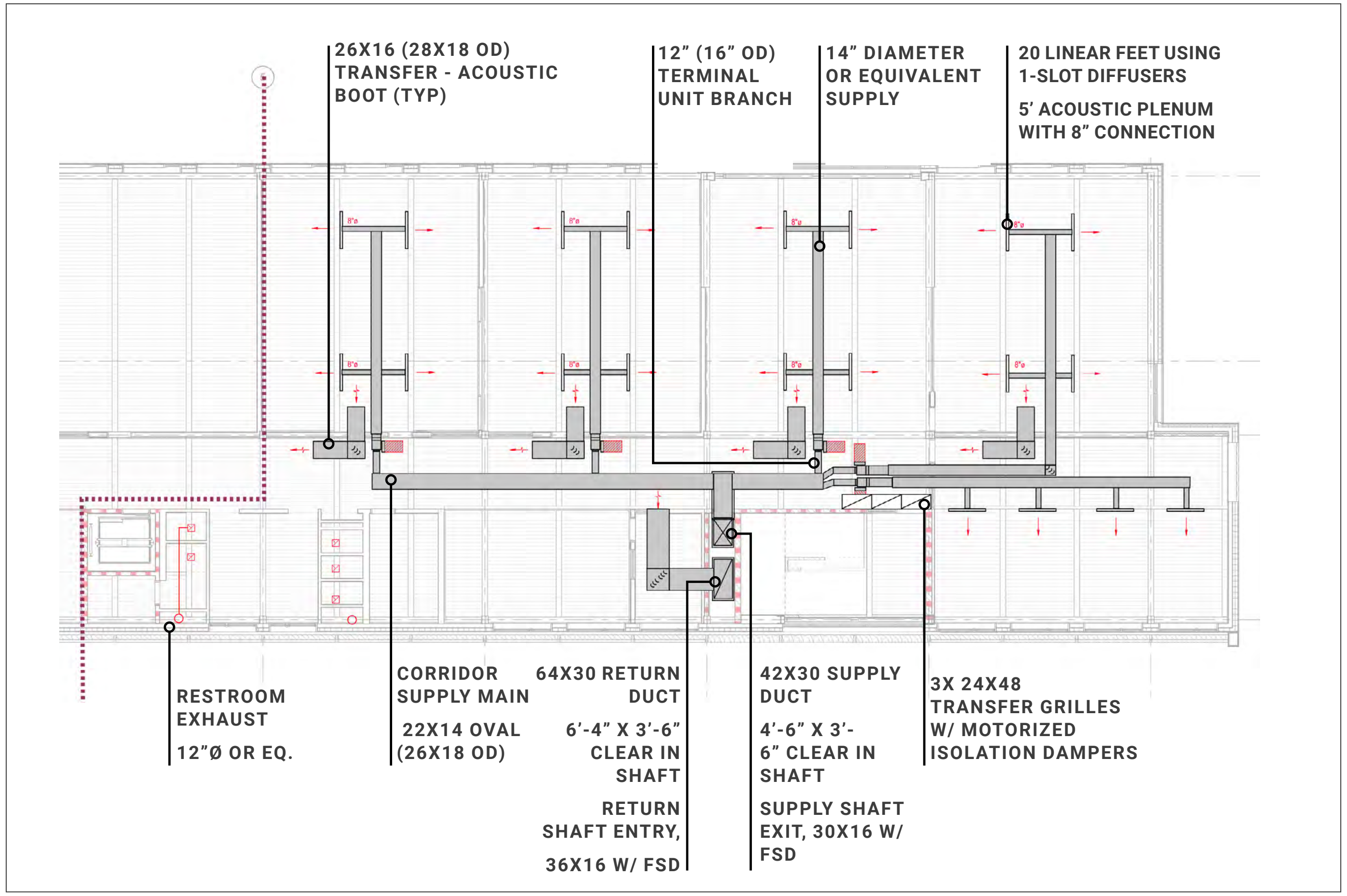
K-12 Mass Timber Prototype
(Designed by Mahlum Architects)

To drive down energy use, the school is designed to maximize the use of natural ventilation and passive cooling in the classrooms.

RIGHT:
Diagram of Energy Recovery Ventilation (ERV) Unit for DOAS system; ERVs reduces heating and cooling needs by recapturing waste heat and coolth, saving large amounts of energy use.

BELOW:
HVAC typical ducting layout. Dropped interior beams allow the ducting to run unimpeded throughout the building and accommodate different layouts and future flexibility.





This is accomplished with a high-performance envelope, operable windows, and additional passive strategies including ventilation stacks, exposed mass for minimization of temperature swings, careful placement of glazing, use of exterior and interior shades in select locations, and ceiling fans within classrooms.

In addition to reducing energy use, the high-performance envelope and passive elements represent a cost saving opportunity for mechanical systems. **The system described below can be expected to cost 30-40% less than a conventional HVAC system.**

When the outside air temperature is 28°F or above, the heat loss through the envelope will be lower than the heat generated inside the space due to occupants and lights. For night low limit, morning warmup, and colder days, electric cove heaters will be provided to maintain space temperature. Cooling will be achieved through natural ventilation provided by manual operable windows and relief stacks, supplemented with cooling of the mechanically provided ventilation air.

Ventilation air will be provided via centralized dedicated outside air units (DOAS) with heating/cooling coils served by remote heat pumps. The DOAS units will be equipped with a heat recovery wheel, which transfers energy from the return airstream to the supply air stream (see diagram, top right). The heat recovery wheels will have a minimum total effectiveness of 65%. The heat recovery wheels will be provided with face and bypass dampers to reduce fan energy when heat recovery is not desirable.

There will be two DOAS units located in the mechanical penthouse, each serving one half of the building.

Two vertical shafts provide the main supply and exhaust air ducting for each half of the building. Horizontal corridor mains tap off from the vertical supply duct. Because the central beam running down the corridor is dropped, supply ducts can tap off the corridor main and access any space in the building unimpeded. This strategy facilitates flexibility by allowing the fresh air supply and exhaust to be easily updated whenever room types change over time.

The building is designed to operate as a "mixed mode" system that provides both natural ventilation and supplemental heating and cooling. This system will be very energy efficient. The design strategy behind this system will require the occupants to understand there will be a wider range of operating temperatures in the classroom than what they might be used to.

ABOVE: Criteria for Human Comfort (clockwise from top); clothing insulation, air flow, air temperature, radiant temperature, metabolic rate and humidity.

ABOVE: A red light/green light panel mounted adjacent to operable windows allows teachers and students to know when to open and close windows for passive cooling.

ABOVE: Chart indicating indoor and outdoor air temperatures in late July. Blue area is time of day when night flush and operable windows can be used for passive cooling. Red area is time when windows should be closed.

OPERATION	REFERENCE	TEMPERATURE
Cooling	ASHRAE 0.4% (Dry Bulb/Mean Coincident Wet Bulb)	85.3°/65.1°F
Heating	ASHRAE 99.6% (Dry Bulb)	25.4°F

TABLE A: Outdoor Conditions – Zone 4C, Seattle, WA

OPERATION	REFERENCE	TEMPERATURE
Cooling	ASHRAE 0.4% (Dry Bulb/Mean Coincident Wet Bulb)	92.9°/62.8°F
Heating	ASHRAE 99.6% (Dry Bulb)	5.1°F

TABLE B: Outdoor Conditions – Zone 5B, Spokane, WA

The design team will use the following strategies to minimize the range of operating temperatures:

Extended Comfort Range
Criteria for acceptable thermal comfort are taken from ASHRAE Standard 55, "Thermal Environmental Conditions for Human Occupancy." There are six factors that determine thermal comfort: (1) Metabolic Rate, a measure of the body's heat output for a given activity level; (2) Clothing Insulation; (3) Air Temperature of the surrounding air; (4) Mean Radiant Temperature, a measure of the temperatures of surfaces in a space; (5) Air Speed across a building occupant's body; and (6) Humidity, the water vapor content of the air in the interior environment. Ceiling fans extend the range of acceptable temperatures for cooling by 3 to 5 degrees Fahrenheit by increasing air speed in the space, which increases heat transfer from the skin.

Active Heating Mode
During the heating season, one hour before the teachers are set to arrive, the cove heaters located in the classrooms will switch on to bring the room up to a temperature suitable for normal occupancy. Once normal occupancy begins, and ventilation air is needed, the DOAS units will deliver tempered ventilation air.

Active Cooling Mode
The DX cooling coil in the DOAS units will deliver ventilation air to the space at temperatures down to 55 0F based on demand.

Natural Ventilation Mode
Classrooms will have operable windows and a red light/green light system to alert the teachers and students that outdoor conditions are conducive to natural ventilation and passive cooling. During these times, the operable windows are to be opened and the HVAC systems are to be turned off. Outdoor air will pass through the classrooms into the corridor ceilings, then exit the building via the stairwells, which are designed as ventilation stacks (see further discussion on the following page).

As a supplemental option, exhaust fans in the DOAS unit may be activated to increase the draw of outside air through the classrooms. Teachers/students will need to be educated on the importance of closing the windows at the end of the day or when outdoor temperatures are unfavorable for natural ventilation.

Equipment List

> Dedicated outdoor air handling units: Two at 12,000 CFM

> Remote Air-Cooled Condenser: Two at 32 Tons

> Terminal Units: Thirty-five at 700 CFM

> Electric Cove Heaters: One-hundred at 900W (Climate Zone 4C) or 1200W (Climate Zone 5B)

EXHAUST SYSTEMS

Exhaust air for restrooms, janitor closets, and other general room exhaust will be ducted to the mechanical penthouse and used for heat recovery at the DOAS units.

Radon Exhaust System
Exhaust fans and sub-slab soil exhaust system will be provided for radon gas mitigation.

> One fan will be provided for each 15,000 SF area of building sub-slab area served.

> An audible alarm will be provided to notify fan failure.

> Exhaust fans will be located at roof level.

> Exhaust fans will operate continuously.

Equipment List

> Exhaust fan: Two at 200 CFM

> 2.4 controls

CONTROLS

A direct digital control (DDC) system will be provided to control and monitor all HVAC equipment and systems. Valve and damper actuation will be electric type. The control system will perform all required control functions, including optimization of equipment and system performance, reliability, equipment life and energy consumption.

MEASUREMENT AND VERIFICATION

An extensive measurement and verification system is anticipated to carefully monitor the building's energy use. Data on incoming solar energy will be collected and displayed on flat screen monitors in the lobby. The building's energy use will be compared to this natural budget and the building's CO2 emissions can also be tracked.

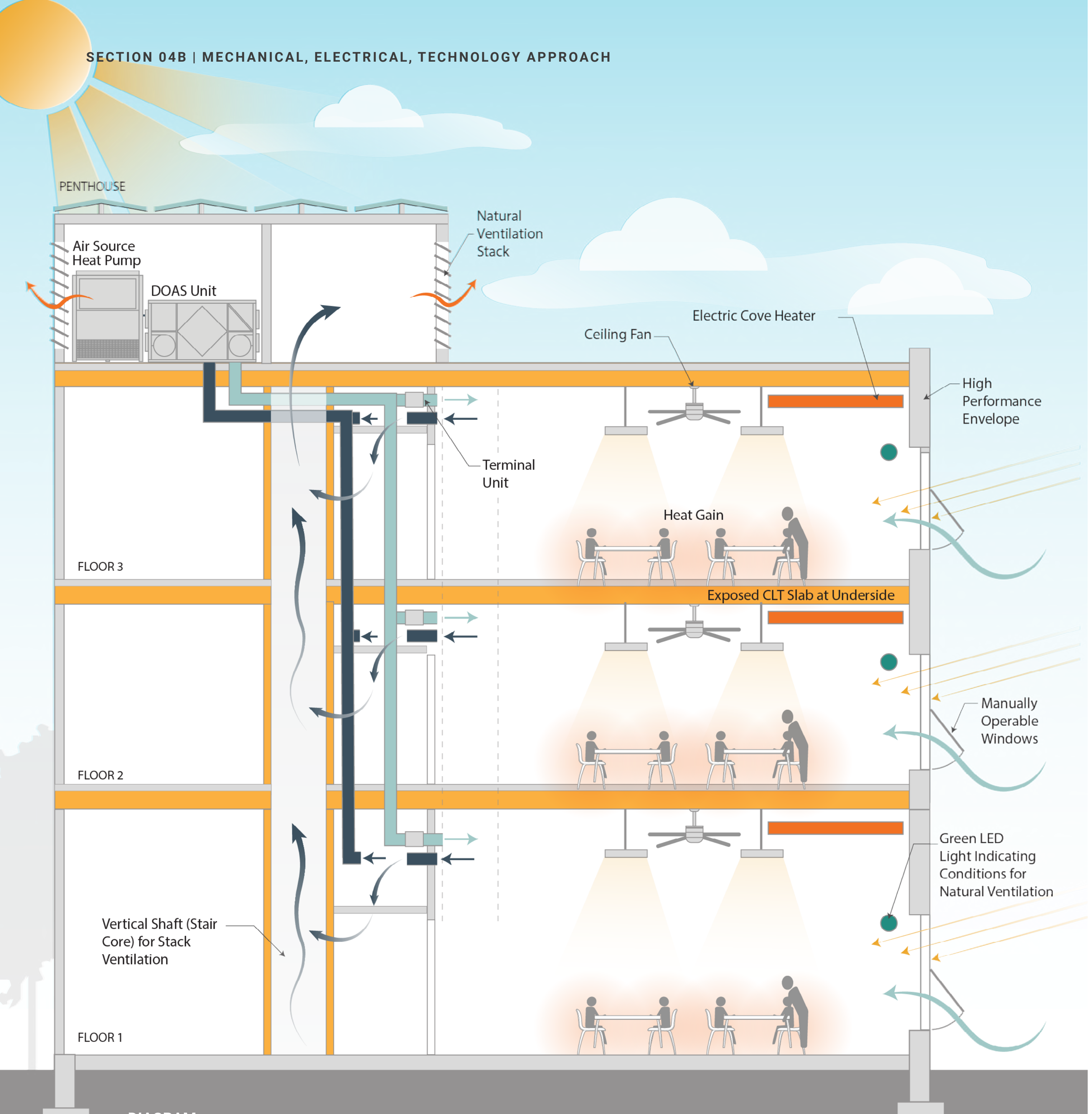


DIAGRAM:
Stack ventilation strategy, passive cooling and integration with active systems.

Integration of passive cooling systems with required building elements provides double-duty. This is a pathway to reduced energy consumption without adding new building elements and subsequent costs.

Windows are needed for learning spaces, for example, so why wouldn't they be operable to allow natural ventilation? Stair cores are needed for circulation, so what if these could be effectively harnessed for stack ventilation?

STACK VENTILATION

Stack ventilation is a technique that takes advantage of warm air's natural buoyancy, moving air vertically without fans or other mechanical equipment. With flexibility of interior space a core tenet of this design, adding stack ventilation chimneys to individual classrooms does not make sense because this would inhibit future changes. Because the stair cores are fixed elements, integrating stack ventilation at these areas will not impact future flexibility. Here's how utilizing stack ventilation at the stair cores could work:

> Stair doors use automatic hold-opens to allow air to passively move from corridors into the stair cores. Exhaust air is transferred from classrooms to the corridors, where it can be mechanically exhausted or not. Transfer grilles above the exit stair doors allow air to move naturally into these vertical cores and out of the building.

> Stair doors are integrated with the building's fire alarm system and close during an emergency to prevent air movement and most importantly smoke from entering these egress paths.

> Automatic ventilation dampers are located at the top of the stair core to allow exhaust air to naturally escape the building. These dampers are connected to the building's fire alarm system and would close automatically in the event of a fire.

This approach may be questioned by building jurisdictions as utilizing interior exit stairs for anything other than egress may not be allowed. Nevertheless, with the urgent need to radically decrease energy use in buildings, the design team sees this as a solution necessitating further exploration. Stair doors on hold opens are allowed, as are openings in stair exterior walls. However, in the case that a building authority rejects the design outlined above, there are several alternative options outlined below:

> Provide additional fire and life safety measures so that the design exceeds perceived code required levels of safety.

> Provide additional vertical shafts independent of stairs to allow stack ventilation. This approach adds cost and has spatial implications but is quite possible without inhibiting future flexibility.

> Make the primary vertical exhaust shaft cores slightly larger and use them for natural ventilation. These shafts would terminate at the roof with a roof turbine to assist in moving stack air.

> Use existing exhaust cores but provide fan assist to move ventilation air vertically out of the building. If desired this strategy can easily be combined with the 3rd option above to create a hybrid system.

Stack ventilation works in unison with operable windows at the building's exterior to bring-in cool air when exterior conditions are right. In the cooling season, this will likely mean opening windows in the morning hours and closing them in late morning or early afternoon. For passive ventilation, operable window free area needs be about 4% of floor area for a room and window should open approximately 30 degrees.

Exposing mass timber ceilings could provide additional energy efficiency measures through thermal mass. Some building materials can effectively store thermal energy to buffer against internal temperature fluctuations. Exposed concrete is the best-known material used to take advantage of thermal mass. Materials with high thermal mass absorb heat generated during the day, thereby reducing cooling loads. At night, thermal mass surfaces are cooled to release heat they gained during the day and pre-cool them for capacity to absorb heat again the following day. While mass timber is not as effective as concrete for thermal mass, studies have shown that it does provide some benefit. One study from Australia "confirmed the ability for mass-timber to act as a thermal capacitor, and additional insulator, reduce general heating and cooling energy loads and reduce peak heating and cooling energy loads".[1] While this area requires additional research, utilizing exposed CLT for thermal mass as part of the overall cooling strategy could provide additional benefits.

IMAGE:
Discovery Fire in Klickitat Meadows, east of Yakima, Washington

Implications of Wildfire Smoke and Ventilation

In much of the western United States, wildfires have become more frequent and severe. Wildfire smoke is a well-known health hazard, particularly for vulnerable populations such as young children.

During the summer of 2021, more than 80 large fires burned across the Western States creating thick smoke plumes that spread thousands of miles, leading to dangerous concentrations of air pollution known as PM2.5.

When outdoor air is hazardous, the best mitigation strategies are ventilation reduction and air filtration. In areas where wildfire smoke is a concern, DOAS ventilation systems can be equipped with HEPA filters, carbon filters, and a recirculation damper. The damper will allow the units to operate in recirculation mode during fire season (see diagram at right). Such strategies can allow schools to be occupied safely, even when outdoor air quality is very poor.

DIAGRAM:
Carbon dampers allow DOAS ventilation systems to operate in recirculation mode during fire season.

COVID-19 AND HVAC DESIGN

The COVID-19 pandemic upended in-person learning for hundreds of thousands of K-12 students across Washington State.[2] Closed schools impacts children and parents in many ways, often unequal and disproportionate depending on socio-economic status. In addition to complicating the learning process and growth of interpersonal skills, school closures create hardships for families without reliable internet access (or none), for those that depend on free or reduced meals, or those that cannot find childcare during school hours, to name just a few issues. Keeping schools open and reducing the risk of viral spread is paramount for our State's communities.

COVID-19 also precipitated a shrinking school enrollment in many places around Washington State as parents turned to home schooling or other private educational options. A digital divide has meant many simply cannot attend school, which leaves an educational gap when students return to school post-pandemic. Across the country, the school boards association in Fall 2020 estimated between 1 and 3 million students did not attend school due to pandemic-related issues.[3]

School design can be one strategy, amongst many, to keep children enrolled, even during a health crisis. While our knowledge of COVID-19 and its transmission is incomplete but growing, there are several agreed-upon strategies that can be employed to reduce the risk of spread. For a complete discussion of COVID-19 and schools, please refer to the American Institute of Architects (AIA) report Reopening America: Strategies for Safer Schools, which can be found on-line at the AIA's website.[4]

It is believed that COVID-19 virus droplets can be aerosolized and transmitted through the air, which is likely the most important culprit for spread. This project has confronted this issue with several key design strategies: Use a Dedicated Outdoor Air System (DOAS) to supply fresh ventilation air to the building occupants. Unlike other types of mechanical air delivery systems, DOAS provides 100 percent fresh outdoor without any mixing or recirculation of air from inside the building. The fresh air is pulled from the building's roof where there is little threat of the presence of COVID-19.

> Utilize large operable windows to allow fresh air from the outside to enter classrooms and other spaces in the building.

> Provide generous amounts of windows and ensure that most spaces have direct access to outside views. While natural daylight and views has been demonstrated to be healthy for indoor users, daylight has also been shown to kill the COVID-19 virus. Consequently, interior spaces with generous windows and natural light can be safer.

> Provide larger classrooms or classrooms with fewer students to maintain a safe distance between occupants to limit the spread of the virus. Because the design of this building does not utilize interior load-bearing walls, classroom configurations can be expanded, contracted or reconfigured in a variety of different ways.

> Provide a one-way flow of students, which can be accommodated by the building's design and location of stairs.

> Provide hand washing areas at major building entries and throughout the building. Sinks, lavatories and hand drying should be touchless if possible.

> Utilize single occupancy water closets to reduce the risk of fecal transmission of the virus.

> Generous hallways that allow for appropriate social distancing.

HVAC OPERATIONAL RECOMMENDATIONS

> During perceived periods of risk, maximize outdoor air ventilation rates. Disabling demand control ventilation is a recommended strategy.

> During periods of perceived high risk, ASHRAE recommends 24/7 operation of air handling systems to improve dilution ventilation. This measure can have significant energy impacts and should only be considered during perceived periods of high risk. When outdoor conditions are appropriate, natural ventilation or mixed-mode strategies may be used in lieu of mechanical ventilation.

> Prior to building startup and reoccupation, HVAC systems should be operated for extended hours. Review HVAC programming to provide flushing at least two hours before and post occupancies. This includes operating the exhaust fans as well as opening the outside air dampers. Again, when outdoor conditions are appropriate, natural ventilation or mixed-mode strategies may be used in lieu of mechanical ventilation.

For mass timber buildings, electrical, data, lighting, and device coordination needs to occur early in the design process.

ABOVE:
Careful coordination around the CLT ceiling at the Capitol Childcare Center in Olympia, Washington (designed by Mahlum Architects) allowed conduit and other services to be concealed, thereby highlighting the beauty of wood without any other visual distraction. This strategy requires early coordination and planning with design, building, and manufacturing teams.

ELECTRICAL SERVICES APPROACH

Mass timber's solid construction means that this construction type does not typically have chases to run services. This lack of voids creates a conflict when exposing mass timber, as it could also lead to exposing service runs on the surface of these elements. Conduit, cabling, trays, and other services can lead to a cluttered, haphazard appearance that diminishes the beauty of the wood. With proper early planning, there are several strategies available to minimize the visual disruption of exposed services and allow the beauty of exposed timber to shine through as much as possible.

For ceilings, options to conceal services, include:

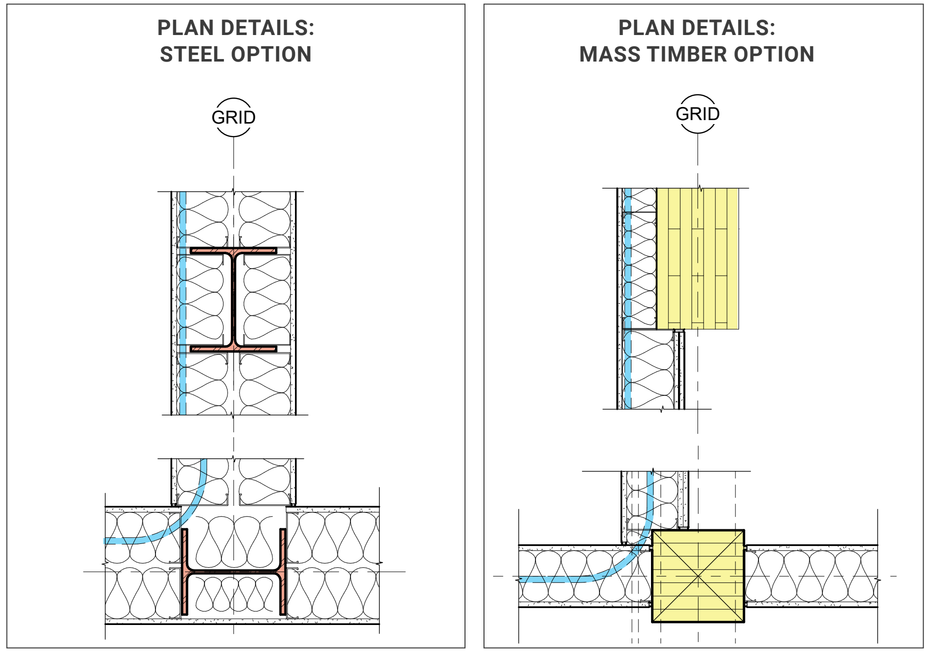
> Using gaps between timber panels to run services – the gap can be exposed or covered with a face plate
> Areas of dropped ceiling
> Acoustic baffles
> Raised floor system
> Concealing small services in floor topping layer
> Conceal small services by routing channel in top of timber panel. This requires structural coordination to ensure that strength of panel is not compromised
> Minimizing service runs with wireless technology

Solid wood walls create the same conflicts for services as solid wood ceilings – there is no chase space to run power, data and other services. Fortunately, post and beam structures make this issue less daunting since interior walls are non-bearing and do not contain solid structural elements that might impede service runs.

However, for easy routing, power and data must be able to circumnavigate around columns, beams and shear elements. To do so, partition walls can be offset from columns and beams to allow services to pass by, but still expose the structural elements. In some cases, coring through beams is another strategy to run services, but this requires coordination with the project's structural engineer. Utilizing drop beams is also effective way to deliver services unimpeded.

For walls, options to conceal services include:

> Use of framed walls instead of solid walls
> Furr-out one side or both sides of mass timber walls
> Use of wire molding
> Run services through floor in lieu of wall mounted
> Recess services in routed channel or gap between timber panels. This can be covered with a face plate. Cutting away portions of timber elements will require analysis by the structural engineer to ensure strength is not compromised.



ABOVE:
Plan details at classroom demising wall showing strategy to route conduit around structural elements for a steel design and mass timber design. Note that typical steel detailing requires additional framing and thicker walls that can add cost and reduce usable interior space.

DIAGRAM, ABOVE:
Core drill locations at main girder to deliver power/data to devices into framed wall below, if required. Core drills should not occur in central portion of girder.

IMAGE, ABOVE:
Example of luminaire with embedded controls. The sensor in lighting could include CO2, Temperature, Humidity, Occupancy, Photosensor, Bluetooth beacon, etc.

ELECTRICAL LIGHTING, CONTROLS AND CEILING COORDINATION

Acoustically, in typical classrooms and other spaces, an area of suspended acoustic ceiling finish was necessary to meet reverberation criteria (see Acoustic section). The suspended finish provided an ideal location for concealing building services. The dropped acoustic baffle ceiling conceals ducting and power runs but allows most of the ceiling to be exposed.

It was determined that concealing services in a floor topping layer had acoustic implications, potentially short-circuiting the acoustic underlayment, as well as inhibiting future flexibility. A raised floor system was outside of the project budget and using a chase between timber panels was also not an ideal solution given the orientation of panels to beams. Instead, the most flexible option was to conceal most services above a discrete dropped acoustic ceiling and expose a minimal number of other services. After careful coordination, it was determined that only a single ¾" conduit would need to be exposed at each bay without a dropped ceiling. A single conduit has minimal visual impact and provided the most flexibility for future changes. Emergency power for egress lighting requires a second conduit, but emergency lighting is only required at the area of dropped ceiling, so this additional conduit need not be exposed.

The lighting industry is moving toward fixture integrated controls that are truly wireless. This means that fewer devices and less power/data runs are required for the ceiling plane. For example, photoelectric, CO2, occupancy sensors, speakers, and more can all be incorporated into a single device that can be mounted/integrated with the light fixture itself. This greatly reduces the number of ceiling and/or wall mounted devices and allows an uncluttered, clean ceiling plane.

Conduit for data is not needed to serve lighting controls. The caveat is that not all lighting fixture lines play well with control lines, and relationships are constantly changing. Coordination with local lighting representatives is critical to determine cost effective lighting and controls lines that function together. Occupancy sensors and CO2 sensors for HVAC can be integrated with wall thermostats and do not need to be ceiling mounted.

For controls, the imbedded sensor is a wireless device. Power is derived from the fixture's driver so the only cable need is the 120V or 277V power to the fixture.[5]
The coverage radius for the embedded sensors is only about 12 feet, so long linear runs will require multiple sensors.

Each zone needs its own sensor (sensor = distinct control address = zone). The Washington State electric code requires primary and secondary daylight zones. Consequently, a long linear run will potentially require up to three sensors – one each for the primary zone, secondary zone and non-daylight zone. Linear fixture lengths need to be a minimum of 4-feet for all the components to fit (i.e. 2-foot lengths cannot use the imbedded solution). For lighting fixtures, it is often better to have longer/larger fixtures to reduce the number of electrical boxes and reduce cost per drop.

The use of integrated sensors can support flexibility in learning settings. Many integral sensors come with Bluetooth beacons that allow detection of other devices, such as a missing AV cart, for example, or to track space utilization and generate heat maps of occupant traffic. The latter can help staff better understand how spaces are being used or not used.

If underutilized spaces need to be adapted, sensors can also be redefined. If a teaching wall needs to move, for example, sensors can be reprogrammed without needing an electrician to come-out and rewire anything. This can be a big time and cost savings that also supports flexibility.

When coordinating power drops, linear runs with both normal and emergency sections require two power feeds (one for normal, one for emergency). Downlights, if used, will still require control wires, batteries or power packs. Power over ethernet (POE) works well for AV and technology devices, but lighting may draw too much power for POE to be practical. However, this is quickly changing with the efficacy of LED increasing and the cost of network switch gear lowering. With current cat6 standards POE is becoming much more feasible for lighting.

ELECTRICAL LIGHTING, CONTROLS AND WALL COORDINATION APPROACH

The majority of interior walls in the project are light stud framed partitions. This allows services to easily run through walls and meet an ideal distribution of receptacles throughout the space. For lighting, a lighting control station is wall mounted. This control station can be as simple as just 4-8 buttons, or a more detailed and interface that looks like an iPad mounted to the wall. The control station will be located near room entries and mounted near light switches.

Depending on how classrooms are arranged, the main interior glulam girder may align with the corridor/classroom wall. To provide power to devices in this wall, the main girder can be core-drilled through. Per structural requirements, the main girder can be core drilled at the ends, but not midspan. (See diagram at top).

Other wall devices include:

> **Smoke Detection**: Area detection typically mounted to ceiling but could be wall mounted.

> **Public address**: Combined with wall mounted clock at classrooms.

> **Speakers**: Mount to wall at teaching wall.

> **Cameras**: Not needed in classrooms.

A potential sang point for running services in walls is when walls intersect columns and beams. To resolve this issue, interior partitions are offset from columns and beams to allow conduit and cabling to slide-by and reach all areas of interior spaces.

Acoustic sealing is required for walls abutting beams and columns. A second approach could be to completely encapsulate the beams and columns and slightly oversize the wall to allow services to run past.

The project has planned for two ¾” conduit at shared demising walls, between classrooms to serve receptacles on both sides of wall. The conduit can be side by side or stacked if space is tight. Stacked conduits will means the height of fixtures will be slightly different between classrooms. Back-to-back receptacles will be staggered and sealed for acoustical performance.

TECHNOLOGY AND AV INTEGRATION

Classroom technology is constantly changing, making it essential that learning spaces be capable to easily modify equipment and infrastructure. To keep audio and visual (AV) devices off the ceiling, all will be wall mounted. Typical classroom AV devices include:

> **Wireless Access Points (WAPs)**: One per classroom and wall mounted above teaching station.

> **Video display**: Large wall mounted LCD monitor with annotation and multitouch.

> **Integrated speaker bar with beam forming microphone**: Wall mounted above video display. Microphone can pick up teacher clearly from anywhere in the room and eliminates sound not in the vocal spectrum.

> **Smart power distribution unit (PDU):** Mounted behind video display. Powers down AV components based upon time of day or occupancy sensors.

> **Data receptacles**: Wall mounted

> **USB-C/HDMI AV:** Input plate behind teacher’s desk.

> **Wireless presentation and collaboration client** mounted behind display- allows teacher to wireless present with laptop or iPad from anywhere in the room.

> **Public address:** Wall mounted with clock.

> **Cameras:** Back of the room for lesson capture.

> **Lecture capture processor:** Behind video display. Capture control via tablet of phone app.

RIGHT:
TECHNOLOGY INTEGRATION AT TYPICAL CLASSROOM

LEGEND

AUDIO & VISUAL

1. 98” multi-touch-video display with annotation and integrated OCC Sensor for display shutoff
2. Speaker-bar with integrated beam-forming microphone mounted 8’ off finish floor. Speaker tracking camera mounted below display
3. Wall-mounted, wireless access point
4. Clock with integrated speaker for public addresses and intercom and mounted above the door
5. Media input plate with USB-C and HDMI inputs

VENTILATION CONTROLS

6. Thermostat with integrated OCC and CO_2 sensors
7. Window green/red light indicator

LIGHTING + RECEPTACLES

8. Lighting control station
9. Lighting on/off switch and manual on/auto off
10. Electrical receptacles
11. Photo-sensors integral to light fixtures, minimum 3 zones:
    Daylight 1, Daylight 2, Not Daylight

LEFT:
Sprinkler lines are painted to match the wood DLT ceiling as a strategy to camouflage this safety feature at Lakeridge Middle School. (Designed by Mahlum Architects)

FIRE PROTECTION FOR MASS TIMBER SCHOOLS

In Washington State, all schools with 51 or more occupants are required to be fully NFPA 13 sprinklered.

When exposing mass timber ceilings, determining how sprinklers are routed through space is a major design and coordination topic. Often structural beams, ducting, and general lack of space (among other issues) are an impediment to full sprinkler coverage. These impediments can translate to undesirable routing of sprinkler pipes. In many cases, fire protection contractors are not integrated into the design team and sprinkler design may languish until late in the construction document phase.

Mass timber buildings require early engagement with fire protection contractors to develop a schematic approach that is closely coordinated with structural, mechanical, electrical, plumbing and technology elements as the building takes shape. An integrated design approach is key to prevent conflicts once construction starts.

FIRE PROTECTION DESIGN APPROACH

Sprinklers, while essential for fire and life safety, should not be a focal point of design. For this project, sprinkler lines are held tight to glued laminated beams and utilize side throw sprinkler heads at areas of exposed CLT to provide full coverage to each 10’ structural bay. This approach minimizes their presence in space and largely prevents them from being seen. Side throw sprinklers typically need to be mounted 4-6-inches below the exposed CLT deck.

For the design approach presented here, ducts are held tight to the ceiling and beams, and are not considered an obstruction so no additional sprinklers are needed. When dropped ceilings are utilized, up and down sprinkler heads are needed, unless the void is a small space over an isolated room. The up head is required to protect concealed combustible materials, such as the CLT deck, and the down head is to protect objects below the ceiling.

Sprinkler mains (assumed 4” diameter pipe in this design) run south of gridline C and individual sprinkler lines (assumed 1.5” diameter pipe in this design) can tap-off the main and reach any space unobstructed due to the dropped beam along this gridline.

Standpipes are required where the top floor is 30’ above the lowest level of fire department access. A 3-story school with 14’ floor-to-floor heights would therefore likely not need standpipes unless site specific grading put the building 24” or higher above the lowest level of fire access. For PV arrays, sprinklering is likely not required unless the system is structurally supporting the roof.

IMAGE:
Sprinkler lines are held tight to beams and timber ceiling so they are less visually apparent in the space at Kellogg Middle School in Shoreline, Washington. (Designed by Mahlum Architects)

SECTION 04B FOOTNOTES

FOOTNOTES

1. Dewsbury, Mark. (2016). Mass-timber as thermal mass. Forest & Wood Products Australia; pg. 33. Downloaded from: https://www.researchgate.net/publication/299366799_Mass-timber_as_thermal_mass
2. Seattle Times reported in December, 2020, only 15% of Washington State Students were attending classes in person. See:
   Resmovits, J., Gutman, D., & Bazzaz, D. (2020, December 18). Inslee releases new state standards, urges Washington districts to begin reopening some schools after covid-19 closures. The Seattle Times. Retrieved December 20, 2020, from https://www.seattletimes.com/education-lab/inslee-releases-new-state-standards-urges-washington-districts-to-begin-reopening-some-schools/
3. Jacobson, L. (2020, October 21). Report estimates 1 to 3 million students missing from school since March 2020, but data on disrupted learning is 'at best a moving target'. Retrieved December 20, 2021, from https://www.the74million.org/report-estimates-1-to-3-million-students-missing-from-school-since-march-but-data-on-disrupted-learning-is-at-best-a-moving-target/
4. Kotob, J., Amt, M., Callahan, K., Lutze, S., & Bates, T. (2020). (rep.). Reopening America: Strategies for Safer Schools. The American Institute of Architects (AIA). Retrieved August 2020, from https://content.aia.org/sites/default/files/2020-08/Reopening_America__Strategies_for_Safer_Schools_June_2020_.pdf
5. IoT Ready (Profile 0 or 1) drivers need no additional devices, others require an additional embedded device typically known as a fixture control unit which acts as a localized power pack within the luminaire.

SECTION 04B IMAGE CREDITS

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SECTION 05

Cost, Constructability, and Sourcing

Mahlum worked closely with Walsh Construction, to create a single modular design that was efficiently built on three individual school sites with few modifications. All load-bearing walls in the buildings are constructed from CLT and are left exposed on the interior. The work proved that CLT could be cost competitive with other building technologies.

CLT Classroom Building, Seattle Public School District, Seattle, Washington
(Designed by Mahlum Architects)

Mass timber is a highly technical coordinated approach to building.

IMAGE:
Walsh Construction served as General Contractor for a mass timber installation: PAE's Living Building Corporate Headquarters, Portland, Oregon

ABOVE:
Simpson Strong-Tie concealed beam hanger for mass timber construction

ABOVE:
Simpson Strong-Tie CDCP screws for mass timber construction

BUILDING WITH MASS TIMBER

Mass timber is a modern method of construction. Understanding the differences between mass timber and other material types will set the stage for a successful project.

The decision to use mass timber must come early in the schematic development of a project. Translating a concrete or steel building design to mass timber will almost always lead to inefficiencies and redesign. Instead, mass timber should be well integrated early – at least by the end of the Design Documents (DD) phase for projects with traditional milestones. Committing to mass timber early means that architect, structural engineer, contractor, and material manufacturer can work together and continually refine and optimize the project.

Because each entity views the project through their own lens and expertise, this process can highlight a wide range of challenges, promote collaboration – and ultimately consensus – before issuing final construction documents. Having everyone at the table ensures a smooth project schedule and greatly reduces risk in terms of conflicts, omissions, oversights, and other errors.

This workflow requires early commitment to design concepts and massing so that efforts can be spent resolving details, minimizing material use, and integrating services and connections. Pre-construction planning, while heavily front-loaded, can pay significant dividends once construction begins by increasing accuracy rates for placement and install, as well as less waste, RFIs, and change orders. **While more time is spent early in the project, less time is spent coordinating later during construction.** The overall time commitment is similar but distributed differently than a traditional project. Instead of a linear pattern, integrated design is characterized by constant feedback loops between all disciplines as the project parts are continually refined and integrated.

Mass timber elements are prefabricated, meaning they arrive to the job site in their final size and shape, often with connection hardware already installed and ready to be lifted into place. Prefabrication not only means speedy on-site construction, but also provides downstream benefits that contribute to schedule confidence for trade installations, as well as certainty that their work has been coordinated and will fit. Safety is enhanced by fewer on-site workers, reduced materials and waste lying around, and use of small tools in lieu of heavy cutting, abrasives, torches, and implements that are detrimental to worker's bodies over time.

K-12 PROTOTYPE

The K-12 school building presented throughout this report has been designed to optimize mass timber in its construction.

The project's floor plate is relatively narrow, so once material has been delivered to site, the mass timber elements can be moved and installed by a wide variety of crane sizes. The prototype is designed to accommodate different massing configurations, yet the floor plate, regardless of final building shape, can be accommodated by an efficiently sized mobile crane. Truck deliveries of mass timber elements should be timed so the crane is in constant use during working hours.

For purposes of comparison and to test feasibility, the team considered similarities and differences between the K-12 Mass Timber Prototype and a similar, typical project type built with a steel superstructure.

INSTALLATION EFFICIENCIES

The focus on prefabrication, coordination, and repetitiveness of the glulam and CLT components leans toward a fast installation. All mass timber projects must reconcile connection design and efficient crane time. Minimizing the number of components to lift and fasten as well as proper sequencing of column, girder, and purlin install reduces crane picks and material handling during installation. One of the benefits of working early with a mass timber manufacturer is that a panel layout plan can be developed. A coordinated panel plan maximizes panel sizes, thereby minimizing crane picks and material waste.

In this study, steel connections for timber are designed with simplicity and speed in mind. Vaagen Timbers recommends optimization of connection types to allow for pre-installation and multiple uses for particular components. The steel post-to-post connection, for example, would be pre-installed at the factory and would serve both as a structural connection and a hoisting pick-point. This provides dual benefits of avoiding additional installation of temporary pick points, as well as elimination of site-installation of the structural connections. These subtle improvements in efficiency translate to significant schedule savings over the course of the entire build, as well as a smoother process on site.

An economic pain point, especially for early mass timber projects, was connection hardware. Before U.S. producers started manufacturing hardware like long, self-tapping wood screws, steel angles and dovetail connectors, these components were imported from Europe at often significant cost. Now, with domestic companies like Simpson Strong-Tie producing a suite of expanding mass timber connection hardware (see above), the cost of this scope has decreased.

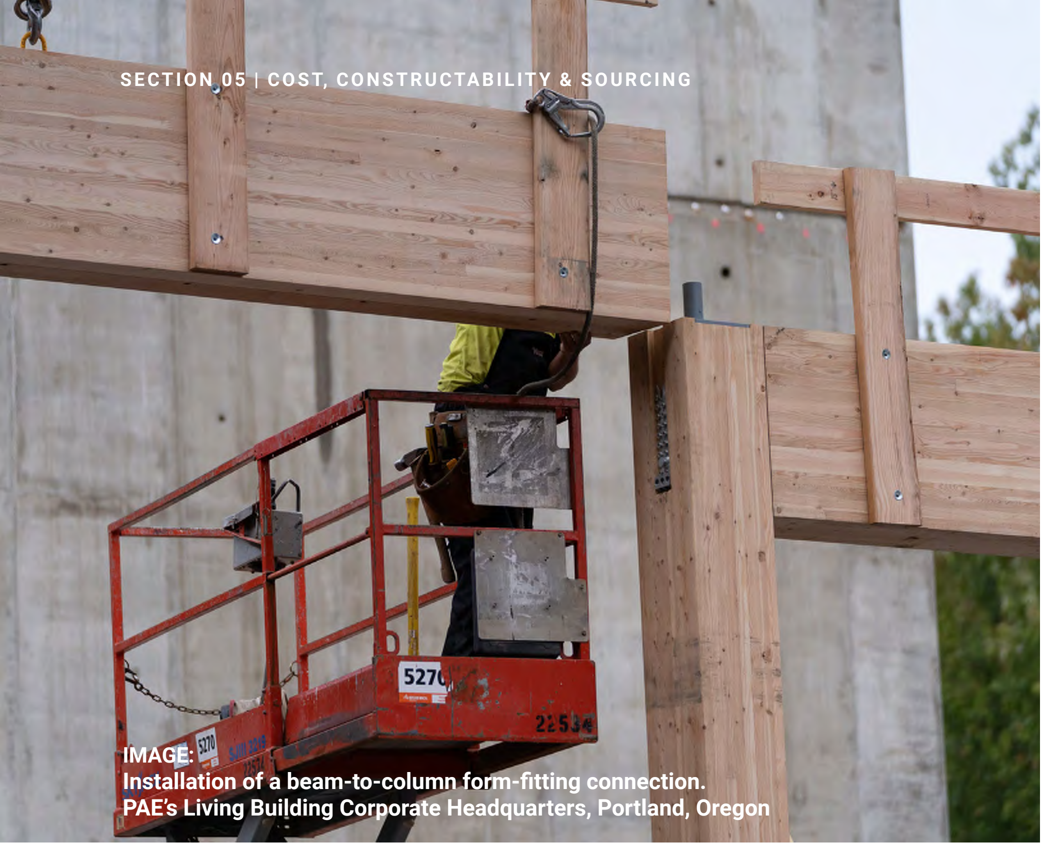
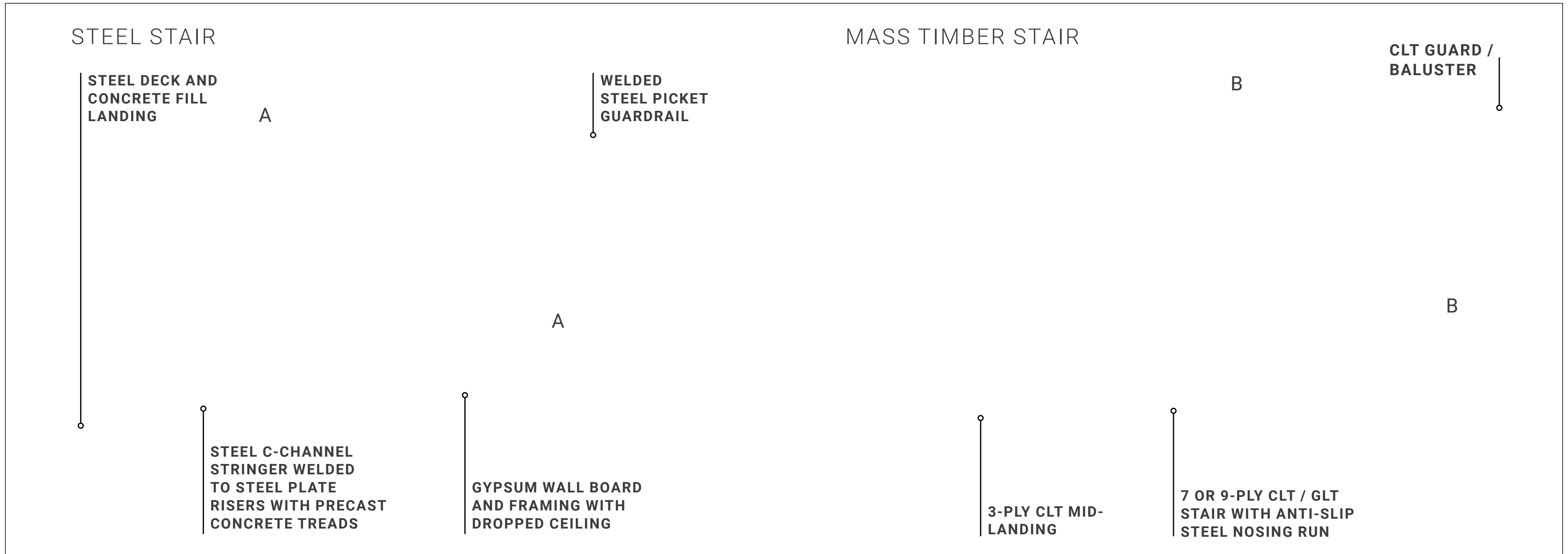


IMAGE:
Installation of a beam-to-column form-fitting connection.
PAE's Living Building Corporate Headquarters, Portland, Oregon



ABOVE:
Comparison between welded steel stair construction (left) and CLT stair construction (right). The mass timber stair greatly reduces the number of parts and pieces, as well as shop time and on-site construction and finishing time.

The components also come with U.S. code approved testing that allows their use without need of time-intensive testing or code alternate documentation to demonstrate conformance to required standards.

Connection hardware can be prefabricated steel elements or elements custom fabricated from steel for the specific job. Custom fabricated, welded steel connections generally involve knife plates, bearing plates, bucket-type connections, or a combination. Prefabricated form-fitting, dovetail connectors have a benefit in that they are completely concealed by timber elements, do not require wood plugs or site finishing, can be installed at the manufacturing facility, and are simple to join on the construction site. They can also readily achieve a fire-resistance rating if that is a project requirement. These elements have small tolerances, so accuracy in project layout and construction is essential. While these prefabricated connectors and hardware from Europe are traditionally expensive, domestic production combined with labor savings and aesthetics is making them competitive with custom fabricated connectors. For this prototype mass timber K-12 building, all beam-to-beam connections are assumed to be prefabricated, concealed dovetail connectors, and the column-to-column hardware is assumed to be custom fabricated steel stand-offs. This approach offers the best combination of speed, aesthetics, and cost. See the Structural Approach section for more detail on connection hardware for this project.

BUILDER-FRIENDLY STRATEGIES

To keep the mass timber design economic, the team focused on "builder-friendly" concepts for simple integration of services like piping, ductwork, and conduit. Rather than using beam penetrations (which have structural limitations for location and size) or other structural feats, the team settled on dropping the central glulam girder to create beam pockets between the columns. These pockets provide ample openings to route Mechanical, Electrical, and Plumbing (MEP) services. The regular 10-foot spacing of purlins also provides generous space for MEP routing through and beyond the dropped beam pockets. Integration of acoustical ceiling treatments at intermittent 10-foot purlin bays provides a location for acoustical treatments and an opportunity to conceal most services, while also keeping most of the mass timber exposed on the ceiling plane. The sprinkler layout has been simplified to align with beam layouts and makes efficient use of sidewall head configurations to reduce piping quantities and visual impacts of overhead infrastructure. Electrical conduit layout makes use of an organized, surface-mounted installation to promote future flexibility and easy, cost-effective installation.

The acoustical strategy outlined in the previous section is important for reducing complexity and installation time. By exposing a large percentage of mass timber ceilings, there is a considerable time-savings compared to a typical K-12 building where all ceilings may have an ACT or other acoustic dropped ceiling specified (see Schedule Impacts chart on page 100). In addition, the use of a cementitious gypsum-based floor topping leads to schedule advantages.

The entire mass timber frame can be erected, roofed and dried-in prior to pouring the acoustic topping layer. Steel frame construction requires composite steel deck, rebar, and concrete topping to be installed as part of the structural floor system. In all, the team found a 5-day added duration related to forming, reinforcing, and placing the concrete topping slabs in our steel comparison, as opposed to the timber and gypsum-based topping assembly. The use of a steel pan-deck and concrete topping slab assembly requires piping penetrations to be cored, following placement of concrete. This leads to additional cost and time required prior to being able to start framing and/or piping risers. In the prototype design, the gypsum-based topping could be placed after exterior walls and interior partitions are in place, allowing a more seamless integration with schedule. Piping penetrations would already be contained within walls, and penetrations in the field of flooring panels would be vastly fewer, requiring minimal preparation. In addition, the gypsum-based topping has a relatively quick drying period, again relieving a potential bottleneck point for interiors work. One consideration for gypsum-based topping is that it may not be able to take the same heavy loading as a concrete deck. Consequently, it is recommended that all overhead work and heavy machinery be complete before installing the gypsum-based topping.

The K-12 prototype emphasizes exposed wood structure where possible for visual benefit, but also to reduce finishes and enclosures. This not only reduces the overall schedule by around 2 weeks for finishes, but also reduces carbon emissions from additional finish materials. Driving toward simplicity translates to schedule, cost, and carbon efficiency.

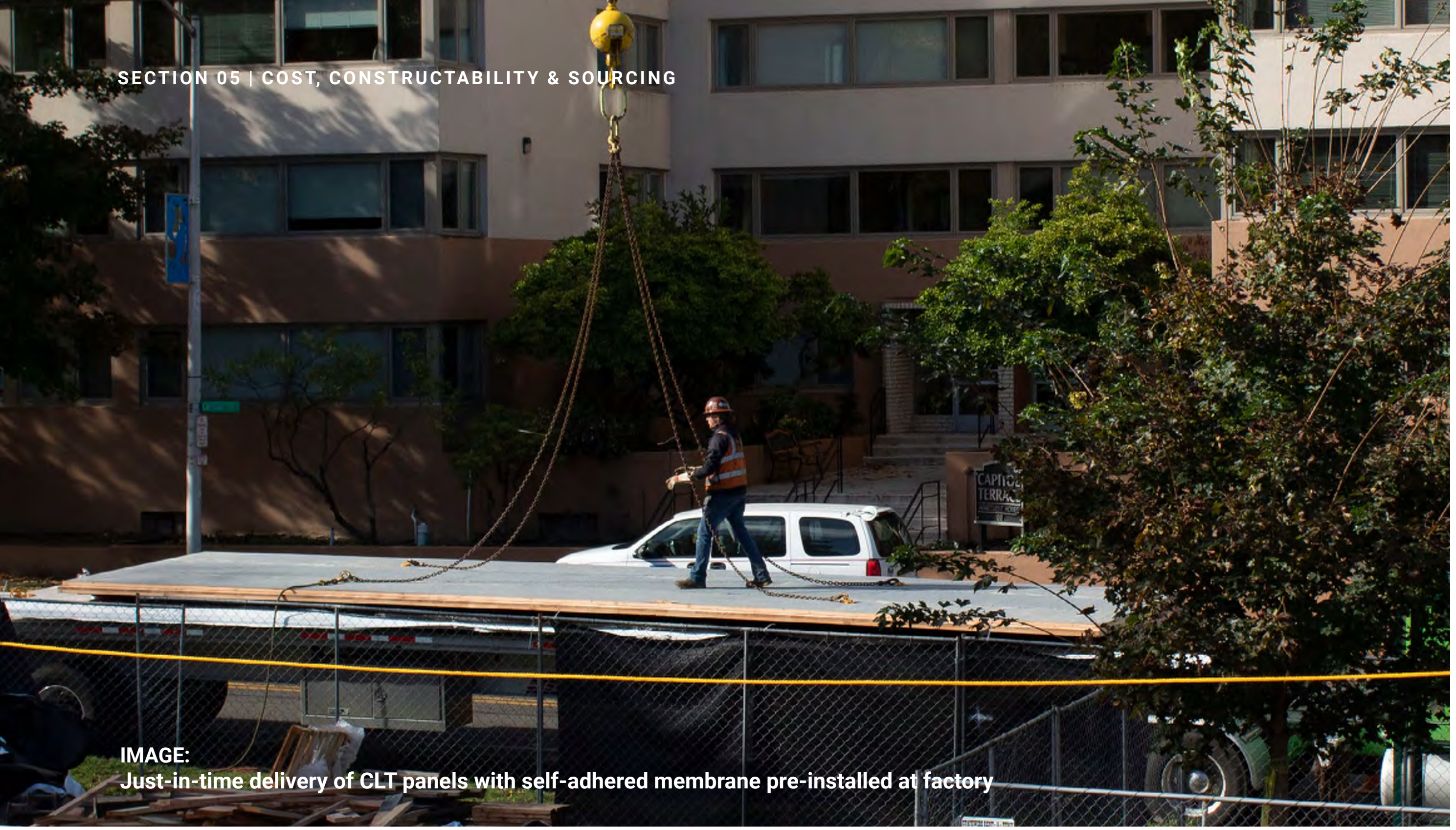


IMAGE:
Just-in-time delivery of CLT panels with self-adhered membrane pre-installed at factory

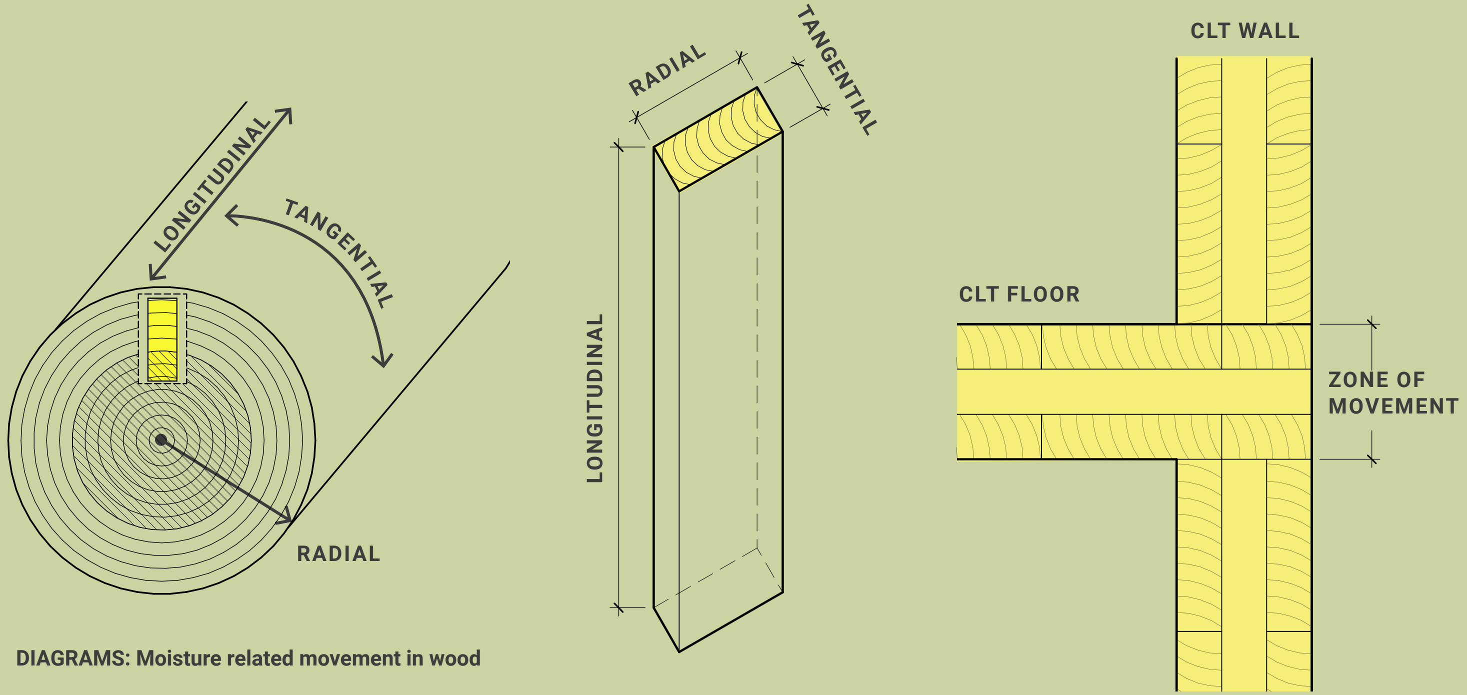
WEATHER PROTECTION

Rain and moisture protection is an critical consideration for mass timber, particularly in Western Washington.
Ideally, mass timber construction should be timed for summer months where precipitation is less frequent. Even in this case, having an agreed upon Moisture Mitigation Plan prior to construction is a key step to achieving success and reducing time-intensive and costly visual remediation of mass timber surfaces due to water.

An agreed upon approach to moisture mitigation can strike a balance between sequencing, level of protection, cost, and risk tolerance. Simply hoping for dry weather during construction is not a recipe for success, especially when mass timber surfaces are exposed as a finished architectural surface. The team should assume that there will be moisture present during construction and plan the project as such.

Mass timber can get wet, and it typically will during construction. Promoting drying is just as important as mitigating moisture intrusion. The presence of moisture is usually a visual threat, not structural. Moisture risk can be broken down into five points: schedule, staining, mold/health, movement and decay.[1] CLT & GLT elements can remain exposed to prolonged moisture without structural issue, however, the team should take precautions and limit this to the greatest extent. Pre-sealing CLT and GLT at the manufacturing facility provides a layer of protection against moisture during installation. CLT end grain should always be sealed. How much of the CLT face layers should be sealed is a discussion point. Sealer finishes can be expensive, so choosing to forgo them in concealed locations is an option, or even forgo installation on exposed surfaces. Sealers can be installed on-site after dry-in as well, often with good results. GLT almost always comes from the manufacturer pre-sealed, so matching the visual appearance of the mass timber elements may be important.

Water management and drainage is essential during construction and there are several approaches to this with varying protection levels and cost implications. Installing a modified bitumen SBS membrane over horizontal surfaces is a method that greatly reduces risk. Water infiltration, especially at horizontal spline connections and intersections of elements can lead to water ingress and water staining on adjacent surfaces and surfaces below. Covering large horizontal surfaces with membranes, whether an SBS or self-adhered membrane, can add cost, time, and material burden. Using adhered strips just over panel joints can decrease water infiltration at these locations and could be a good option for low exposure areas.



DIAGRAMS: Moisture related movement in wood

Wood, Moisture, Humidity

The relationship between wood and water is one that should be well understood by designers, contractors, and owners. A careful eye to moisture and moisture protection will lead to a long-lived and healthy building for decades or longer.

Freshly cut timber, also known as green timber, has varying moisture content (MC), which is the weight of water compared to the weight of wood. MC varies depending on species, time, and location of harvest. Green coastal Douglas Fir can have an MC of 115% (sapwood), whereas the sapwood of old growth Redwood may be over 200%, for example.[A]

There are two types of moisture in wood, known as free and bound water. The former resides in cell cavities (lumen), and as wood dries the free water is the first to escape. The loss of free water does not cause dimensional change in wood. After all the free water is gone, the bound water located in the wood's cell walls is still completely saturated, known as fiber saturation point (FSP). The FSP of most wood species translates to a MC of between 25 to 30%.

Wood will continue to dry (or take on water if the external environment has a high relative humidity) until it reaches an equilibrium moisture content (EMC) with the surrounding environment. The loss or gain of bound water does cause dimensional change in wood, principally shrinkage as wood dries below its FSP. Moisture induced wood shrinkage causes varying dimensional changes.[B] Tangential shrinkage, or that which occurs parallel to growth rings, creates the largest dimensional change as wood dries. Radial shrinkage, which occurs perpendicular to growth rings, creates intermediate dimensional change. The smallest amount of dimensional change is that which occurs along the axis of the tree, parallel to its grain. Mass timber elements that utilize adhesive bonds between laminations, like CLT and GLT, generally have good dimensional stability.

The MC of wood in-service will change depending on the relative humidity (RH) and temperature. If the RH and temperature remain constant, wood will reach an equilibrium moisture content (EMC). The EMC of wood exposed to the outdoor atmosphere will be different based on the season and region. Summer in the arid American Southwest could see wood's EMC of 6.5, where winter in the moist Pacific Northwest could see wood's EMC at 20 or higher.[C] Wood that is too wet or too dry can experience dimensional changes.

Moisture Exposure Level

The moisture exposure level identifies the likelihood of a project's mass timber panel being exposed to wetting events that may occur in transport, in storage, or after placement. The descriptions below identify examples relative to the building schedule and duration of exposure; however, all factors that may contribute to moisture exposure need to be cumulatively considered.

HIGH	High Exposure → No roof above with precipitation expected during exposure duration, *or* → Roof above but open perimeter with wind-driven precipitation expected during exposure duration, *or* → Extended exposure timeline that increases the risk of wetting potential.
MODERATE	Moderate Exposure → Roof above, but open at perimeter with periodic precipitation and limited risk of wind-driven rain.
LOW	Low Exposure → Roof above with perimeter protected with tarps or hoarding, *or* → Exposed during dry/drought season when precipitation is unlikely or limited enough to allow full drying of the mass timber.

LEFT: Except from RDH's "Moisture Risk Management Guide for Mass Timber Buildings." Understanding the level of exposure of mass timber elements will inform the choice of materials and methods used to protect these elements during construction. Construction during the rainy wet season of Western Washington would likely lead to different material selection and strategies than summer installation in drier Eastern Washington, for example. For a full discussion please see this guide's expert recommendations and best practices related to mass timber and moisture management. [1]

The estimate and schedule for this prototype study assumes the use of a self-adhered membrane, pre-installed on the CLT roof panels prior to shipping to site, based on the time of year for install. When installing in "dry" conditions, using factory-installed self-adhered membrane is a reasonable approach; if the installation will take place during a typically "wet" timeframe, the team should plan for pre-installed modified bitumen SBS membrane or other waterproof membrane on the panels. Several guides are available that outline best practices for installation of mass timber in relation to on-site moisture.[1, 2]

The estimated mass timber superstructure build time for the roughly 45,000 sf building presented in the Massing & Form section is around 5 days per floor, or about 15 days before the 3rd floor roof panels are set and about 20 days total before the penthouse is complete and the building can be fully dried-in. The mass timber frame allows the build time to be short, and any water staining can be dealt with in sequence with the installation. Water on timber surfaces, while an aesthetic risk, is generally not a structural problem. Cyclical wetting of CLT, however, can change performance characteristics and should be avoided.[3] Allowing the mass timber elements to properly dry is a critical step, and drying should be done slowly. See the pull-out boxes on this page and previous page.

Withstanding end-grain, water infiltration into horizontal CLT surfaces is slow, and even standing water on horizontal surfaces will not increase the moisture content of CLT above 20% unless the water is present for long periods.[4] Moreover, it has been found through field testing that horizontal CLT surfaces dry relatively quickly after the water is removed and the building dried-in. Installing the gypsum-based topping layer later during the construction process allows additional time for the CLT surfaces to dry, if needed. A moisture content of less than 16% is often recommended before covering mass timber elements with other layers of material.

Based on prior mass timber installations, one strategy to reduce risk is a factory installed self-adhered roofing membrane for roof level mass timber panels. This strategy not only protects these timber panels from moisture but saves considerable time on-site and allows the roof insulation and roof membrane installation to proceed much quicker so the project can achieve dry-in – a considerable milestone for all mass timber projects and a point when moisture risk is far less of a concern. Each project should choose the appropriate range of materials from waterproof, water resistant, to water repellent based on project specific exposure and risk.[1]

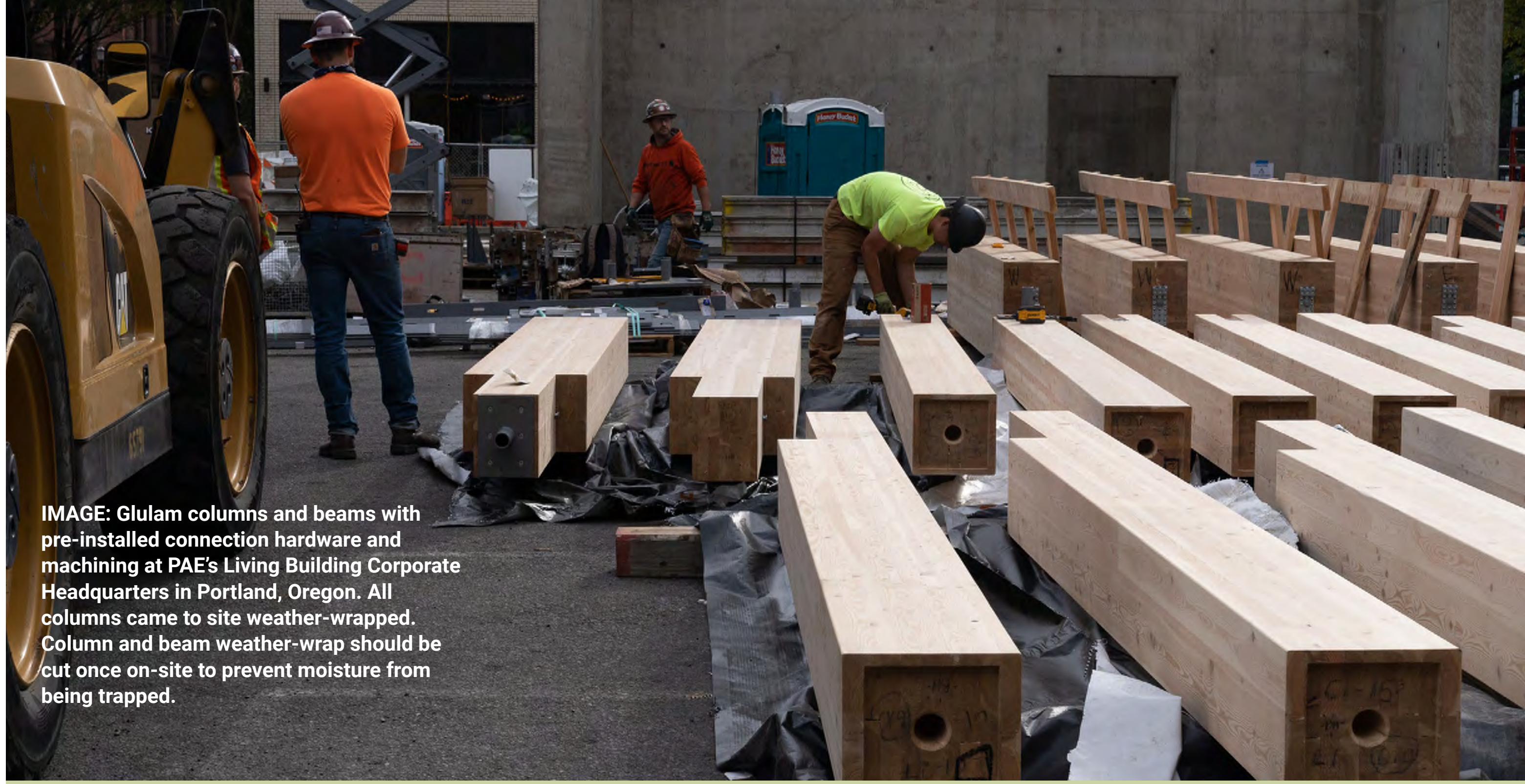


IMAGE: Glulam columns and beams with pre-installed connection hardware and machining at PAE's Living Building Corporate Headquarters in Portland, Oregon. All columns came to site weather-wrapped. Column and beam weather-wrap should be cut once on-site to prevent moisture from being trapped.

Construction Site Moisture

From felling to manufacturing, shipping, construction, to completion, the moisture content (MC) of wood will be in dynamic flux.

Framing lumber, like 2x4s and 2x6s, typically arrive on the construction site with an MC of around 19%. Engineered timber and mass timber components will generally be dried to a lower MC of around 12% (+/- 3%). Construction site conditions such as RH and rain events can increase the moisture content of wood, sometimes significantly, above 19%. It is not uncommon for moisture on the construction site to exceed 20% MC at 80% RH.

The following provides a general estimate of MC in relation to RH. Higher RH will lead to higher MC.

- **RH 25% ~ MC +/- 5%**
- **RH 50% ~ MC +/- 9%**
- **RH 75% ~ MC +/- 14%**
- **RH 90% ~ MC +/- 25%** [C]

Large changes in moisture content can cause dimensional changes in solid sawn wood elements during and after construction, which needs to be managed through proper detailing. In addition to dimensional changes, MC on the construction site should be closely managed to prevent fungal growth. A good rule of thumb is that the moisture content of wood should not exceed 20%. For mass timber, keeping MC below 15-16% when closing it in is ideal. Otherwise a higher MC could lead to moisture redistribution that leads to areas of wood above FSP. Optimal conditions for fungal growth occur at Fiber Saturation Point (FSP) of the wood, which is around 25-30% MC at 100% RH.

Temperature also plays a role in fungal growth. A temperature range between around 70ºF to 90ºF is also optimal for fungal growth. When wood dries below approximately 20% MC, the fungi will become dormant.[D]

When the building is closed-up and conditioned, the interior moisture content typically drops to around 7-15% and interior wood elements will come to an equilibrium moisture content (EMC) at around this range.[E] For interior environments, an RH between 20-60% is generally accepted as a comfortable range. While 30-50% RH is common in Western Washington, schools in the eastern portion of the State could be lower. In this case mechanical systems may be needed to keep interior RH from dropping too low.[F]

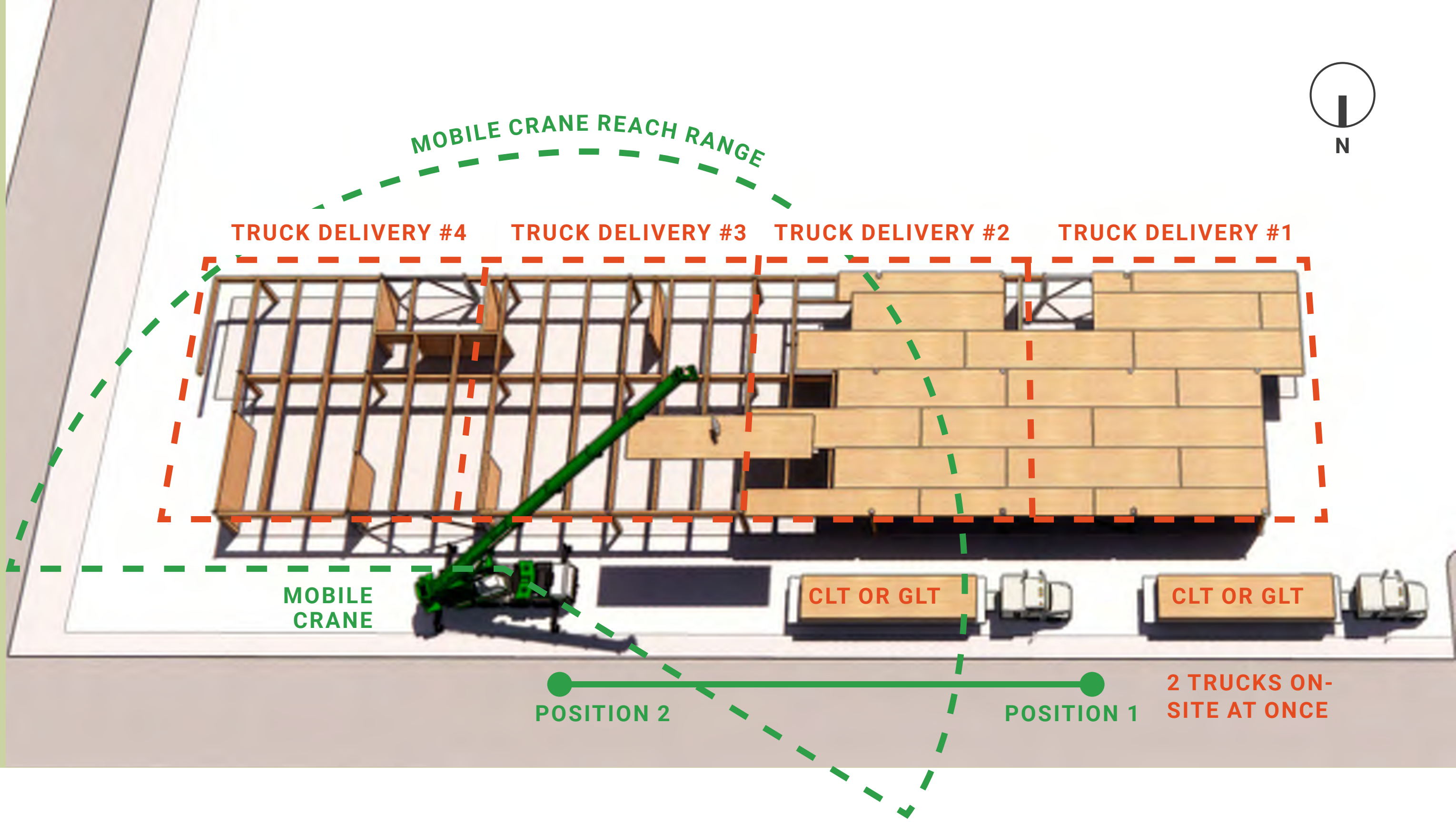
Mass timber elements held within the thermal enclosure means that the EMC should always be lower than 20% MC, thereby eliminating the risk of biological activity.[G]

CLT/GLT Erection Sequence

Hoisting, flow, and efficiency will depend on specific project massing and staging. For this case study and the simple "bar" massing, the erection sequence concept would work as follows:

1) Using two primary crane locations, the project would be able to reach half of the floorplate for placement.
2) Trucks enter adjacent to the crane location, bringing the Level 1 glulam posts and beams first.
3) As the west half of Level 1 nears completion, glulam deliveries show up for the east half. After the crane is moved eastward to reach the next half of the floorplate, erection resumes.
4) Once erection is complete for Level 1 glulams, the team squares and levels the frame, getting ready for Level 2 floor panels.
5) The crane assumes position #1, as CLT floor panels are hoisted onto the west half.
6) Glulam posts and beams are placed on the west half, followed by the next lift of CLT floor panels on the west half, before moving the crane to the east.
7) Following placement of the West Level 3 CLT floor panels, delivery and erection of East Level 2 glulams resume. This flow is repeated until the roof panels are fully placed.

RIGHT:
Aerial view diagram of mass timber erection sequence



SCHEDULE IMPACTS FOR CONSTRUCTION SCOPES

STEEL BUILDING SCOPE	SCHEDULE INCREASE OVER MASS TIMBER OPTION
Steel structure installation	+ 1 week
Gypsum wall board (GWB) and metal framing	+ .5 week
Acoustic ceiling tile (ACT) installation	+ 1 week
Concrete topping slabs at L2, L3 in lieu of gypsum-based topping	+ 1 week
	TOTAL: +4 WEEKS

SCHEDULE & PROCUREMENT

For the three-story prototype school building presented in this report, there are several important differences in construction scheduling to highlight:

Comparing the steel and mass timber options, the schedule savings lead to an estimated 4-week difference in overall construction time (see table at left), translating to almost $120,000. This schedule difference also translates to less time on-site, enabling less overhead costs for the General Contractor to maintain site mobilization, equipment, security, etc. The mass timber option also allows the district to occupy the site, building faster, and have more confidence in the construction schedule. *See the Appendix for detailed mass timber project schedule.*

The procurement process between the steel and mass timber options are similar. In this study, our approach is a turn-key procurement[5] of all mass timber (CLT and GLT), steel brace frames, and steel connections for wood-to-wood and steel-to-wood components. By keeping the structural supply, fabrication, and install within the same team, this provides a high degree of integration and coordination. We chose to procure installation of steel and timber elements as a sub-tier to the timber material supplier/fabricator. The analysis shows this approach would minimize mark-ups on the costliest elements of the package. If the timber supply is procured through the installer, there is a potential of relatively higher proportional mark-up based on component cost. Supply tends to outweigh installation costs significantly. In the current market, the much smaller mark-up on installation was more feasible.

Connection detailing and attention to subtleties required for successful integration of steel and timber scopes rely on seamless communication and agreement on the design direction. The steel and timber detailing and coordination team would be integrated immediately in preconstruction; shop modeling would begin following receipt of a Design Development (DD) Level of Development (LOD) document set. This process is markedly different from traditional design where shop drawings are not considered until after contracts have been awarded and site preparations and mobilization has already started.

Project delivery can vary between three different types: **Design-Bid-Build, General-Contractor-Construction-Manager, and Design-Build.**

> **Design-Bid-Build (DBB):** A traditional approach to project delivery where the contractor is brought on-board following design and development of construction documents. Often, the lowest-bid contractor is awarded the project.

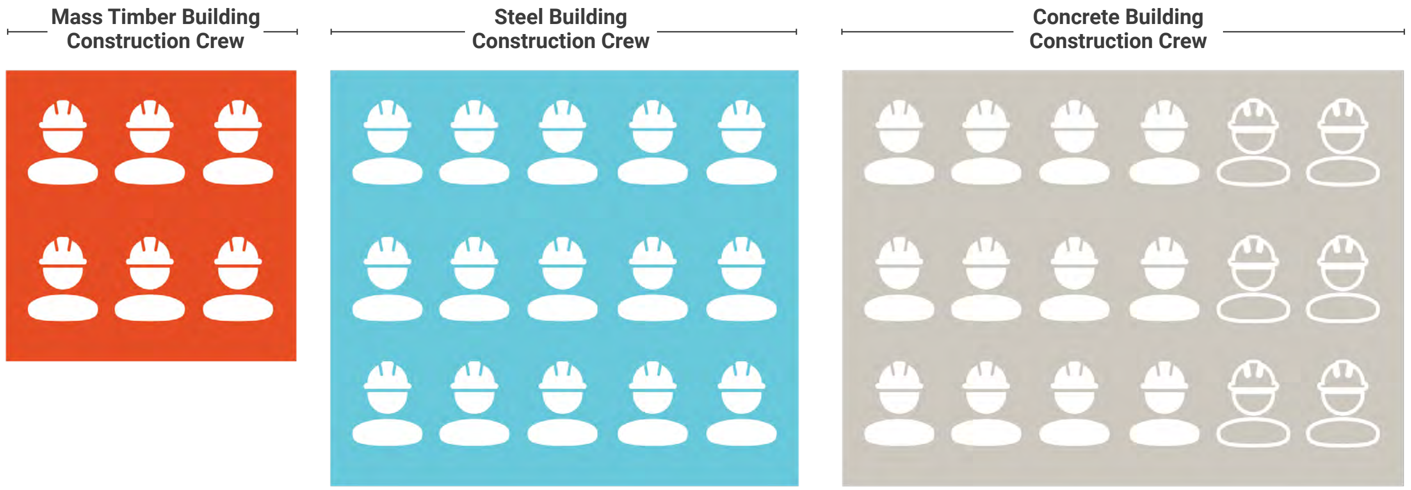
> **Design-Build (DB):** The contractor and architect start the project at the same time, allowing constant coordination and costing between the design and build teams from schematic development to construction documents. In most DB scenarios, the architect and contractor are contractually related.

> **General-Contractor-Construction-Manager (GCCM, also known as CMGC):** A middle ground between DBB and DB in which the contractor is brought on typically at the start of the Design Development phase to coordinate costing and constructability with the design team.

Due to lack of contractor integration into the design team, the DBB delivery method poses the most difficulty for mass timber projects. As noted above, mass timber buildings, especially of larger scale and complexity, benefit greatly from integration of the design, construction, detailing, and fabrication teams.

DB – and to a lesser degree GCCM – provide better opportunity for collaboration and integration than DBB. In Washington State, K-12 projects that seek to use DB or GCCM must get special approval from the State. Permission is contingent on the complexity of the project and benefit from increased collaboration.

Another consideration for mass timber is upfront cost requirements. Mass timber will require a larger deposit on materials and procurement and team for shop drawings, detailing and coordination. Typically, this may mean a 30-50% deposit requested from the mass timber manufacturer to lock-in raw material supply prior to construction and fabrication. This timeline for deposit and procurement is another major challenge for DBB projects.



LEFT:
Construction crew size comparison between mass timber (left), steel (middle), and concrete (right).

RIGHT:
Cost estimate for key differentiating scopes between steel and mass timber.

If K-12 construction costs in Washington State are around $450/SF, for example, a $3/SF cost increase for use of mass timber represents a less than 1% increase. By taking a holistic approach to cost estimating, mass timber can be competitive with steel construction.

KEY DIFFERENTIATING SCOPES	STEEL OPTION	MASS TIMBER OPTION	COST DIFFERENCE
General Conditions	$30.86	$28.40	$(2.46)
Structure: Supply and Install	$52.30	$67.94	$15.64
Drywall & Metal Framing	$26.35	$21.87	$(4.47)
Acoustic Ceilings	$5.93	$1.12	$(4.81)
Acoustic Treatments	$ -	$0.88	$0.88
Paint: GWB Walls & Ceilings	$6.71	$4.72	$(1.99)
Paint: Seal Timber CLT & GL	$ -	$1.89	$1.89
Topping Slab / Gypsum-based Topping	$5.40	$4.33	$(1.07)
Fire Suppression	$1.07	$ -	$(1.07)
Total for all Differentiators	**$129**	**$132**	**$3**

ENVIRONMENTAL IMPACTS OF CONSTRUCTION

Pre-Planning and Prefabrication, inherent for mass timber, leads to less material on-site and less waste generated on-site. Comparable to structural steel construction, waste on a mass timber job site is extremely minimal. However, if compared to concrete, the waste reduction is significant, due to elimination of form-work, form-release agents, miscellaneous lumber, and concrete overage not used in the final construction. That simplifies waste management plans and reduces trucks hauling from site. From previous mass timber projects, the team knows from experience that **mass timber can be significantly less noisy than other construction approaches, generating less traffic, dust and pollution on-site. Handheld drills and other light construction tools are quiet. This can be a particular benefit on urban sites or sites where adjacent school buildings are in use during construction.**

When comparing crew sizes, mass timber crews are typically smaller than a comparably sized concrete or steel project. The prototype project presented in this report would use a crew size of around six, whereas steel erection would rely on a 15-person crew, and a concrete crew would be between 12-18 persons.

COMPARING COSTS: IS MASS TIMBER AFFORDABLE?

This study focused on cost differences between primary steel and mass timber structure, as well as key differences in interior fit-out items. In comparing costs, the steel and mass timber buildings are the same configuration (building shape, structural layout, etc.). Based on the construction type, some elements like ceilings and wall framing are different between the two options, and this has been considered in the costing. The costing study here is presented with a few caveats.

This is not a cost estimate, but rather a comparative study of costs between steel and mass timber to test the economic viability of the latter. It should not be taken as an estimate of total project costs. For example, the same design/massing scheme on two vastly different sites might incur significantly different budget costs for utilities, permitting, or other municipality-driven or locale-dependent conditions. These variables should be taken into consideration during pre-construction and estimating, but are not specific to this prototype. Cost variables may include:

Site Specific Variables

> Due to site configurations and existing conditions, there can be a large swing in costs due to utilities, groundwork, and other non-relevant scopes.

> Project location will impact costs, with higher construction costs occurring in more urban areas like Seattle.

> Travel, shipping distances, access, and site logistics will impact construction costs.

Jurisdiction Specific Variables:

> Energy codes could vary depending on the local jurisdiction and impact costs.

> Seismic design requirements are variable across the State, with Western Washington having a higher seismic design category than Eastern Washington. Locations with a higher seismic demand will likely have higher related structural costs than those with a lower seismic demand.

> Municipal permitting and review costs and timelines all vary depending on project location.

Project Specific Variables:

> Prevailing wage requirements for public works.

Material prices throughout 2021 were volatile due to supply chain issues, climate change implications (like wildfires), increased residential demands, bottlenecks, and other unforeseen issues related to the COVID-19 pandemic. As such, presenting a cost analysis is fraught with uncertainty, such as:

> How do we price materials at today's potentially elevated levels for both steel and timber?

> Do we make assumptions that material prices will return to some normalcy in the future?

For this study, the team has taken a mixed approach that looks at both historical pricing and current pricing – striking a balance between the two.[6] While material prices will most likely fall somewhat in the future, they will likely not return to historic levels.

With this assumption, the team estimated pricing for a procurement date two years in the future.

Using Vaagen Timbers' historical pricing and expertise in analyzing futures markets and commodities trends over the next one to two years, the team established a reasonable cost-basis of $650 per thousand board feet. This effort considered current-day pricing, historical trends (typical years), recent market escalation crises (COVID-19 related market escalation), and project pricing based on a mid-2022 delivery date.

The result of this study indicated an approximate $3/sf cost increase for the mass timber option (see chart above). While our study found the mass timber package approximately 25% more expensive than the steel package, early cost estimates–and especially those that have not optimized the mass timber design–may see larger differences between the two.

EXPLORING OTHER COST SAVING OPTIONS

While the mass timber building is cost competitive with the steel frame option, there are additional opportunities to further align the two. Below are a few additional options that could be used to reduce costs of the mass timber building option:

- Lateral Force Resisting System (LRFS): A cost analysis of a steel brace frame to a similarly sized CLT shear wall indicated that the two systems are roughly cost neutral. Steel brace frames have a higher performance value (seismic response modification coefficient of R-6 or higher) than CLT shear walls (R-factor of between 2 and 4, depending on the design). Consequently, if only steel brace frames are used, then fewer overall bracing elements are required versus a hybrid system of steel and CLT. Between 2-4 bracing elements in the building could be eliminated if only steel braces are used, saving material and installation costs. See the [Structural Approach] section for more discussion.
- Classroom Acoustical Strategy: The basis of design acoustical baffle ceiling is more expensive than a traditional acoustic ceiling tile (ACT). An alternate option is to use the same total area of an ACT ceiling (such as Armstrong Ultima, NRC 0.95) with a minimum 16-inch airspace, in lieu of the basis of design Heartfelt ceiling. In addition, the 1-inch acoustical wall paneling must be increased to 2-inch thick and approximately 35 additional square feet added to typical ~900 sf classrooms if the Heartfelt is removed.
- CLT Stair Walls: The CLT walls running east-west at the two stair cores are load bearing, but not used as shear walls. The 5-ply thickness provides the required fire-resistance rating for these shaft walls. In lieu of CLT shaft walls, it is possible to use a light-framed steel wall with a glulam beam above for purlins to frame into. A steel wall assembly would also need to be fire-resistance rated. This strategy impacts the visual experience at the stair, but it does reduce the amount of wood fiber as well as crane lifts. Both strategies could bring down project costs.
- Other Mass Timber Materials: While this study focuses on GLT and CLT, other mass timber products like Mass Plywood Panels (MPP) or Dowel-Laminated Timber (DLT) could be advantageous for cost, depending on the design and market.

CONCLUSION

This study has found that mass timber can be a cost competitive option to traditional steel frame construction. Too often mass timber appears more expensive because a holistic approach to cost estimating was not taken during design. Even if raw material costs are higher for mass timber than steel, this does not mean that the overall design will ultimately cost more. By quantifying deviations in design approach between mass timber and steel, as well as scheduling and constructability differences, mass timber can be a favorable option. Simple detailing, efficient use of wood, and builder-friendly approaches can close the cost gap while maintaining the aesthetic and sustainability benefits of mass timber. Additional value engineering options can make mass timber even more competitive, whether that be looking at acoustical design approaches or different hybrid structural approaches for the building's lateral force-resisting system.

As a prototype design, the mass timber K-12 building framework can be adapted to different school districts and different sites with a high degree of flexibility, scalability, and repeatability while competing in cost with other types of construction.

For questions, comments or feedback, please reach out to the [project team].

SECTION 05 FOOTNOTES

FOOTNOTES

1. RDH Learn Building Science. (n.d.). Moisture risk management strategies for mass timber buildings. learnbuildingscience.com. Retrieved September 12, 2021, from https://learnbuildingscience.com/collections/guides-and-resources/products/copy-of-moisture-risk-management-strategies-for-mass-timber-buildings https://learnbuildingscience.com/collections/guides-and-resources/products/copy-of-mass-timber-building-enclosure-best-practice-design-guide
2. WoodWorks. (n.d.). Mass timber construction manual form. WoodWorks. Retrieved October 12, 2021, from https://www.woodworks.org/mt-construction-manual-form/
3. Evan L. Schmidt, Mariapaola Riggio, Andre R. Barbosa, Ignace Mugabo, Environmental response of a CLT floor panel: Lessons for moisture management and monitoring of mass timber buildings, Building and Environment, Volume 148, 2019, Pages 609-622, ISSN 0360-1323, https://doi.org/10.1016/j.buildenv.2018.11.038
4. Note: While water infiltration into horizontal CLT surfaces is slow, the same is not true for other wood materials like OSB, plywood and DLT. Often plywood splines used in CLT construction can be among the wettest areas. Discussion from Graham Finch, RDH Building Science Services, January 2022.
5. Turnkey = supply and install in one contract/package. One entity has a prime subcontract to provide both; they will likely sub-out aspects of their contract, such as installation or component supply.
6. Lumber Supply Pricing, per Thousand Board Feet:
    a. Low, Typical Historical Trend = $370
    b. High, Typical Historical Trend = $502
    c. Avg, Typ. Historical Pricing = $450
    d. Projected Pricing, including $200 adder for CLT grade lumber = $650

WOOD, MOISTURE & HUMIDITY (PAGE 98)

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CONSTRUCTION SITE MOISTURE (PAGE 99)

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F Wang, J. (2018). Field measurement of vertical movement and roof moisture performance of the Wood Innovation and Design Centre. fpinnovations.ca. Retrieved September 20, 2021, from https://docs.smtresearch.ca/papers/FPI_WIDC.pdf

G. Interior relative humidity should not exceed 60% because there is an increased risk of biological activity at 70%, where mold growth, dust mite growth, decay, corrosion, etc., can occur on surfaces.

SECTION 05 IMAGE CREDITS

Page 95: Photo by **Mahlum Architects**

Page 96: Images from left to right:
Photo by **Walsh Construction**
Images by **Simpson StrongTie**

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Page 98: Photo by **Mahlum Architects**

Page 99: Photo by **Walsh Construction**

Page 102: Photo by **Walsh Construction**

SECTION 06

Appendix

Section 03A Sustainability and Operational Carbon Appendix

TABLE 1: Climate Summary Chart – Zone 4C: Seattle, Washington

Geographical		Notes
Latitude	47° 26' N	
Longitude	122° 19' W	
Summer		
Cooling		
- Degree Days (50 degrees F)	2068	
- Degree Days (65 degrees F)	196	
- Extreme (Annual)	93 degrees F	
- 0.4% DB/MWB - 1.0% DB/MWB	85/65 degrees F 82/64 degrees F	Many days have natural ventilation potential.
Daily Range	18.7 degrees F	Large daily range good for natural ventilation
Winter		
Heating		
- Degree Days (65 degrees F)	4705	Heating load dominated.
- Degree Days (50 degrees F)	1101	
- Extreme (Annual)	21 degrees F	
- 99.6%	25 degrees F	
- 99%	29 degree F	
Precipitation		
- Annual Rainfall	38-inches	
- Snowfall	12-inches	
Sources: 2017 ASHRAE Fundamentals and Western Regional Climate Center		

TABLE 2: Climate Summary Chart – Zone 5B: Spokane, Washington

Geographical		Notes
Latitude	47° 37' N	
Longitude	117° 32' W	
Summer		
Cooling		
- Degree Days (50 degrees F)	2189	
- Degree Days (65 degrees F)	461	
- Extreme (Annual)	98 degrees F	
- 0.4% DB/MWB - 1.0% DB/MWB	93/63 degrees F 90/62 degrees F	Dry summers have evaporative cooling potential. Many days have natural ventilation potential.
Daily Range	26.2 degrees F	Large daily range good for natural ventilation
Winter		
Heating		
- Degree Days (65 degrees F)	6627	Heating load dominated.
- Degree Days (50 degrees F)	2878	
- Extreme (Annual)	-3 degrees F	
- 99.6%	5 degrees F	Low design temperatures make insulation and airtightness critical to building performance.
- 99%	11 degrees F	
Precipitation		
- Annual Rainfall	16-inches	
- Snowfall	42-inches	
Sources: 2017 ASHRAE Fundamentals and Western Regional Climate Center		

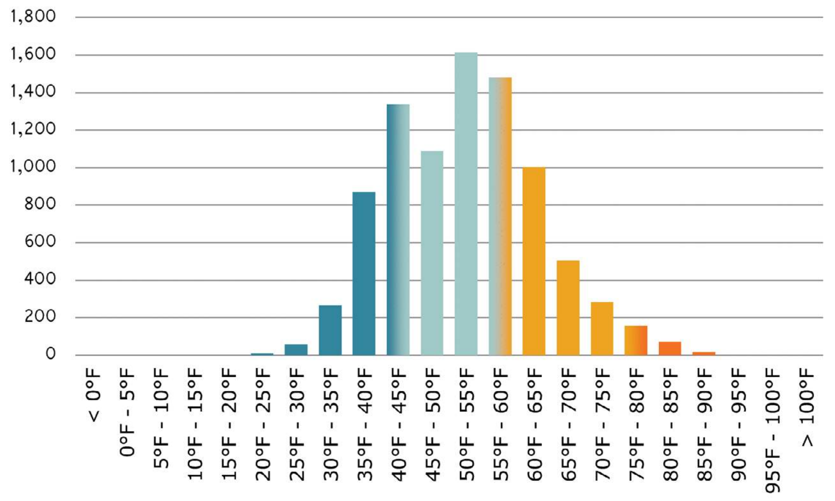


FIGURE 3: Zone 4C Temperature Distribution, Number of Hours Per Year (Seattle, WA)

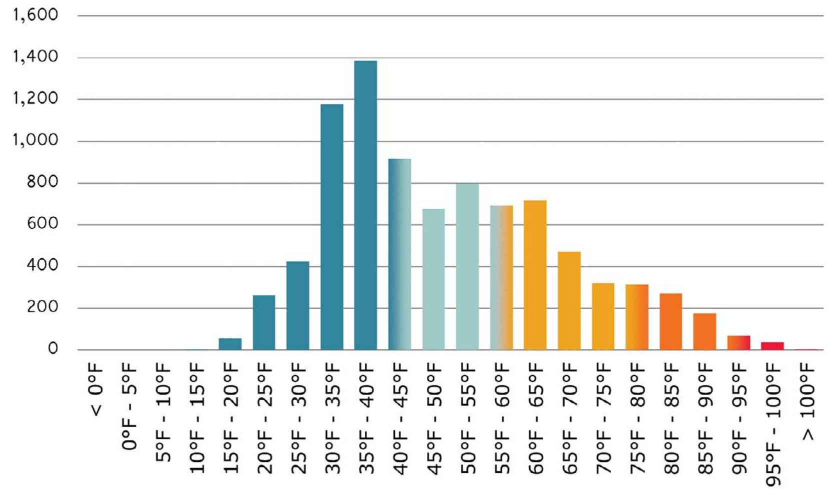


FIGURE 5: Zone 5B Temperature Distribution, Number of Hours Per Year (Spokane, WA)

Section 03D Acoustics Appendix

KNOWN RISKS/ISSUES REQUIRING FURTHER COORDINATION

The following is a list of known acoustic risks and issues that were discovered as part of the design process. These items require further investigation and design and the team hopes to look deeper at these issues for future research:

> Flanking issues

> Lab testing to confirm predicted STC/IIC performance of CLT floor assemblies (noting that the performance herein was interpolated from existing floor assemblies and predictive analysis due to the lack of existing comparative test data)

> Room acoustics if alternative materials specified

> Exterior noise ingress

Section 04B Mechanical, Electrical & Technology Approach

1.1 CODES AND STANDARDS

The following codes, guidelines, regulations and other references that will be put into practice in the design of the building.

> 2018 Washington State Building Code
> 2018 Washington State Fire Code
> 2018 Washington State Mechanical Code
> 2018 Washington State Energy Code
> 2018 Washington State Plumbing Code
> 2018 Washington State Residential Code
> 2020 National Electrical Code with Washington Amendments
> ASHRAE Standard 55-2017 – Thermal Environmental Conditions for Human Occupancy
> ADA or Uniform Federal Accessibility Standards
> National Fire Protection Association (NFPA) Standards
> American's with Disabilities Act (ADA) require additional classroom capacity.

2.1 DESIGN CRITERIA

Description paragraph before jumping into chart might help here Description paragraph before jumping into chart might help here Description paragraph before jumping into chart might help here Description paragraph before jumping into chart might help here

DESIGN CRITERIA

TABLES [2.1]

TABLE A: Outdoor Conditions – Zone 4C, Seattle, WA

Operation	Reference	Temperature
Cooling	ASHRAE 0.4% (Dry Bulb/Mean Coincident Wet Bulb)	85.3°F/65.1°F
Heating	ASHRAE 99.6% (Dry Bulb)	25.4°F

TABLE B: Outdoor Conditions – Zone 5B, Spokane, WA

Operation	Reference	Temperature
Cooling	ASHRAE 0.4% (Dry Bulb/Mean Coincident Wet Bulb)	92.9°F/62.8°F
Heating	ASHRAE 99.6% (Dry Bulb)	5.1°F

TABLE C: Indoor Climate Conditions

Occupancy	Relative Humidity	Cooling	Heating
Offices & Classrooms	< 50%	75°F ±2°F	70°F ±2°F
Circulation & Restrooms	n/a	78°F ±2°F	68°F ±2°F
Mechanical, Electrical, IDF	n/a	80°F ±2°F	60°F ±2°F

TABLE D: Minimum Airflow Rates

Occupancy	Outdoor Air	Exhaust Air
Offices	17 CFM/person	n/a
Classrooms	15 CFM/person	n/a
Restrooms	n/a	2 CFM/SF

TABLE E: Duct Sizing Criteria

Low-Pressure Ductwork	
Static Pressure Loss	Maximum 0.10 inches water column per 100 feet
Main Velocity	Maximum 1,500 feet per minute
Branch Velocity	Maximum 1,200 feet per minute
Flexible Ducts	Maximum length 8 feet, minimize total 90 degree bends
Medium-Pressure Ductwork	
Static Pressure Loss	Maximum 0.28 inches water column per 100 feet
Main Velocity	Maximum 2,400 feet per minute
Branch Velocity	Maximum 2,000 feet per minute

3.0 ELECTRICAL

3.1 DESIGN GUIDELINES

TABLE 1: The following load allowances will be provided for the project:

System	VA/SF	kW
Lighting	0.8	40
General Power	1.5	70
Mechanical	7	325
Plumbing	1	50
Technology	0.5	25
Elevator	--	30
Building Total Load		**540 kW**

3.2 SERVICE AND DISTRIBUTION

Building Main Power Service

The building will connect to the local utility with a pad mounted transformer onsite. A utility vault and raceway will be required to connect the utility point of service from the vault into the building main distribution panel. The service will be provided per the local utility standards. The utility will provide the primary conductors, the pad mounted transformer, and the secondary conductors into the building main distribution panel (MDP).

Building Distribution

The main service will be 800 amps at 480Y/277V. An 800 main distribution panel (MDP) in the main electrical room will be used to feed lighting and large mechanical loads. If PV is included on the project, the bus in MDP likely will need to be upsized to comply with the requirements of NEC 705.12. The calculation will be performed based on the building's PV system size.

A 480/277V mechanical sub distribution panel (SDP-MECH) will be located in the mechanical penthouse to serve the large mechanical equipment in that area. A 480/277V branch panelboard will be located on the 1st and 3rd floors to serve the lighting circuits on its own floor and the floor above.

In the main electrical room a 480V-208Y/120V transformer served by the MDP will connect to a 208/120V sub distribution panel (SDP). The SDP will serve 208/120V branch panelboards on each floor for branch circuits to receptacles and other miscellaneous power needs.

The electrical power system will incorporate metering at the main distribution and sub-distribution panels. The metering will output to a dashboard for monitoring of energy usage and building performance.

Power Quality

Quality of power supply is affected by noise sources within a facility as well as outside (utility transferred). The power distribution system will include measures to help safeguard equipment from utility surges and transient conditions. Surge Protective Devices (SPD) will be provided at the service entrance electrical equipment for a first level of protection and at the branch panelboards for a second level of protection. Load types will be separated on panels to prevent large mechanical loads from affecting general-purpose branch circuitry and to allow for more granular metering of building systems.

Branch Circuit Wiring

Copper conductors routed in EMT raceway will be used throughout the building for branch distribution. EMT will be used for branch circuit pathways in CLT channels. Flexible metal clad (MC) cabling will be used in classroom areas for local distribution of branch circuits in areas outside the CLT structure. All homeruns back to the panel will be EMT with copper conductors.

All branch circuits will have a dedicated neutral and equipment grounding conductor. Ground fault circuit interrupter receptacles will be provided in toilet rooms at sinks, roof, outdoor and wet areas.

Equipment Connections

Electrical power connections will be made to all mechanical equipment, to include providing all electrically associated devices such as disconnect switches, contactors, magnetic or manual starters, lock-out switches, etc., not furnished under Division 23. VFDs furnished under Division 23 and installed under Division 26.

Electrical power connections will be made to support miscellaneous equipment. Connections include disconnect safety switches and wiring to support interlocks to remote devices.

Grounding System

A grounded power system will be provided in compliance with the NEC. This ground system consists of the building service ground consisting of multiple ground rods, UFER ground, ground ring around the building perimeter and bonding to the water service and structure steel. The grounding system will be extended thru out all electrical systems in facility. Grounding busses will be provided in the electrical and telecom network rooms. All metallic systems will be grounded to the building grid. An equipment grounding conductor will be provided in all feeder and branch wiring runs. Separate isolated ground conductors will be provided for branch circuits with sensitive loads.

3.3 ON-SITE POWER SYSTEMS

Emergency Generator

The basis of design emergency power loads are:

> Egress lighting

> Fire alarm

Egress lighting will be supported by a 6kVA egress lighting battery inverter system. Fire alarm will be supported by integral batteries that can support 24-hours of operation.

If site factors result in a fire pump being included in the project, the addition of a 100kW diesel or natural gas generator may be required. The generator will be exterior mounted with a weather proof, sound attenuated housing and built in base fuel tank. A single feeder from the generator will be brought into the building to a generator main power distribution panel. Separate transfer switches will be provided for emergency loads and standby loads. Onsite fuel storage will provide for 12-hours power source operation at full load.

3.4 RENEWABLE POWER SYSTEM (PV)

A renewable power source using PV (Photovoltaic) is proposed for the facility. The photovoltaic array will be located on the roof. Power inverters will be located within the mechanical penthouse on the roof and will tied into the building normal power source via the mechanical sub distribution panel also located in the penthouse. The bus of the distribution board must be sized to comply with NEC 705.12 based on the final size of the PV array. The PV panels must have a minimum efficiency of 18%.

3.5 ELECTRIC VEHICLE CHARGING

Electrical vehicle charging has not been included in the building design but could be added to nearby parking facilities depending on the site. If electric vehicle (EV) charging stations are added to the project site, the main service sizing calculation needs to be updated accordingly to accommodate the additional load.

3.6 LIGHTNING PROTECTION SYSTEMS

It is recommended that a site specific lightning risk assessment is performed in accordance with NFPA 780 to determine whether a lightning protection system is recommended for the site. The Owner may also choose to discuss the installation of a lightning protection system with an insurance underwriter.

If included in the project, the lightning protection system shall be design and installed by a qualified firm that is a member of the Lighting Protection Institute.

3.7 FIRE ALARM

System Description

The Fire Alarm system will consist of a supervised addressable supervised, Class B hard wired system and include an automatically actuated alarm as shown in table below. This class E occupancy is required to have a voice evacuation system integrated into the fire alarm system. Along with the Fire Alarm Control Panel, a Voice Evacuation Panel and annunciation devices including speakers in lieu of horns shall be provided to meet this criteria. Speakers shall be located throughout each space to ensure intelligibility of the voice message broadcast during an emergency.

The activation of any sprinkler flow switch, smoke detection device or manual pull station will operate the alarm system. The fire alarm annunciator will provide indication of the floor of an alarm and the type of alarm, i.e., manual, sprinkler flow, or smoke. The fire alarm system will be connected to an approved central monitoring service.

The activation of any standpipe or sprinkler valve tamper switch activates the fire alarm system supervisory audible signal and illuminates the indicator at the control panel.

The activation of any sprinkler pre-action system pressure or low air switch activates the fire alarm system supervisory audible signal and illuminates the indicator at the control panel.

The activation of any duct detector or area detection device will initiate a HVAC unit shutdown and fire alarm system to close the combination fire/smoke dampers for the zone.

System Equipment
Fire alarm equipment will be housed within electrical or telecom equipment rooms or as required by the AHJ. Equipment located within the space will include:

> Fire Alarm System Control Panel
> Annunciator Panel
> NAC Panels

Fire alarm system equipment located remotely will include:

> Remote annunciator panel at the building entry point
> NAC panels
> Voice evac amplifiers

TABLE 2: Fire Alarm Device Coverage

Device	Coverage
Manual pull stations	Located at each exit and each exit leaving an elevated floor.
Smoke Detectors	Corridors, Air handlers (>2,000CFM), Elevators lobbies, Elevator machine rooms, Elevator hoistways.
Fire Sprinkler	Tamper and Flow
Annunciation	Remote Annunciation at entry
Building Annunciation	Horn and Strobe annunciation thru out the facility.
System output	Relay interface for mechanical system shut down and elevator recall.
Monitoring	Central Station Monitoring

4.0 LIGHTING

4.1 DESIGN CRITERIA

Light Sources
The luminaires will employ LED light sources in all project areas, including back of house spaces. Incandescent, fluorescent, and metal halide sources will not be used on this project unless specifically required by a program requirement. All LED lighting used on this project will conform to all applicable codes and standards, including energy codes and performance standards.

All light sources used will feature a minimum color-rendering index of 80 CRI. Color temperature (CCT) will be standardized to 3000K or 3500K nominal, pending selection of interior finishes and review with the design team.

Where possible, LED chip suppliers will be standardized to ensure that a minimal number of manufacturers are used on the project. LEDs manufactured by Philips, Osram Sylvania, General Electric, Xicato, Bridgelux, Nichia, Cree, are considered acceptable.

LEDs will have minimum CRI of 80 and will maintain color consistency within three MacAdam Ellipses over the rated life of the lamp. LED luminaires will conform to IES LM-80-08 and LM 79-08 test procedures for chromaticity, lumen output and lamp life. All LED luminaires (including LED arrays, drivers, housings, lenses, transformers and accompanying components) will carry a minimum 5-year, non-pro-rated, full replacement warranty.

Lighting Controls
To meet State Energy Code requirements, the lighting control system, at a minimum, requires dimming, occupancy and vacancy sensing and will require astronomical time function with automatic shut-off controls, load shedding capabilities and local over-ride switches.

Daylighting harvesting will be pursued when adequate daylight is available. Daylight harvesting will dim the luminaires when there is high natural light entering the space in primary and secondary daylight zones, and will be adjusted to meet target light levels.

Exterior lighting will be controlled and dimmed via an astronomic time scheduling program, occupancy sensors, and exterior photocells.

In all cases, LED connectors, drivers, and all other interconnected parts of the system rated for use with the LED array specified and will be warranted as an array and assembly for a 5 year full replacement, non-pro-rated warranty.

Wireless occupancy sensors and photocells must be integrated in the luminaire housing for all classroom linear luminaires to reduce the amount of conduit and eliminate the need for conduit or additional devices in the CLT ceiling.

TABLE 3: Lighting Control Strategy Matrix

Task/Area	Control Method
Building Exterior	Time Clock
Common Areas	Photocell, Occupancy Sensor, Wall Switch
Corridor	Corridor Occupancy Sensor
Classrooms	Photocell, Occupancy Sensor, Wall Switch
Maintenance Spaces	Occupancy Sensor, Wall Switch
Restrooms	Occupancy Sensor, Wall Switch
Building Interior – Perimeter	Photocell, Occupancy Sensor, Wall Switch

4.2 LUMINAIRES

All luminaires used on this project will be specification grade and of a quality appropriate to the application. The luminaire specification produced in a manner as to provide the project with the best possible long-term value. Multiple manufacturers may be specified for each luminaire type, except those types for which no performance or aesthetic equivalent exists.

All luminaires are to be installed in a manner to simplify maintenance and allow electrical components to be easily accessible. Samples and/or simple mock-ups may be requested by the owner or design team to confirm design concepts or equipment suitability.

All luminaires and controls will be UL listed, meet applicable codes, and installed as a complete, coordinated, and functional system, integrated with the other impacted and applicable building systems.

Occupancy sensors and photocells must be wireless and integral to the luminaire. This is to minimize the number of devices located on ceilings and walls, as well as reduce the number of conduits required in the CLT ceiling cavities.

4.3 EGRESS LIGHTING

Emergency lighting power will be provided via a central lighting battery inverter. Light fixtures throughout the space will be designated as emergency and will provide 90 minutes of standby power to provide illuminance of the path of egress. The path of egress will be required to provide an average of 1 footcandle at the floor as required by code.

5.0 PLUMBING

5.1 DESIGN CRITERIA

TABLE 4: Plumbing Piping Sizing Criteria

Domestic and Non-Potable Water Piping	
Minimum Pressure	35 PSI at most remote outlet
Maximum Pressure	70 PSI
Friction Loss	Maximum 3 feet per 100 feet
Velocity	Maximum 6 feet per second (Cold & Non-potable Water) Maximum 5 feet per second (Hot Water) Maximum 3 feet per second (Hot Water Return)
Sizing	Per Code (UPC 2018 – Appendix A)
Below Grade Material	3 inch and smaller, Type K, Hard drawn copper tubing, Soldered\brazed fittings 4 inch and larger, Ductile iron, Incoming main, Class 150 Boltite mechanical joint 4 inch and smaller, Type L, Hard drawn copper tubing, Soldered\brazed fittings 6 inch and larger, Type L or Schedule 10 Stainless Steel, Brazed fittings
Domestic Hot Water Supply/Return, Above Grade Insulation	3/4 inch and smaller, 1 inch thick fiberglass, all-purpose jacket or elastomeric 1 inch and larger, 1-1/2 inch thick fiberglass or all-purpose jacket
Storm Drainage Piping	
Rainfall Rate (Seattle and Spokane, for other sites refer to UPC)	1.0 inches per hour 2.0 inches per hour (combined)
Piping Slope	Minimum 1/8 inch per foot
Sizing	Per Code (UPC 2018)
Material	Service weight cast iron with no-hub couplings
Insulation	Drain bodies and first 10 feet of pipe connected to the drain body 1/2 inch, Fiberglass, All-purpose jacket
Waste and Vent Piping	
Piping Slope	Minimum 1/4 inch per foot for piping less than 4 inches, 1/8 inch per foot for 4 inches and larger
Sizing	Per Code (UPC 2018)
Material	Service weight cast iron with no-hub couplings

5.2 PLUMBING FIXTURES

Commercial grade low flow fixtures will be provided where indicated on the architectural drawings. Refer to table below for representative flow rates for each type of fixture.

TABLE 5: Plumbing Fixture Types and Locations

Fixture	Location	Type	Control	Flow*	Basis of Design	Notes
WC-1 Water Closet	Restrooms	Wall hung, vitreous china	Sensor Operated flush valve	1.28 GPF	Kohler water closets with Sloan flush valve	
WC-2 Water Closet	Restrooms (ADA wheel chair and ambulatory stalls)	Wall hung, vitreous china	Sensor Operated flush valve	1.28 GPF	Kohler water closets with Sloan flush valve	Seat at 18 inches above floor, centerline at 17 inches from wall
L-1 Lavatory	Restrooms	Counter mounted, vitreous china	Sensor Operated	0.5 GPM	Kohler sink basin with Delta faucet	All locations are ADA accessible
U-1 Urinal	Restrooms	Wall Hung, vitreous china	Sensor Operated flush valve	0.125 GPF	Kohler Urinal with Sloan flush valve	
U-2 Urinal	Restrooms (ADA)	Wall Hung, vitreous china	Senor Operated flush valve	0.125 GPF	Kohler Urinal with Sloan flush valve	Rim mounted at 17inches above floor
S-1 Sink	Kitchenettes	Self rimming, counter mounted, Stainless steel	Single lever faucet, swing spout	1.5 GPM	Elkay sink basin with Delta faucet	ADA faucet
S-2 Sink	Lactation room	Self rimming, counter mounted, Stainless steel	Dual handle faucet, goose neck spout	1.5 GPM	Elkay sink basin with Delta faucet	ADA faucet
DF-1 Drinking fountain with bottle filler	Varies	Dual height with bottle filling station, stainless steel	Front push pad operation for drinking fountains and sensor operation at bottle filler	1.5 GPM at bottle filler	Elkay	Non-refrigerated

*Code minimum flush/flow rates.

TABLE 6: Fixture Options and Alternates

Fixture Type	Code Flow	*0/2817 Low Flow	Ultra-Low Flow	No Flow	ASHRAE 189	Proposed
Water Closet	1.28 GPF	1.6/1.1 GPF Dual Flush	1.28 GPF	Composting	1.28 GPF	1.28 GPF
Urinal	1.0 GPF	0.5 GPF	0.125 GPF	Waterless	0.5 GPF	0.125 GPF
Lavatory–Commercial	0.5 GPM	1.0 GPM	0.5 GPM	--	0.5 GPM	0.5 GPM
Kitchen Faucet	2.2 GPM	2.2 GPM	1.5 GPM	--	2.2 GPM	1.5 GPM

GPF = Gallons per Flush
GPM = Gallons per Minute

5.3 DOMESTIC COLD-WATER SYSTEM

An existing water main designated by the Civil engineer will serve the domestic water system. A backflow device will be provided on the incoming domestic water supply, in the plumbing riser room or in a utility vault outside as designated by the local AHJ. The domestic water system will be provided with positive means to control backflow, with appropriate backflow preventers at sources of possible contamination within the building, such as mechanical equipment or irrigation systems.

Cold water will be distributed to the plumbing fixtures and other areas requiring water. Refer to Architectural Drawings for plumbing fixtures and room locations. Freeze-proof hose bibs to be distributed around perimeter of building at every 100 feet and be provided for mechanical rooms in the penthouse.

Irrigation
A backflow device will be provided for the irrigation system within the water service room. Irrigation piping will be stubbed out of the building for the landscape use.

5.4 DOMESTIC HOT WATER SYSTEM

> New electric tank water heaters will provide domestic hot water to the building.

> A recirculating hot water loop and hot water circulation pump will be provided.

> The water heaters will produce 140 degrees F for health and equipment efficiency purposes.

> A master thermostatic mixing valve will temper the hot water to 120 degrees F for general use.

> Expansion tanks will be provided on hot water systems at water heaters to eliminate pressure buildup when the system is not being used.

5.5 STORM DRAIN SYSTEM

> A roof and overflow drain system will be provided as required by code. Overflow storm drain system will daylight utilizing downspout nozzles at the floor level above grade.

> A running trap will be provided on the storm water piping leaving the building to prevent sewer gases from entering the building storm water piping systems.

5.6 SANITARY SEWER SYSTEM

> Sanitary waste and vent piping will be provided in toilet rooms and other spaces as required.

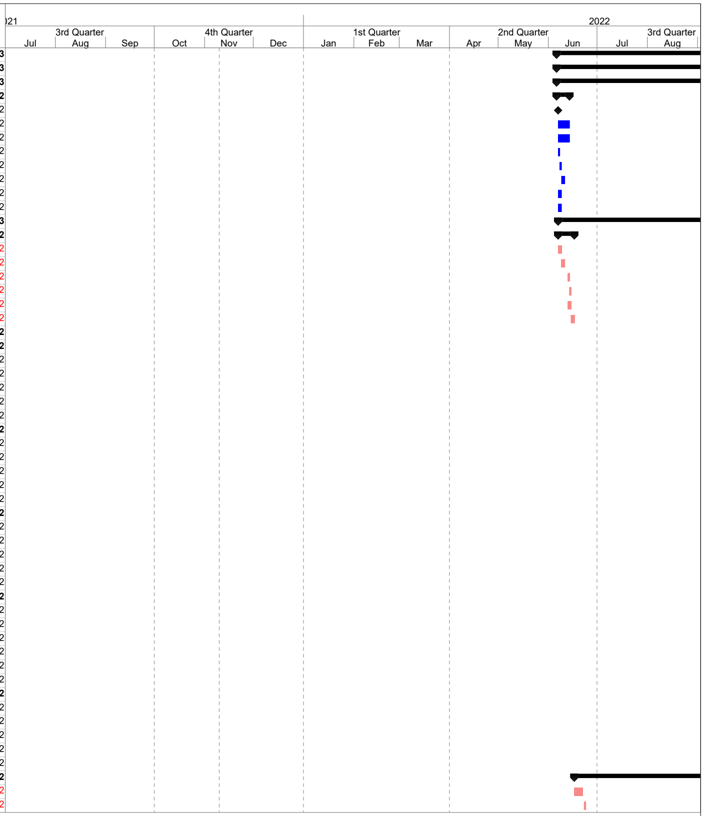
> Sanitary waste piping leaving the site will connect to a sanitary sewer main location provided by Civil.

> Sump pumps will be provided for elevator shafts and connected to the gravity sanitary system within the building.

Section 06 Cost, Constructability & Sourcing Appendix

6.1 PROJECT SCHEDULE

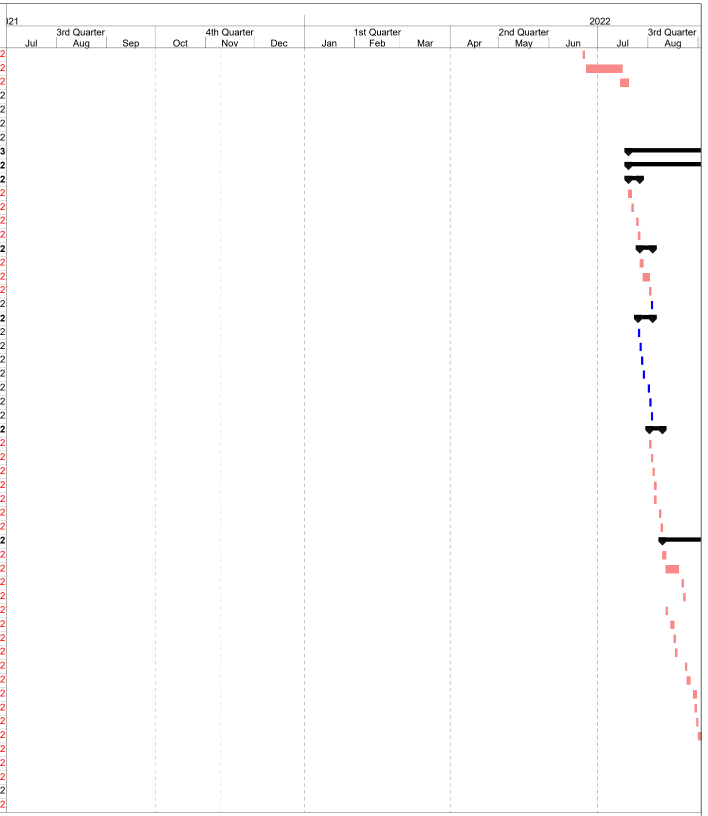
ID	% Complete	Task Name	Duration	Start	Finish
1	**0%**	**USFS Grant School Project**	**256 days**	**Mon 6/6/22**	**Wed 6/7/23**
2	**0%**	**Construction**	**256 days**	**Mon 6/6/22**	**Wed 6/7/23**
3	**0%**	**EARLY SITE PACKAGE**	**163 days**	**Mon 6/6/22**	**Thu 1/26/23**
4	**0%**	**Mobilize**	**6 days**	**Mon 6/6/22**	**Mon 6/13/22**
5	0%	Notice To Proceed	1 day	Mon 6/6/22	Mon 6/6/22
6	0%	WCC Awards Subcontracts	5 days	Tue 6/7/22	Mon 6/13/22
7	0%	Mobilize Job-Site Offices & Facilities	5 days	Tue 6/7/22	Mon 6/13/22
8	0%	Call for Locates	1 day	Tue 6/7/22	Tue 6/7/22
9	0%	Install Site Fence	1 day	Wed 6/8/22	Wed 6/8/22
10	0%	Temp Power	2 days	Thu 6/9/22	Fri 6/10/22
11	0%	Receive Early Site Permits and Final Plans	2 days	Tue 6/7/22	Wed 6/8/22
12	0%	Receive Building Permits and Final Plans	2 days	Tue 6/7/22	Wed 6/8/22
13	**0%**	**Submittals For Long Lead Items**	**162 days**	**Tue 6/7/22**	**Thu 1/26/23**
89	**0%**	**TESC/CLEAR & GRADE**	**8 days**	**Tue 6/7/22**	**Thu 6/16/22**
90	0%	Install tree protection	2 days	Tue 6/7/22	Wed 6/8/22
91	0%	Install TESC	2 days	Thu 6/9/22	Fri 6/10/22
92	0%	Cut & Cap Existing Sewer/ Storm/ Catch Basins	1 day	Mon 6/13/22	Mon 6/13/22
93	0%	Retire Existing Water lines	1 day	Tue 6/14/22	Tue 6/14/22
94	0%	Set up Baker Tanks and Treatment System	2 days	Mon 6/13/22	Tue 6/14/22
95	0%	Clear and Grub Site	2 days	Wed 6/15/22	Thu 6/16/22
96	**0%**	**Site Utilities**	**22 days**	**Thu 9/8/22**	**Fri 10/7/22**
97	**0%**	**Domestic and Fire Water Services**	**8 days**	**Mon 9/19/22**	**Wed 9/28/22**
98	0%	Layout; Horizontal & Vertical control	1 day	Mon 9/19/22	Mon 9/19/22
99	0%	Excavate water lines	3 days	Tue 9/20/22	Thu 9/22/22
100	0%	Install water lines	2 days	Fri 9/23/22	Mon 9/26/22
101	0%	Inspect water lines	1 day	Tue 9/27/22	Tue 9/27/22
102	0%	Backfill water lines	1 day	Wed 9/28/22	Wed 9/28/22
103	**0%**	**Sewer**	**7 days**	**Thu 9/8/22**	**Fri 9/16/22**
104	0%	Layout; Horizontal & Vertical control	1 day	Thu 9/8/22	Thu 9/8/22
105	0%	Excavate sewer lines	2 days	Fri 9/9/22	Mon 9/12/22
106	0%	Install sewer lines	2 days	Tue 9/13/22	Wed 9/14/22
107	0%	Inspect sewer lines	1 day	Thu 9/15/22	Thu 9/15/22
108	0%	Backfill sewer lines	1 day	Fri 9/16/22	Fri 9/16/22
109	**0%**	**Storm**	**7 days**	**Thu 9/29/22**	**Fri 10/7/22**
110	0%	Layout; Horizontal & Vertical control	1 day	Thu 9/29/22	Thu 9/29/22
111	0%	Excavate storm lines	2 days	Fri 9/30/22	Mon 10/3/22
112	0%	Install storm lines	2 days	Tue 10/4/22	Wed 10/5/22
113	0%	Inspect storm lines	1 day	Thu 10/6/22	Thu 10/6/22
114	0%	Backfill storm lines	1 day	Fri 10/7/22	Fri 10/7/22
115	**0%**	**Electrical**	**7 days**	**Mon 9/19/22**	**Tue 9/27/22**
116	0%	Layout; Horizontal & Vertical control	1 day	Mon 9/19/22	Mon 9/19/22
117	0%	Excavate Primary Power trench	2 days	Tue 9/20/22	Wed 9/21/22
118	0%	Install Conduit Primary Power trench	2 days	Thu 9/22/22	Fri 9/23/22
119	0%	Inspect Primary Power	1 day	Mon 9/26/22	Mon 9/26/22
120	0%	Encase/Back Fill Primary Power trench	1 day	Tue 9/27/22	Tue 9/27/22
121	0%	Permanent Power	0 days	Tue 9/27/22	Tue 9/27/22
122	**0%**	**Telecomm**	**6 days**	**Mon 9/19/22**	**Mon 9/26/22**
123	0%	Layout; Horizontal & Vertical control	1 day	Mon 9/19/22	Mon 9/19/22
124	0%	Excavate comm trench	2 days	Tue 9/20/22	Wed 9/21/22
125	0%	Install conduit comm trench	1 day	Thu 9/22/22	Thu 9/22/22
126	0%	Inspect comm	1 day	Fri 9/23/22	Fri 9/23/22
127	0%	Encase/Back Fill comm trench	1 day	Mon 9/26/22	Mon 9/26/22
128	**0%**	**Excavation and Backfill**	**65 days**	**Fri 6/17/22**	**Mon 9/19/22**
129	0%	Build pad for ground imporovements	3 days	Fri 6/17/22	Tue 6/21/22
130	0%	Mobilize Geopier equipment	1 day	Thu 6/23/22	Thu 6/23/22



Project: USFS Grant School Project
Print Date: Wed 11/10/21

Page 1

ID	% Complete	Task Name	Duration	Start	Finish
131	0%	Layout Geopiers	1 day	Wed 6/22/22	Wed 6/22/22
132	0%	Install Geopiers	15 days	Fri 6/24/22	Fri 7/15/22
133	0%	Grade building pad / Excavate footings	3 days	Fri 7/15/22	Tue 7/19/22
134	0%	Waterproof slab edge	2 days	Thu 9/8/22	Fri 9/9/22
135	0%	Install Rigid Insulation	1 day	Mon 9/12/22	Mon 9/12/22
136	0%	Install footing drains	3 days	Tue 9/13/22	Thu 9/15/22
137	0%	Backfill slab edge	2 days	Fri 9/16/22	Mon 9/19/22
138	**0%**	**BUILDING PACKAGE**	**225 days**	**Wed 7/20/22**	**Wed 6/7/23**
139	**0%**	**Concrete**	**36 days**	**Wed 7/20/22**	**Thu 9/8/22**
140	**0%**	**Footing Pour#1 (Interior)**	**5 days**	**Wed 7/20/22**	**Tue 7/26/22**
141	0%	Form Footings	2 days	Wed 7/20/22	Thu 7/21/22
142	0%	Install and Inspect Rebar	1 day	Fri 7/22/22	Fri 7/22/22
143	0%	Pour Footings	1 day	Mon 7/25/22	Mon 7/25/22
144	0%	Strip Footings	1 day	Tue 7/26/22	Tue 7/26/22
145	**0%**	**Footing Pour#2 (Perimeter)**	**6 days**	**Wed 7/27/22**	**Wed 8/3/22**
146	0%	Form Footings	2 days	Wed 7/27/22	Thu 7/28/22
147	0%	Install and Inspect Rebar	2 days	Fri 7/29/22	Mon 8/1/22
148	0%	Pour Footings	1 day	Tue 8/2/22	Tue 8/2/22
149	0%	Strip Footings	1 day	Wed 8/3/22	Wed 8/3/22
150	**0%**	**Stem Wall Pour#1 (Interior)**	**7 days**	**Tue 7/26/22**	**Wed 8/3/22**
151	0%	Layout Walls	1 day	Tue 7/26/22	Tue 7/26/22
152	0%	Form Inside Face	1 day	Wed 7/27/22	Wed 7/27/22
153	0%	Install Rebar	1 day	Thu 7/28/22	Thu 7/28/22
154	0%	Close Wall Forms	1 day	Fri 7/29/22	Fri 7/29/22
155	0%	Inspect Rebar	1 day	Mon 8/1/22	Mon 8/1/22
156	0%	Pour Wall	1 day	Tue 8/2/22	Tue 8/2/22
157	0%	Strip Walls	1 day	Wed 8/3/22	Wed 8/3/22
158	**0%**	**Stem Wall Pour#2 (Perimeter)**	**6 days**	**Tue 8/2/22**	**Tue 8/9/22**
159	0%	Layout Walls	1 day	Tue 8/2/22	Tue 8/2/22
160	0%	Form Inside Face	1 day	Wed 8/3/22	Wed 8/3/22
161	0%	Install Rebar	1 day	Thu 8/4/22	Thu 8/4/22
162	0%	Close Wall Forms	1 day	Fri 8/5/22	Fri 8/5/22
163	0%	Inspect Rebar	1 day	Fri 8/5/22	Fri 8/5/22
164	0%	Pour Wall	1 day	Mon 8/8/22	Mon 8/8/22
165	0%	Strip Walls	1 day	Tue 8/9/22	Tue 8/9/22
166	**0%**	**Slab on Grade**	**21 days**	**Wed 8/10/22**	**Thu 9/8/22**
167	0%	Excavate below grade plumbing	2 days	Wed 8/10/22	Thu 8/11/22
168	0%	Install below grade plumbing	6 days	Fri 8/12/22	Fri 8/19/22
169	0%	Inspect below grade plumbing	1 day	Mon 8/22/22	Mon 8/22/22
170	0%	Backfill below grade plumbing	1 day	Tue 8/23/22	Tue 8/23/22
171	0%	Excavate below grade electrical	1 day	Fri 8/12/22	Fri 8/12/22
172	0%	Install below grade electrical	2 days	Mon 8/15/22	Tue 8/16/22
173	0%	Inspect below grade electrical	1 day	Wed 8/17/22	Wed 8/17/22
174	0%	Backfill below grade electrical	1 day	Thu 8/18/22	Thu 8/18/22
175	0%	Inspect backfill compaction	1 day	Wed 8/24/22	Wed 8/24/22
176	0%	Grade to subgrade	2 days	Thu 8/25/22	Fri 8/26/22
177	0%	Install cap break	2 days	Mon 8/29/22	Tue 8/30/22
178	0%	Inspect capbreak compaction	1 day	Tue 8/30/22	Tue 8/30/22
179	0%	Install vapor barrier	1 day	Wed 8/31/22	Wed 8/31/22
180	0%	Install re-steel	2 days	Thu 9/1/22	Fri 9/2/22
181	0%	Install achor bolts for wood framing	1 day	Tue 9/6/22	Tue 9/6/22
182	0%	Inspect Slab on Grade	1 day	Tue 9/6/22	Tue 9/6/22
183	0%	Place Concrete Slab on Grade	1 day	Wed 9/7/22	Wed 9/7/22
184	0%	Place Concrete Slab on Grade	0 days	Wed 9/7/22	Wed 9/7/22
185	0%	Saw Cut Slab on Grade	1 day	Thu 9/8/22	Thu 9/8/22



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ID	% Complete	Task Name	Duration	Start	Finish
186	**0%**	**Framing**	**26 days**	**Thu 9/8/22**	**Thu 10/13/22**
187	0%	Deliver CLT Package	1 day	Thu 9/8/22	Thu 9/8/22
188	0%	Snap, Plate, Detail	1 day	Fri 9/9/22	Fri 9/9/22
189	0%	Set Level 1 Columns	1 day	Mon 9/12/22	Mon 9/12/22
190	0%	Set Level 1 CLT Wall panels	1 day	Tue 9/13/22	Tue 9/13/22
191	0%	Set Level 1 Glu-lam Girders	1 day	Wed 9/14/22	Wed 9/14/22
192	0%	Set Level 1 Glu-lam Purlins	1 day	Thu 9/15/22	Thu 9/15/22
193	0%	Set Level 2 CLT Floor panels	2 days	Fri 9/16/22	Mon 9/19/22
194	0%	Set Level 2 Columns	1 day	Tue 9/20/22	Tue 9/20/22
195	0%	Set Level 2 CLT Wall panels	1 day	Wed 9/21/22	Wed 9/21/22
196	0%	Set Level 2 Glu-lam Girders	1 day	Thu 9/22/22	Thu 9/22/22
197	0%	Set Level 2 Glu-lam Purlins	1 day	Fri 9/23/22	Fri 9/23/22
198	0%	Set Level 3 CLT Floor panels	1 day	Mon 9/26/22	Mon 9/26/22
199	0%	Set Level 3 Columns	1 day	Tue 9/27/22	Tue 9/27/22
200	0%	Set Level 3 CLT Wall panels	1 day	Wed 9/28/22	Wed 9/28/22
201	0%	Set Level 3 Glu-lam Girders	1 day	Thu 9/29/22	Thu 9/29/22
202	0%	Set Level 3 Glu-lam Purlins	1 day	Fri 9/30/22	Fri 9/30/22
203	0%	Set Level 4 CLT Floor/Roof panels	1 day	Mon 10/3/22	Mon 10/3/22
204	0%	Set Level 4 Columns	1 day	Tue 10/4/22	Tue 10/4/22
205	0%	Set Level 4 CLT Wall panels	1 day	Wed 10/5/22	Wed 10/5/22
206	0%	Set Level 4 Glu-lams	1 day	Thu 10/6/22	Thu 10/6/22
207	0%	Set Penthouse CLT Roof panels	1 day	Fri 10/7/22	Fri 10/7/22
208	0%	CLT Complete	0 days	Fri 10/7/22	Fri 10/7/22
209	0%	Frame Parapets & Roof Curbs	3 days	Mon 10/10/22	Wed 10/12/22
210	0%	Insulation at roof parapets	1 day	Thu 10/13/22	Thu 10/13/22
211	**0%**	**Mechanical & Electrical Rough-In**	**56 days**	**Tue 9/20/22**	**Thu 12/8/22**
212	**0%**	**Level 1**	**56 days**	**Tue 9/20/22**	**Thu 12/8/22**
213	0%	Frame interior walls	5 days	Tue 9/20/22	Mon 9/26/22
214	0%	Pre Rock at concealed spaces	3 days	Tue 9/27/22	Thu 9/29/22
215	0%	Plumbing Drain/Waste/Vent RI	5 days	Fri 9/30/22	Thu 10/6/22
216	0%	Sprinkler RI	5 days	Fri 10/7/22	Thu 10/13/22
217	0%	HVAC RI	5 days	Fri 10/14/22	Thu 10/20/22
218	0%	Electrical RI	5 days	Fri 10/21/22	Thu 10/27/22
219	0%	Plumbing Water RI	3 days	Fri 12/2/22	Tue 12/6/22
220	0%	MEP Cover Inspection Walls	1 day	Wed 12/7/22	Wed 12/7/22
221	0%	MEP Cover Inspection Walls	0 days	Wed 12/7/22	Wed 12/7/22
222	0%	Firestop Penetrations	1 day	Wed 12/7/22	Wed 12/7/22
223	0%	Install HM door frames	1 day	Wed 12/7/22	Wed 12/7/22
224	0%	Framing Inspection	1 day	Thu 12/8/22	Thu 12/8/22
225	0%	Framing Inspection	0 days	Thu 12/8/22	Thu 12/8/22
226	**0%**	**Level 2**	**48 days**	**Tue 9/27/22**	**Mon 12/5/22**
227	0%	Frame interior walls	5 days	Tue 9/27/22	Mon 10/3/22
228	0%	Pre Rock at concealed spaces	3 days	Tue 10/4/22	Thu 10/6/22
229	0%	Plumbing Drain/Waste/Vent RI	5 days	Fri 10/7/22	Thu 10/13/22
230	0%	Sprinkler RI	5 days	Fri 10/14/22	Thu 10/20/22
231	0%	HVAC RI	5 days	Fri 10/21/22	Thu 10/27/22
232	0%	Electrical RI	5 days	Fri 10/28/22	Thu 11/3/22
233	0%	Plumbing Water RI	3 days	Tue 11/29/22	Thu 12/1/22
234	0%	MEP Cover Inspection Walls	1 day	Fri 12/2/22	Fri 12/2/22
235	0%	MEP Cover Inspection Walls	0 days	Fri 12/2/22	Fri 12/2/22
236	0%	Firestop Penetrations	1 day	Fri 12/2/22	Fri 12/2/22
237	0%	Install HM door frames	1 day	Fri 12/2/22	Fri 12/2/22
238	0%	Framing Inspection	1 day	Mon 12/5/22	Mon 12/5/22
239	0%	Framing Inspection	0 days	Mon 12/5/22	Mon 12/5/22
240	**0%**	**Level 3**	**40 days**	**Tue 10/4/22**	**Wed 11/30/22**

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ID	% Complete	Task Name	Duration	Start	Finish
241	0%	Frame interior walls	5 days	Tue 10/4/22	Mon 10/10/22
242	0%	Pre Rock at concealed spaces	3 days	Tue 10/11/22	Thu 10/13/22
243	0%	Plumbing Drain/Waste/Vent RI	5 days	Fri 10/14/22	Thu 10/20/22
244	0%	Sprinkler RI	5 days	Fri 10/21/22	Thu 10/27/22
245	0%	HVAC RI	5 days	Fri 10/28/22	Thu 11/3/22
246	0%	Electrical RI	5 days	Fri 11/4/22	Thu 11/10/22
247	0%	Plumbing Water RI	3 days	Tue 11/22/22	Mon 11/28/22
248	0%	MEP Cover Inspection Walls	1 day	Tue 11/29/22	Tue 11/29/22
249	0%	MEP Cover Inspection Walls	0 days	Tue 11/29/22	Tue 11/29/22
250	0%	Firestop Penetrations	1 day	Tue 11/29/22	Tue 11/29/22
251	0%	Install HM door frames	1 day	Tue 11/29/22	Tue 11/29/22
252	0%	Framing Inspection	1 day	Wed 11/30/22	Wed 11/30/22
253	0%	Framing Inspection	0 days	Wed 11/30/22	Wed 11/30/22
254	**0%**	**Level 4**	**33 days**	**Mon 10/10/22**	**Wed 11/23/22**
255	0%	Frame interior walls	5 days	Mon 10/10/22	Fri 10/14/22
256	0%	Pre Rock at concealed spaces	3 days	Mon 10/17/22	Wed 10/19/22
257	0%	Plumbing Drain/Waste/Vent RI	5 days	Thu 10/20/22	Wed 10/26/22
258	0%	Sprinkler RI	5 days	Thu 10/27/22	Wed 11/2/22
259	0%	HVAC RI	5 days	Thu 11/3/22	Wed 11/9/22
260	0%	Electrical RI	5 days	Thu 11/10/22	Wed 11/16/22
261	0%	Plumbing Water RI	3 days	Thu 11/17/22	Mon 11/21/22
262	0%	MEP Cover Inspection Walls	1 day	Tue 11/22/22	Tue 11/22/22
263	0%	MEP Cover Inspection Walls	0 days	Tue 11/22/22	Tue 11/22/22
264	0%	Firestop Penetrations	1 day	Tue 11/22/22	Tue 11/22/22
265	0%	Install HM door frames	1 day	Tue 11/22/22	Tue 11/22/22
266	0%	Framing Inspection	1 day	Wed 11/23/22	Wed 11/23/22
267	0%	Framing Inspection	0 days	Wed 11/23/22	Wed 11/23/22
268	**0%**	**Building Envelope**	**53 days**	**Thu 9/8/22**	**Mon 11/21/22**
269	0%	Building Envelope Coordination Meeting	1 day	Thu 9/8/22	Thu 9/8/22
270	**0%**	**Mock Up**	**12 days**	**Fri 9/9/22**	**Mon 9/26/22**
271	0%	Mock up drawing completion and approval	5 days	Fri 9/9/22	Thu 9/15/22
272	0%	Build mock up	5 days	Fri 9/16/22	Thu 9/22/22
273	0%	Test mock up	1 day	Fri 9/23/22	Fri 9/23/22
274	0%	Envelope Pre-Con Meeting	1 day	Mon 9/26/22	Mon 9/26/22
275	**0%**	**Roof Membrane**	**22 days**	**Wed 10/12/22**	**Thu 11/10/22**
276	0%	Roofing Pre-Con Meeting	1 day	Wed 10/12/22	Wed 10/12/22
277	0%	Set Roof Curbs	1 day	Thu 10/13/22	Thu 10/13/22
278	0%	Pre-strip vapor barrier at roof anchors	1 day	Fri 10/14/22	Fri 10/14/22
279	0%	Install roof anchors	1 day	Mon 10/17/22	Mon 10/17/22
280	0%	Deliver Roofing	1 day	Tue 10/18/22	Tue 10/18/22
281	0%	Install vapor barrier	2 days	Wed 10/19/22	Thu 10/20/22
282	0%	Install rigid insulation and cover board	3 days	Fri 10/21/22	Tue 10/25/22
283	0%	Install TPO membrane	5 days	Wed 10/26/22	Tue 11/1/22
284	0%	Building Dried In	0 days	Mon 11/7/22	Mon 11/7/22
285	0%	Install roof walkway pads	1 day	Tue 11/8/22	Tue 11/8/22
286	0%	Install temp roof protection	1 day	Wed 11/9/22	Wed 11/9/22
287	0%	Set roof top equipment	1 day	Thu 11/10/22	Thu 11/10/22
288	**0%**	**North Elevation**	**19 days**	**Mon 10/10/22**	**Thu 11/3/22**
289	0%	Install vapor barrier	4 days	Mon 10/10/22	Thu 10/13/22
290	0%	Prep Exterior Openings	2 days	Fri 10/14/22	Mon 10/17/22
291	0%	Install windows/doors	3 days	Tue 10/18/22	Thu 10/20/22
292	0%	Exterior Cladding System	10 days	Fri 10/21/22	Thu 11/3/22
293	**0%**	**West Elevation**	**19 days**	**Fri 10/14/22**	**Wed 11/9/22**
294	0%	Install vapor barrier	4 days	Fri 10/14/22	Wed 10/19/22
295	0%	Prep Exterior Openings	2 days	Thu 10/20/22	Fri 10/21/22

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ID	% Complete	Task Name	Duration	Start	Finish
296	0%	Install windows/doors	3 days	Mon 10/24/22	Wed 10/26/22
297	0%	Exterior Cladding System	10 days	Thu 10/27/22	Wed 11/9/22
298	**0%**	**South Elevation**	**19 days**	**Thu 10/20/22**	**Tue 11/15/22**
299	0%	Install vapor barrier	4 days	Thu 10/20/22	Tue 10/25/22
300	0%	Prep Exterior Openings	2 days	Wed 10/26/22	Thu 10/27/22
301	0%	Install windows/doors	3 days	Fri 10/28/22	Tue 11/1/22
302	0%	Exterior Cladding System	10 days	Wed 11/2/22	Tue 11/15/22
303	**0%**	**East Elevation**	**19 days**	**Wed 10/26/22**	**Mon 11/21/22**
304	0%	Install vapor barrier	4 days	Wed 10/26/22	Mon 10/31/22
305	0%	Prep Exterior Openings	2 days	Tue 11/1/22	Wed 11/2/22
306	0%	Install windows/doors	3 days	Thu 11/3/22	Mon 11/7/22
307	0%	Exterior Cladding System	10 days	Tue 11/8/22	Mon 11/21/22
308	**0%**	**Insulation To Paint Activity**	**62 days**	**Tue 11/8/22**	**Tue 2/7/23**
309	**0%**	**Level 4**	**56 days**	**Tue 11/8/22**	**Mon 1/30/23**
310	0%	Building Dry Out/Temp Heat	5 days	Tue 11/8/22	Mon 11/14/22
311	0%	Stock & Insulate	3 days	Mon 11/28/22	Wed 11/30/22
312	0%	Inspect Insulation	1 day	Thu 12/1/22	Thu 12/1/22
313	0%	Stock Drywall	1 day	Fri 12/2/22	Fri 12/2/22
314	0%	Hang Drywall	5 days	Mon 12/5/22	Fri 12/9/22
315	0%	Scrap Drywall	1 day	Mon 12/12/22	Mon 12/12/22
316	0%	Frame ceilings and soffits	3 days	Tue 12/13/22	Thu 12/15/22
317	0%	Electrical RI	2 days	Fri 12/16/22	Mon 12/19/22
318	0%	HVAC RI	2 days	Tue 12/20/22	Wed 12/21/22
319	0%	Sprinkler RI	2 days	Thu 12/22/22	Fri 12/23/22
320	0%	MEP Cover Inspection Ceilings	1 day	Tue 12/27/22	Tue 12/27/22
321	0%	MEP Cover Inspection Ceilings	0 days	Tue 12/27/22	Tue 12/27/22
322	0%	Framing Inspection	1 day	Wed 12/28/22	Wed 12/28/22
323	0%	Hang Soffits	2 days	Thu 12/29/22	Fri 12/30/22
324	0%	Tape Drywall	7 days	Tue 1/3/23	Wed 1/11/23
325	0%	PVA	1 day	Thu 1/12/23	Thu 1/12/23
326	0%	QC Drywall	1 day	Fri 1/13/23	Fri 1/13/23
327	0%	Final Finish Drywall	1 day	Mon 1/16/23	Mon 1/16/23
328	0%	Prime For Paint	1 day	Tue 1/17/23	Tue 1/17/23
329	0%	Paint Interior Ceiling (2) Walls (1)	3 days	Wed 1/18/23	Fri 1/20/23
330	0%	Paint Interior Ceiling (2) Walls (1)	0 days	Fri 1/20/23	Fri 1/20/23
331	0%	Pour Gyp-crete	1 day	Mon 1/23/23	Mon 1/23/23
332	0%	Dry-Out	7 edays	Mon 1/23/23	Mon 1/30/23
333	**0%**	**Level 3**	**59 days**	**Tue 11/8/22**	**Thu 2/2/23**
334	0%	Building Dry Out/Temp Heat	5 days	Tue 11/8/22	Mon 11/14/22
335	0%	Stock & Insulate	3 days	Thu 12/1/22	Mon 12/5/22
336	0%	Inspect Insulation	1 day	Tue 12/6/22	Tue 12/6/22
337	0%	Stock Drywall	1 day	Wed 12/7/22	Wed 12/7/22
338	0%	Hang Drywall	5 days	Thu 12/8/22	Wed 12/14/22
339	0%	Scrap Drywall	1 day	Thu 12/15/22	Thu 12/15/22
340	0%	Frame ceilings and soffits	3 days	Fri 12/16/22	Tue 12/20/22
341	0%	Electrical RI	2 days	Wed 12/21/22	Thu 12/22/22
342	0%	HVAC RI	2 days	Fri 12/23/22	Tue 12/27/22
343	0%	Sprinkler RI	2 days	Wed 12/28/22	Thu 12/29/22
344	0%	MEP Cover Inspection Ceilings	1 day	Fri 12/30/22	Fri 12/30/22
345	0%	MEP Cover Inspection Ceilings	0 days	Fri 12/30/22	Fri 12/30/22
346	0%	Framing Inspection	1 day	Tue 1/3/23	Tue 1/3/23
347	0%	Hang Soffits	2 days	Wed 1/4/23	Thu 1/5/23
348	0%	Tape Drywall	7 days	Fri 1/6/23	Mon 1/16/23
349	0%	PVA	1 day	Tue 1/17/23	Tue 1/17/23
350	0%	QC Drywall	1 day	Wed 1/18/23	Wed 1/18/23

021 | 2022
3rd Quarter | 4th Quarter | 1st Quarter | 2nd Quarter | 3rd Quarter
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug

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WALSH CONSTRUCTION CO.

ID	% Complete	Task Name	Duration	Start	Finish
351	0%	Final Finish Drywall	1 day	Thu 1/19/23	Thu 1/19/23
352	0%	Prime For Paint	1 day	Fri 1/20/23	Fri 1/20/23
353	0%	Paint Interior Ceiling (2) Walls (1)	3 days	Mon 1/23/23	Wed 1/25/23
354	0%	Paint Interior Ceiling (2) Walls (1)	0 days	Wed 1/25/23	Wed 1/25/23
355	0%	Pour Gyp-crete	1 day	Thu 1/26/23	Thu 1/26/23
356	0%	Dry-Out	7 edays	Thu 1/26/23	Thu 2/2/23
357	**0%**	**Level 2**	**62 days**	**Tue 11/8/22**	**Tue 2/7/23**
358	0%	Building Dry Out/Temp Heat	5 days	Tue 11/8/22	Mon 11/14/22
359	0%	Stock & Insulate	3 days	Tue 12/6/22	Thu 12/8/22
360	0%	Inspect Insulation	1 day	Fri 12/9/22	Fri 12/9/22
361	0%	Stock Drywall	1 day	Mon 12/12/22	Mon 12/12/22
362	0%	Hang Drywall	5 days	Tue 12/13/22	Mon 12/19/22
363	0%	Scrap Drywall	1 day	Tue 12/20/22	Tue 12/20/22
364	0%	Frame ceilings and soffits	3 days	Wed 12/21/22	Fri 12/23/22
365	0%	Electrical RI	2 days	Tue 12/27/22	Wed 12/28/22
366	0%	HVAC RI	2 days	Thu 12/29/22	Fri 12/30/22
367	0%	Sprinkler RI	2 days	Tue 1/3/23	Wed 1/4/23
368	0%	MEP Cover Inspection Ceilings	1 day	Thu 1/5/23	Thu 1/5/23
369	0%	MEP Cover Inspection Ceilings	0 days	Thu 1/5/23	Thu 1/5/23
370	0%	Framing Inspection	1 day	Fri 1/6/23	Fri 1/6/23
371	0%	Hang Soffits	2 days	Mon 1/9/23	Tue 1/10/23
372	0%	Tape Drywall	7 days	Wed 1/11/23	Thu 1/19/23
373	0%	PVA	1 day	Fri 1/20/23	Fri 1/20/23
374	0%	QC Drywall	1 day	Mon 1/23/23	Mon 1/23/23
375	0%	Final Finish Drywall	1 day	Tue 1/24/23	Tue 1/24/23
376	0%	Prime For Paint	1 day	Wed 1/25/23	Wed 1/25/23
377	0%	Paint Interior Ceiling (2) Walls (1)	3 days	Thu 1/26/23	Mon 1/30/23
378	0%	Paint Interior Ceiling (2) Walls (1)	0 days	Mon 1/30/23	Mon 1/30/23
379	0%	Pour Gyp-crete	1 day	Tue 1/31/23	Tue 1/31/23
380	0%	Dry-Out	7 edays	Tue 1/31/23	Tue 2/7/23
381	**0%**	**Level 1**	**59 days**	**Tue 11/8/22**	**Thu 2/2/23**
382	0%	Building Dry Out/Temp Heat	5 days	Tue 11/8/22	Mon 11/14/22
383	0%	Stock & Insulate	3 days	Fri 12/9/22	Tue 12/13/22
384	0%	Inspect Insulation	1 day	Wed 12/14/22	Wed 12/14/22
385	0%	Stock Drywall	1 day	Thu 12/15/22	Thu 12/15/22
386	0%	Hang Drywall	5 days	Fri 12/16/22	Thu 12/22/22
387	0%	Scrap Drywall	1 day	Fri 12/23/22	Fri 12/23/22
388	0%	Frame ceilings and soffits	3 days	Tue 12/27/22	Thu 12/29/22
389	0%	Electrical RI	2 days	Fri 12/30/22	Tue 1/3/23
390	0%	HVAC RI	2 days	Wed 1/4/23	Thu 1/5/23
391	0%	Sprinkler RI	2 days	Fri 1/6/23	Mon 1/9/23
392	0%	MEP Cover Inspection Ceilings	1 day	Tue 1/10/23	Tue 1/10/23
393	0%	MEP Cover Inspection Ceilings	0 days	Tue 1/10/23	Tue 1/10/23
394	0%	Framing Inspection	1 day	Wed 1/11/23	Wed 1/11/23
395	0%	Hang Soffits	2 days	Thu 1/12/23	Fri 1/13/23
396	0%	Tape Drywall	7 days	Mon 1/16/23	Tue 1/24/23
397	0%	PVA	1 day	Wed 1/25/23	Wed 1/25/23
398	0%	QC Drywall	1 day	Thu 1/26/23	Thu 1/26/23
399	0%	Final Finish Drywall	1 day	Fri 1/27/23	Fri 1/27/23
400	0%	Prime For Paint	1 day	Mon 1/30/23	Mon 1/30/23
401	0%	Paint Interior Ceiling (2) Walls (1)	3 days	Tue 1/31/23	Thu 2/2/23
402	0%	Paint Interior Ceiling (2) Walls (1)	0 days	Thu 2/2/23	Thu 2/2/23
403	**0%**	**Finishes**	**54 days**	**Mon 1/23/23**	**Thu 4/6/23**
404	**0%**	**Level 4**	**49 days**	**Mon 1/23/23**	**Thu 3/30/23**
405	0%	Install ceiling grid	2 days	Mon 1/23/23	Tue 1/24/23

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ID	% Complete	Task Name	Duration	Start	Finish
406	0%	MEP rough in at grid ceiling	3 days	Wed 1/25/23	Fri 1/27/23
407	0%	Switch/Plug/Lights	4 days	Mon 1/23/23	Thu 1/26/23
408	0%	Fire sprinkler trim	2 days	Mon 1/23/23	Tue 1/24/23
409	0%	Set Cabinets	2 days	Tue 1/31/23	Wed 2/1/23
410	0%	Install Doors and Millwork	5 days	Thu 2/2/23	Wed 2/8/23
411	0%	Install Acoustic Wall Panels	4 days	Tue 2/7/23	Fri 2/10/23
412	0%	Caulk windows and HM frames	2 days	Thu 2/9/23	Fri 2/10/23
413	0%	Install counter tops	2 days	Thu 2/2/23	Fri 2/3/23
414	0%	Install flooring	4 days	Thu 2/9/23	Tue 2/14/23
415	0%	Install ACT ceiling tiles	2 days	Mon 1/30/23	Tue 1/31/23
416	0%	Install Base	2 days	Wed 2/15/23	Thu 2/16/23
417	0%	Prep / paint interior trim	4 days	Fri 2/17/23	Wed 2/22/23
418	0%	Install Hardware	3 days	Thu 2/9/23	Mon 2/13/23
419	0%	Plumbing Trim	5 days	Wed 2/15/23	Tue 2/21/23
420	0%	Install bath accessories	2 days	Wed 2/22/23	Thu 2/23/23
421	0%	Install Blinds	2 days	Mon 1/23/23	Tue 1/24/23
422	0%	Deliver/Install Major Appliances	1 day	Wed 2/22/23	Wed 2/22/23
423	0%	Install Signage	1 day	Thu 2/23/23	Thu 2/23/23
424	0%	Drywall QC/Repairs	1 day	Fri 2/24/23	Fri 2/24/23
425	0%	Paint Final Coat	3 days	Mon 2/27/23	Wed 3/1/23
426	0%	Pre-punch Clean	1 day	Thu 3/2/23	Thu 3/2/23
427	0%	M,E,P finals	1 day	Fri 3/3/23	Fri 3/3/23
428	0%	M,E,P finals	0 days	Thu 3/2/23	Thu 3/2/23
429	0%	WCC Punch	1 day	Fri 3/3/23	Fri 3/3/23
430	0%	Response to Punch	3 days	Mon 3/6/23	Wed 3/8/23
431	0%	Clean	2 days	Thu 3/9/23	Fri 3/10/23
432	0%	Architects Punch	1 day	Mon 3/13/23	Mon 3/13/23
433	0%	Response to Punch	5 days	Tue 3/14/23	Mon 3/20/23
434	0%	Final Clean	3 days	Tue 3/21/23	Thu 3/23/23
435	0%	Final Closeout	5 days	Fri 3/24/23	Thu 3/30/23
436	0%	Lock Down	0 days	Thu 3/30/23	Thu 3/30/23
437	**0%**	**Level 3**	**48 days**	**Thu 1/26/23**	**Mon 4/3/23**
438	0%	Install ceiling grid	2 days	Thu 1/26/23	Fri 1/27/23
439	0%	MEP rough in at grid ceiling	3 days	Mon 1/30/23	Wed 2/1/23
440	0%	Switch/Plug/Lights	4 days	Thu 1/26/23	Tue 1/31/23
441	0%	Fire sprinkler trim	2 days	Thu 1/26/23	Fri 1/27/23
442	0%	Set Cabinets	2 days	Fri 2/3/23	Mon 2/6/23
443	0%	Install Doors and Millwork	5 days	Tue 2/7/23	Mon 2/13/23
444	0%	Install Acoustic Wall Panels	4 days	Fri 2/10/23	Wed 2/15/23
445	0%	Caulk windows and HM frames	2 days	Tue 2/14/23	Wed 2/15/23
446	0%	Install counter tops	2 days	Tue 2/7/23	Wed 2/8/23
447	0%	Install flooring	4 days	Tue 2/14/23	Fri 2/17/23
448	0%	Install ACT ceiling tiles	2 days	Thu 2/2/23	Fri 2/3/23
449	0%	Install Base	2 days	Mon 2/20/23	Tue 2/21/23
450	0%	Prep / paint interior trim	4 days	Wed 2/22/23	Mon 2/27/23
451	0%	Install Hardware	3 days	Tue 2/14/23	Thu 2/16/23
452	0%	Plumbing Trim	5 days	Thu 2/9/23	Wed 2/15/23
453	0%	Install bath accessories	2 days	Thu 2/16/23	Fri 2/17/23
454	0%	Install Blinds	2 days	Thu 1/26/23	Fri 1/27/23
455	0%	Deliver/Install Major Appliances	1 day	Thu 2/16/23	Thu 2/16/23
456	0%	Install Signage	1 day	Fri 2/17/23	Fri 2/17/23
457	0%	Drywall QC/Repairs	1 day	Tue 2/28/23	Tue 2/28/23
458	0%	Paint Final Coat	3 days	Wed 3/1/23	Fri 3/3/23
459	0%	Pre-punch Clean	1 day	Mon 3/6/23	Mon 3/6/23
460	0%	M,E,P finals	1 day	Tue 3/7/23	Tue 3/7/23

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ID	% Complete	Task Name	Duration	Start	Finish
461	0%	M,E,P finals	0 days	Mon 3/6/23	Mon 3/6/23
462	0%	WCC Punch	1 day	Tue 3/7/23	Tue 3/7/23
463	0%	Response to Punch	3 days	Wed 3/8/23	Fri 3/10/23
464	0%	Clean	2 days	Mon 3/13/23	Tue 3/14/23
465	0%	Architects Punch	1 day	Wed 3/15/23	Wed 3/15/23
466	0%	Response to Punch	5 days	Thu 3/16/23	Wed 3/22/23
467	0%	Final Clean	3 days	Thu 3/23/23	Mon 3/27/23
468	0%	Final Closeout	5 days	Tue 3/28/23	Mon 4/3/23
469	0%	Lock Down	0 days	Mon 4/3/23	Mon 4/3/23
470	**0%**	**Level 2**	**48 days**	**Tue 1/31/23**	**Thu 4/6/23**
471	0%	Install ceiling grid	2 days	Tue 1/31/23	Wed 2/1/23
472	0%	MEP rough in at grid ceiling	3 days	Thu 2/2/23	Mon 2/6/23
473	0%	Switch/Plug/Lights	4 days	Tue 1/31/23	Fri 2/3/23
474	0%	Fire sprinkler trim	2 days	Tue 1/31/23	Wed 2/1/23
475	0%	Set Cabinets	2 days	Wed 2/8/23	Thu 2/9/23
476	0%	Install Doors and Millwork	5 days	Fri 2/10/23	Thu 2/16/23
477	0%	Install Acoustic Wall Panels	4 days	Wed 2/15/23	Mon 2/20/23
478	0%	Caulk windows and HM frames	2 days	Fri 2/17/23	Mon 2/20/23
479	0%	Install counter tops	2 days	Fri 2/10/23	Mon 2/13/23
480	0%	Install flooring	4 days	Fri 2/17/23	Wed 2/22/23
481	0%	Install ACT ceiling tiles	2 days	Tue 2/7/23	Wed 2/8/23
482	0%	Install Base	2 days	Thu 2/23/23	Fri 2/24/23
483	0%	Prep / paint interior trim	4 days	Mon 2/27/23	Thu 3/2/23
484	0%	Install Hardware	3 days	Fri 2/17/23	Tue 2/21/23
485	0%	Plumbing Trim	5 days	Tue 2/14/23	Mon 2/20/23
486	0%	Install bath accessories	2 days	Tue 2/21/23	Wed 2/22/23
487	0%	Install Blinds	2 days	Tue 1/31/23	Wed 2/1/23
488	0%	Deliver/Install Major Appliances	1 day	Tue 2/21/23	Tue 2/21/23
489	0%	Install Signage	1 day	Wed 2/22/23	Wed 2/22/23
490	0%	Drywall QC/Repairs	1 day	Fri 3/3/23	Fri 3/3/23
491	0%	Paint Final Coat	3 days	Mon 3/6/23	Wed 3/8/23
492	0%	Pre-punch Clean	1 day	Thu 3/9/23	Thu 3/9/23
493	0%	M,E,P finals	1 day	Fri 3/10/23	Fri 3/10/23
494	0%	M,E,P finals	0 days	Thu 3/9/23	Thu 3/9/23
495	0%	WCC Punch	1 day	Fri 3/10/23	Fri 3/10/23
496	0%	Response to Punch	3 days	Mon 3/13/23	Wed 3/15/23
497	0%	Clean	2 days	Thu 3/16/23	Fri 3/17/23
498	0%	Architects Punch	1 day	Mon 3/20/23	Mon 3/20/23
499	0%	Response to Punch	5 days	Tue 3/21/23	Mon 3/27/23
500	0%	Final Clean	3 days	Tue 3/28/23	Thu 3/30/23
501	0%	Final Closeout	5 days	Fri 3/31/23	Thu 4/6/23
502	0%	Lock Down	0 days	Thu 4/6/23	Thu 4/6/23
503	**0%**	**Level 1**	**42 days**	**Fri 2/3/23**	**Mon 4/3/23**
504	0%	Install ceiling grid	2 days	Fri 2/3/23	Mon 2/6/23
505	0%	MEP rough in at grid ceiling	3 days	Tue 2/7/23	Thu 2/9/23
506	0%	Switch/Plug/Lights	4 days	Fri 2/3/23	Wed 2/8/23
507	0%	Fire sprinkler trim	2 days	Fri 2/3/23	Mon 2/6/23
508	0%	Set Cabinets	2 days	Fri 2/3/23	Mon 2/6/23
509	0%	Install Doors and Millwork	5 days	Tue 2/7/23	Mon 2/13/23
510	0%	Install Acoustic Wall Panels	4 days	Fri 2/10/23	Wed 2/15/23
511	0%	Caulk windows and HM frames	2 days	Tue 2/14/23	Wed 2/15/23
512	0%	Install counter tops	2 days	Tue 2/7/23	Wed 2/8/23
513	0%	Install flooring	4 days	Tue 2/14/23	Fri 2/17/23
514	0%	Install ACT ceiling tiles	2 days	Fri 2/10/23	Mon 2/13/23
515	0%	Install Base	2 days	Mon 2/20/23	Tue 2/21/23

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ID	% Complete	Task Name	Duration	Start	Finish
516	0%	Prep / paint interior trim	4 days	Wed 2/22/23	Mon 2/27/23
517	0%	Install Hardware	3 days	Tue 2/14/23	Thu 2/16/23
518	0%	Plumbing Trim	5 days	Thu 2/9/23	Wed 2/15/23
519	0%	Install bath accessories	2 days	Thu 2/16/23	Fri 2/17/23
520	0%	Install Blinds	2 days	Fri 2/3/23	Mon 2/6/23
521	0%	Deliver/Install Major Appliances	1 day	Thu 2/16/23	Thu 2/16/23
522	0%	Install Signage	1 day	Fri 2/17/23	Fri 2/17/23
523	0%	Drywall QC/Repairs	1 day	Tue 2/28/23	Tue 2/28/23
524	0%	Paint Final Coat	3 days	Wed 3/1/23	Fri 3/3/23
525	0%	Pre-punch Clean	1 day	Mon 3/6/23	Mon 3/6/23
526	0%	M,E,P finals	1 day	Tue 3/7/23	Tue 3/7/23
527	0%	M,E,P finals	0 days	Mon 3/6/23	Mon 3/6/23
528	0%	WCC Punch	1 day	Tue 3/7/23	Tue 3/7/23
529	0%	Response to Punch	3 days	Wed 3/8/23	Fri 3/10/23
530	0%	Clean	2 days	Mon 3/13/23	Tue 3/14/23
531	0%	Architects Punch	1 day	Wed 3/15/23	Wed 3/15/23
532	0%	Response to Punch	5 days	Thu 3/16/23	Wed 3/22/23
533	0%	Final Clean	3 days	Thu 3/23/23	Mon 3/27/23
534	0%	Final Closeout	5 days	Tue 3/28/23	Mon 4/3/23
535	0%	Lock Down	0 days	Mon 4/3/23	Mon 4/3/23
536	**0%**	**Landscape & Hardscape**	**45 days**	**Fri 11/4/22**	**Wed 1/11/23**
537	**0%**	**North Site Finishes**	**33 days**	**Fri 11/4/22**	**Thu 12/22/22**
538	**0%**	**Hardscape**	**33 days**	**Fri 11/4/22**	**Thu 12/22/22**
539	0%	Prep for hardscape	5 days	Fri 11/4/22	Thu 11/10/22
540	0%	Inspect subgrade	1 day	Fri 11/11/22	Fri 11/11/22
541	0%	Form sidewalk	3 days	Mon 11/14/22	Wed 11/16/22
542	0%	Pour sidewalk	3 days	Thu 11/17/22	Mon 11/21/22
543	0%	Install irrigation	5 days	Tue 11/22/22	Wed 11/30/22
544	0%	Place soil	1 day	Thu 12/1/22	Thu 12/1/22
545	0%	Install trees	3 days	Fri 12/2/22	Tue 12/6/22
546	0%	Inspect tree placement	1 day	Wed 12/7/22	Wed 12/7/22
547	0%	Install plants	4 days	Thu 12/8/22	Tue 12/13/22
548	0%	Install mulch	2 days	Wed 12/14/22	Thu 12/15/22
549	0%	Landscape Punch	5 days	Fri 12/16/22	Thu 12/22/22
550	**0%**	**West Site Finishes**	**33 days**	**Thu 11/10/22**	**Thu 12/29/22**
551	**0%**	**Hardscape**	**33 days**	**Thu 11/10/22**	**Thu 12/29/22**
552	0%	Prep for hardscape	5 days	Thu 11/10/22	Wed 11/16/22
553	0%	Inspect subgrade	1 day	Thu 11/17/22	Thu 11/17/22
554	0%	Form sidewalk	3 days	Fri 11/18/22	Tue 11/22/22
555	0%	Pour sidewalk	3 days	Wed 11/23/22	Tue 11/29/22
556	0%	Install irrigation	5 days	Wed 11/30/22	Tue 12/6/22
557	0%	Place soil	1 day	Wed 12/7/22	Wed 12/7/22
558	0%	Install trees	3 days	Thu 12/8/22	Mon 12/12/22
559	0%	Inspect tree placement	1 day	Tue 12/13/22	Tue 12/13/22
560	0%	Install plants	4 days	Wed 12/14/22	Mon 12/19/22
561	0%	Install mulch	2 days	Tue 12/20/22	Wed 12/21/22
562	0%	Landscape Punch	5 days	Thu 12/22/22	Thu 12/29/22
563	**0%**	**South Site Finishes**	**31 days**	**Wed 11/16/22**	**Tue 1/3/23**
564	**0%**	**Hardscape**	**31 days**	**Wed 11/16/22**	**Tue 1/3/23**
565	0%	Prep for hardscape	1 day	Wed 11/16/22	Wed 11/16/22
566	0%	Inspect subgrade	3 days	Thu 11/17/22	Mon 11/21/22
567	0%	Form sidewalk	3 days	Tue 11/22/22	Mon 11/28/22
568	0%	Pour sidewalk	3 days	Tue 11/29/22	Thu 12/1/22
569	0%	Install irrigation	5 days	Fri 12/2/22	Thu 12/8/22
570	0%	Place soil	1 day	Fri 12/9/22	Fri 12/9/22

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ID	% Complete	Task Name	Duration	Start	Finish
571	0%	Install trees	3 days	Mon 12/12/22	Wed 12/14/22
572	0%	Inspect tree placement	1 day	Thu 12/15/22	Thu 12/15/22
573	0%	Install plants	4 days	Fri 12/16/22	Wed 12/21/22
574	0%	Install mulch	2 days	Thu 12/22/22	Fri 12/23/22
575	0%	Landscape Punch	5 days	Tue 12/27/22	Tue 1/3/23
576	**0%**	**East Site Finishes**	**33 days**	**Tue 11/22/22**	**Wed 1/11/23**
577	**0%**	**Hardscape**	**33 days**	**Tue 11/22/22**	**Wed 1/11/23**
578	0%	Prep for hardscape	5 days	Tue 11/22/22	Wed 11/30/22
579	0%	Inspect subgrade	1 day	Thu 12/1/22	Thu 12/1/22
580	0%	Form sidewalk	3 days	Fri 12/2/22	Tue 12/6/22
581	0%	Pour sidewalk	3 days	Wed 12/7/22	Fri 12/9/22
582	0%	Install irrigation	5 days	Mon 12/12/22	Fri 12/16/22
583	0%	Place soil	1 day	Mon 12/19/22	Mon 12/19/22
584	0%	Install trees	3 days	Tue 12/20/22	Thu 12/22/22
585	0%	Inspect tree placement	1 day	Fri 12/23/22	Fri 12/23/22
586	0%	Install plants	4 days	Tue 12/27/22	Fri 12/30/22
587	0%	Install mulch	2 days	Tue 1/3/23	Wed 1/4/23
588	0%	Landscape Punch	5 days	Thu 1/5/23	Wed 1/11/23
589	**0%**	**Final Inspections**	**62 days**	**Mon 3/13/23**	**Wed 6/7/23**
590	0%	Electrical Final	3 days	Mon 3/13/23	Wed 3/15/23
591	0%	Plumbing Final	3 days	Mon 3/13/23	Wed 3/15/23
592	0%	Mechanical Final	3 days	Mon 3/13/23	Wed 3/15/23
593	0%	Fire Department Inspection	3 days	Thu 3/16/23	Mon 3/20/23
594	0%	Building Department Finals	3 days	Tue 3/21/23	Thu 3/23/23
595	0%	City of _____ Closeout	5 days	Fri 3/31/23	Thu 4/6/23
596	0%	Project Complete/Demob	2 days	Fri 4/7/23	Mon 4/10/23
597	0%	Dept. of Early Learning Licensing	20 days	Tue 4/11/23	Mon 5/8/23
598	0%	Building Flush Out	40 days	Tue 4/11/23	Tue 6/6/23
599	0%	Owner Occupies Building	1 day	Wed 6/7/23	Wed 6/7/23

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