

Designing Modern Wood Schools

How to create high-performance structures that are also cost effective

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There is a strong case to be made for using wood in school construction, both to accommodate a growing number of students with structures that are cost effective, and to do so while creating high-performance buildings that are safe, resilient, and appealing.

Across the United States, there is high demand for new schools. In 2015, an estimated \$6.1 billion was spent on new school construction, and educational facilities accounted for about 88 million square feet of the non-residential market.¹ Since, by 2024, U.S. schools will be required to accommodate an estimated 2.8 million more students than they do today, these numbers can only increase.²

Cost and construction speed are often cited as the main reasons to design a school in wood. Wood building systems typically cost less than

COMMON GROUND HIGH SCHOOL

Location: New Haven, Connecticut

Architect: Gray Organschi Architecture

Timber Engineer: Bensonwood

Exemplifying the trend toward mass timber in school design, this 14,000-square-foot addition to a Type VB high school is comprised of CLT and glulam.

CONTINUING EDUCATION



1.5 AIA LU/HSW



1.5 GBCI CE HOURS



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Learning Objectives

After reading this article, you should be able to:

1. Review provisions of the International Building Code specific to school buildings and discuss opportunities to achieve cost savings through the use of wood.
2. Explore design and detailing best practices used to achieve performance objectives in school assembly design.
3. Discuss structural design considerations unique to school buildings, as well as framing options for floors, walls, and roofs.
4. Consider how wood has been used in modern wood-frame and mass timber schools across the United States.

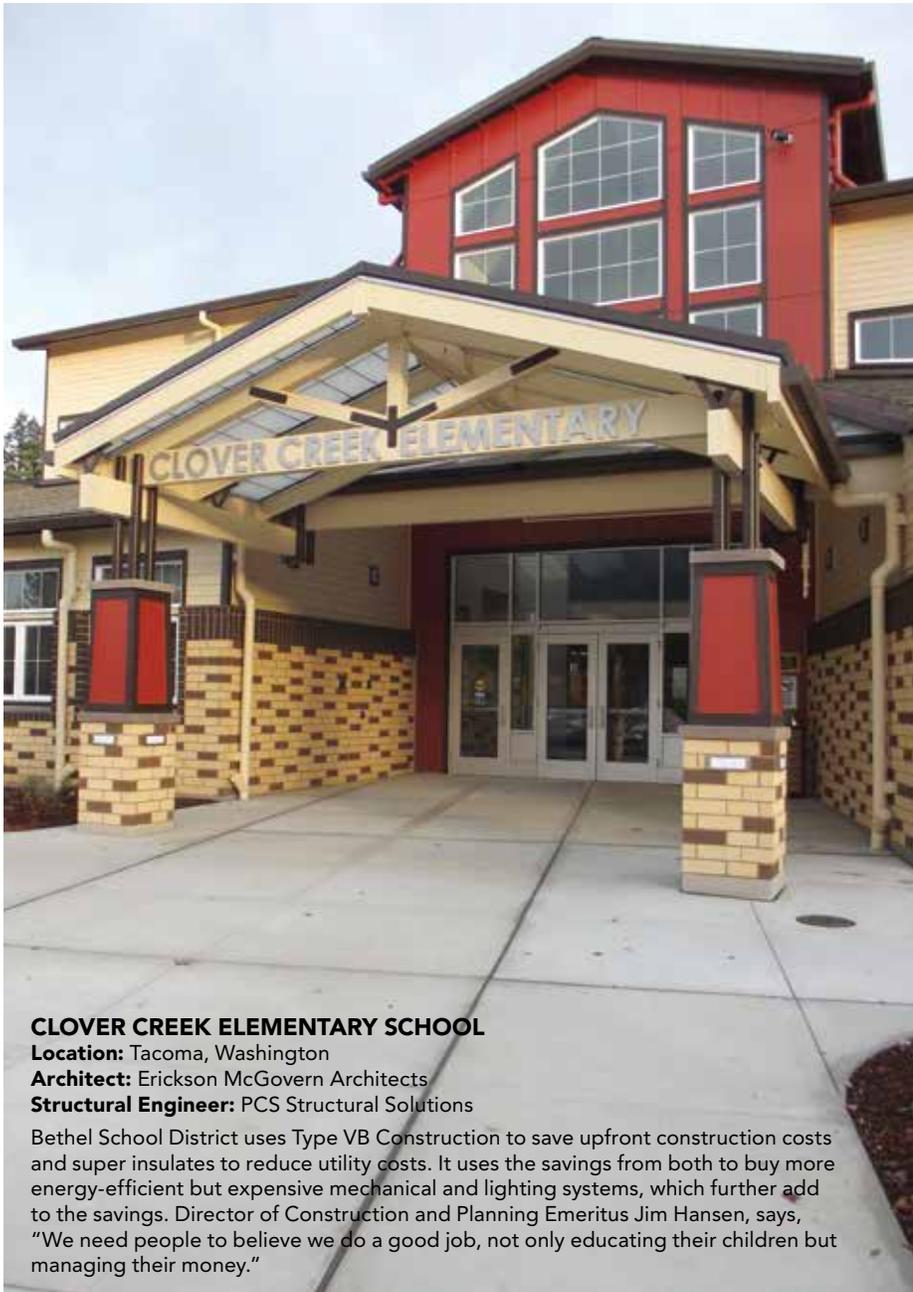
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AIA COURSE #K1701G
GBCI COURSE #0920011660



Photo: David Sundberg

Photo: Bethel School District



CLOVER CREEK ELEMENTARY SCHOOL

Location: Tacoma, Washington
Architect: Erickson McGovern Architects
Structural Engineer: PCS Structural Solutions

Bethel School District uses Type VB Construction to save upfront construction costs and super insulates to reduce utility costs. It uses the savings from both to buy more energy-efficient but expensive mechanical and lighting systems, which further add to the savings. Director of Construction and Planning Emeritus Jim Hansen, says, "We need people to believe we do a good job, not only educating their children but managing their money."

**DESIGN RESOURCE:
PROJECT ASSISTANCE**

Technical information in this course is based on "An Architectural and Engineering Guide to Designing Modern Wood Schools," a presentation by Richard McLain, MS, PE, SE, technical director, Architectural & Engineering Solutions, of the U.S. WoodWorks program. WoodWorks offers free project assistance related to the design of any nonresidential or multifamily wood building. For technical support, or to request an in-house lunch and learn, visit www.woodworks.org/project-assistance and contact the expert nearest you, or email help@woodworks.org.

alternatives, and wood construction is fast, even more so with the trend toward panelized products, such as cross-laminated timber (CLT), and prefabrication. This is especially important for schools, which often have limited budgets and compressed construction schedules.

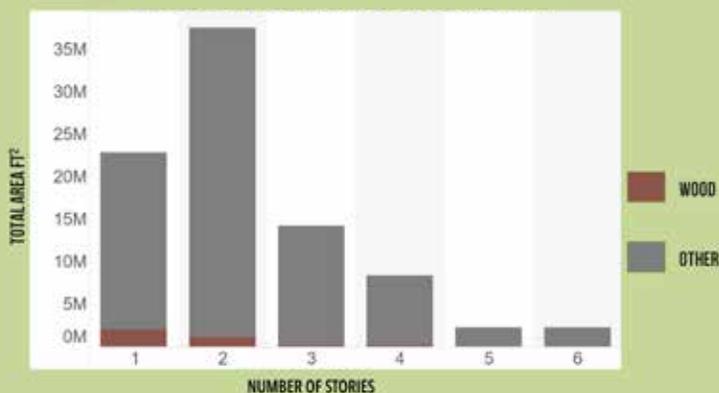
Increasingly, however, school designers and facility planners are citing other attributes of wood as motivating factors for its use. They point to its light carbon footprint, energy performance, and other environmental benefits. They also cite a growing body of research linking the use of exposed wood to occupant well-being, including potential benefits related to increased concentration. In school construction, wood offers endless opportunities to create warm and inspiring places to learn.

This course takes a practical look at the design of wood schools, emphasizing opportunities with traditional wood-frame construction and, in particular, how to reduce costs. Architectural design and detailing topics include allowable heights and areas, detailing for fire resistance, acoustics, and durability, as well as structural design considerations. The trend toward mass timber is also discussed, along with information on wood's biophilic attributes and environmental performance, including energy efficiency and carbon footprint. Examples of wood schools across the United States are also highlighted.

CONSTRUCTION TYPE AND COST

In Washington state, the Bethel School District's strategy is to save money by using wood-frame construction for the majority of school construction, and to use those savings to buy more expensive but efficient mechanical or lighting systems. This provides operational savings—most of its schools are ENERGY STAR leaders—which, over the

FIGURE 1: AVERAGE SCHOOL BUILDING SIZE



Source: Dodge Construction Data, 2015

FIGURE 2: COST PER SQUARE FOOT BY CONSTRUCTION TYPE, EDUCATIONAL GROUP E

IA	IB	IIA	IIB	IIIA	IIIB	IV	VA	VB
\$192	\$185	\$180	\$172	\$161	\$153	\$166	\$140	\$136

Source: ICC Building Valuation Data, August 2016

The ICC publishes cost per square foot averages by occupancy group and construction type.

FIGURE 3: ALLOWABLE BUILDING SIZE BY CONSTRUCTION TYPE, EDUCATIONAL GROUP E

	IA	IB	IIA	IIB	IIIA	IIIB	IV	VA	VB
Height (ft)	Unlimited	60	65	55	65	55	65	50	40
Stories	Unlimited	5	3	2	3	2	3	1	1
Area/Story (sf)	Unlimited	Unlimited	26,500	14,500	23,500	14,500	25,500	18,500	9,500

Source: IBC Table 503

With Type III Construction, a wood-frame building can achieve almost the same height and area as a steel or concrete building of Type II Construction. Designers can then use code provisions for further increases.

FIGURE 4: TOTAL ALLOWABLE BUILDING AREA WITH SPRINKLERS AND FULL FRONTAGE INCREASES, EDUCATIONAL GROUP E

	IIA	IIB	IIIA	IIIB	VA	VB
Stories	4	3	4	3	2	2
Height (ft)	85	75	85	75	70	60
One-Story Total Area (sf)	125,875	68,875	111,625	68,875	87,875	45,125
Two-Story Total Area (sf)	198,750	108,750	176,250	108,750	138,750	71,250
Three-Story Total Area (sf)	298,125	163,125	264,375	163,125	Not permitted	Not permitted

Source: IBC Table 503

With sprinklers and open frontage, Type III and Type V Construction offer ample height and area for most schools.

long term, puts less pressure on the general fund. The district reports construction costs per square foot that are much lower than the average in the region, an achievement Director of Construction and Planning Emeritus Jim Hansen credits to the use of wood.³

According to the “State of School Construction, 2015 Report” by School Planning & Management, the following are average school sizes and costs across the country:

- Elementary schools: 80,000 square feet/\$210 per square foot
- Middle schools: 117,000 square feet/\$270 per square foot
- High schools: 154,700 square feet/\$267 per square foot

The majority of schools are one or two stories (Figure 1), and relatively few are built in wood. Rather, many designers default to steel or concrete, even though wood schools are permitted under the International Building Code (IBC), are required to meet all of the same safety and performance requirements as schools built with other materials, and can offer significant cost savings.

Under the IBC, small and medium-sized spaces in a school typically fall under

Educational Group E occupancy. Although large spaces such as a gymnasium or cafeteria can be classified as Assembly Group A, IBC Section 303.1.3 allows schools to be classified as Group E throughout, and this is a common approach.

IBC Section 602 defines five construction types and allows the use of wood as follows:

- Types IIIA, IIIB, IV, VA, and VB: Structural wood framing permitted throughout
- Types IIIA, IIIB, and IV: Fire retardant-treated (FRT) wood framing required for exterior walls
- Type IV: Exposed heavy timber permitted for interior elements provided they meet the minimum size requirements of IBC Section 602.4
- Types IA, IB, IIA, and IIB: Several provisions for the use of wood per IBC Section 603

The IBC specifies the allowable height and area for each construction type, and each has different requirements, largely related to fire protection.

Twice a year, the International Code Council (ICC) publishes building valuation data that includes the average cost

per square foot for each construction type and occupancy group. Figure 2 shows the average cost of buildings in Educational Group E, and illustrates the cost impact of construction type and, by extension, choice of building material. Buildings of Type I and II Construction, which are typically steel, concrete, or masonry, cost an average of \$172 to \$192 per square foot. Buildings of Type III and V Construction, which are typically wood-frame, cost significantly less at \$136 to \$161 per square foot.

Note: The ICC data includes building costs only (e.g., foundation, structure, mechanical), while the School Planning & Management report cited above includes complete project costs (e.g., furnishings and site work).

Given the potential savings, the question becomes: Is it possible to design an average size school—i.e., 80,000 to 155,000 square feet—as a Type III or V wood building? The answer is yes. Although designers accustomed to steel and concrete often design schools as Type IIA or IIB, nearly identical height and area can be achieved with wood framing (Figure 3).

Code Provisions for Height and Area Increases

For all but Type I buildings, the square footage shown in Figure 3 is clearly much less than the average school sizes stated above. These are base heights and areas, and numerous code provisions exist for increases beyond those amounts. In the context of a wood-frame school, for example, designers may utilize the following:

Sprinklers: The requirement to include an NFPA 13 sprinkler system is not based on materials or construction type. It is based on occupancy group, occupant load, size of the fire area, and other occupant-specific criteria. Per IBC Section 903.2, an NFPA 13 sprinkler system is required throughout all educational and assembly occupancies where the fire area exceeds 12,000 square feet—which includes the vast majority of school construction. Use of an NFPA 13 sprinkler system allows designers to significantly increase the height and area of these facilities.

- Per IBC Section 504.2, buildings equipped throughout with an NFPA 13

sprinkler system can add one story and 20 feet to the base stories and heights in IBC Table 503.

- Per IBC Section 506.3, buildings equipped throughout with an NFPA 13 sprinkler system can add 200–300 percent to the base floor areas in Table 503. For a single-story building, the base area can be multiplied by four. For a multistory building, the base area can be multiplied by three.
- The story and height increases are permitted to be used concurrently with the area increase per IBC Sections 504.2 and 506.3.

Open frontage: Open space around a building, such as a parking lot or major roadway, provides firefighting access to multiple sides of the structure. If more than 25 percent of the building's perimeter is open for a minimum of 20 feet, IBC Section 506.2 allows an increase to the base floor area in Table 503 of up to 75 percent.

The area increases for sprinklers and open frontage are per story. Per IBC Section 506.4.1, a two-story school building's total area is permitted to be twice the increased

area, and a three-story (or taller) school building's total area is permitted to be three times the increased area. Figure 4 shows the total potential square footage impact for Educational Group E occupancy.

Compared to a Type IIA steel or concrete

DESIGN RESOURCES: HEIGHTS AND AREAS

For help calculating the allowable size of a wood-frame school, the 2015 *Code Conforming Wood Design*, a joint publication of the ICC and American Wood Council (AWC), can be downloaded at www.awc.org. WoodWorks also offers a free Heights and Areas Calculator, available at www.woodworks.org, which reviews and analyzes building height and area compliance with the 2012 IBC. As 2015 IBC allowable height and area limits are almost identical to the 2012 IBC limitations, this calculator offers a quick way to estimate the 2015 limitations for educational occupancies.

CREATING EXCEPTIONAL SPACES WITH MASS TIMBER

One of the exciting trends in U.S. school design is the growing use of mass timber—i.e., large solid wood panel products such as CLT, nail-laminated timber (NLT), and glued-laminated timber (glulam)—for floor, wall, and roof construction, or to create innovative sculptural buildings.

Because of their strength and dimensional stability, products such as CLT offer a low-carbon alternative to steel, concrete, and masonry for many applications. A complement to other wood-framing systems, mass timber can be used on its own, in conjunction with other wood systems such as post-and-beam, or in hybrid structures with steel or concrete. Except where desired for aesthetic reasons, mass timber is not necessarily a good substitute for light wood-frame construction, only because dimension lumber framing offers such a compelling combination of structural performance, cost, and environmental advantages where permitted by code.

For school designers, the speed of mass timber construction is especially attractive. Because materials come pre-manufactured as large solid panels, it is possible to construct an entire school during a relatively small window when students are off campus.

For a 14,000-square-foot addition to Common Ground High School in New Haven, Connecticut, for example, Gray Organschi Architecture and engineering partner Bensonwood chose a combination of CLT and glulam. Assisted only by a mobile crane, a five-person assembly crew installed the entire primary structure and enclosure in just four weeks.



WASHINGTON LATIN PUBLIC CHARTER SCHOOL

Location: Washington, D.C.
Architect: Perkins Eastman
Structural Engineer: Arup

Other attributes that make mass timber appealing for schools are the potential efficiencies of replicable modular designs, a lighter carbon footprint than non-wood building materials, and the positive impacts of exposed wood on student well-being.

Architect Alan Organschi, who designed Common Ground High School, says, "It's well-known that, as a hygroscopic material, wood surfaces serve as moisture buffers, moderating swings in interior humidity and thereby improving air quality. It's worth mentioning that during the first few weeks the new building was being used, a teacher commented to me that people were remarking on the freshness of the air in the classrooms. Anecdotal, I know, but it squares with the scientific predictions of health benefits of using wood (especially unfinished wood) in building interiors." (See Health and Well-Being.)

The fact that mass timber weighs less than other materials also has potential benefits, including smaller foundation requirements and lower forces for seismic resistance.

While NLT and glulam have been recognized in the IBC for many years, CLT is a relatively new addition. The 2015 IBC recognizes CLT products manufactured according to the ANSI/APA PRG-320: Standard for Performance Rated Cross-Laminated Timber. Under the IBC, CLT at the required size is specifically stated for prescribed use in Type IV buildings. However, CLT can be used in all types of combustible construction—i.e., wherever combustible framing or heavy timber materials are allowed. AWC's National Design Specification® (NDS®) for Wood Construction is referenced throughout the IBC as the standard for structural wood design, including CLT.

Photo: Dennis Ivy; courtesy of WoodWorks

building, a Type IIIA wood-frame building has the same height limits of four stories and 85 feet. The Type IIIA building offers nearly 90,000 square feet per floor, and more than 176,000 square feet for a two-story building. Even a Type VA structure offers an area of nearly 139,000 square feet for a two-story building, which is larger than many schools.

Unlimited area: Per IBC Section 507.3 and Section 507.10, a wood-frame school may also qualify for unlimited area—if, for example, the building:

- Has a minimum of 60 feet open frontage around the perimeter
- Is Type IIIA or IV Construction, one story, fully sprinklered, and classified as Educational Group E occupancy
- Is Type III or IV Construction, one story, fully sprinklered, and classified as Assembly Group occupancy (A-4)
- Meets other provisions such as those related to egress

Fire walls: Fire walls are the most restrictive type of wall assembly in terms of their construction and hourly fire-rating requirements. However, they allow areas within a structure to be considered as separate buildings for the purpose of calculating height and area, further increasing the potential size of a project.

The Savings Add Up

Combine the ICC's estimated cost per square footage from Figure 2 with the average school size and costs from the School Planning & Management report, and a picture emerges of significant cost savings. By switching from a Type IIA steel or concrete school to a Type IIIA wood-frame school, the ICC estimates show a potential 11 percent savings. Now factor in the average school size:

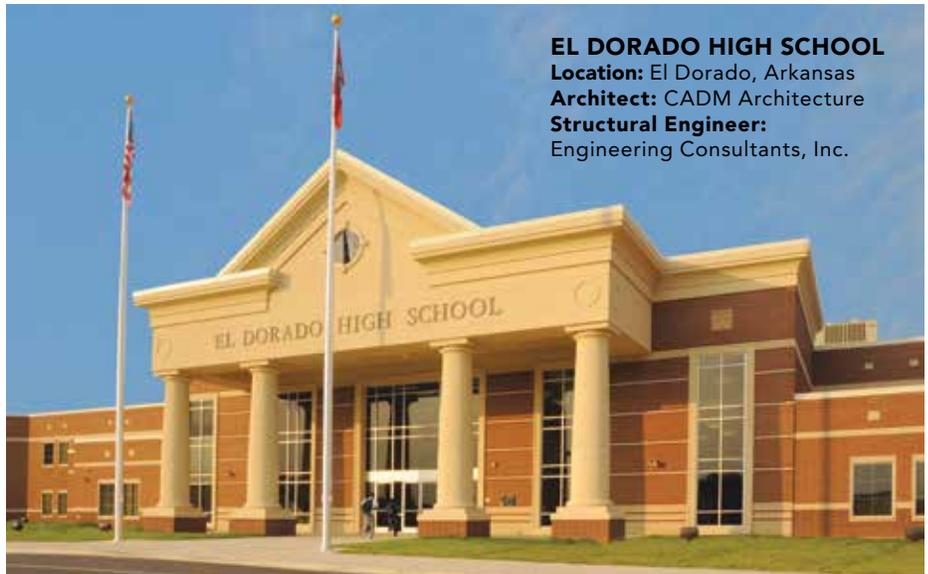
- Elementary school: 80,000 square feet/save \$1.8 million
- Middle school: 117,000 square feet/save \$3.3 million
- High school: 154,700 square feet/save \$4.4 million

For most elementary and middle schools, the average size falls within the maximum allowable by Type VA Construction, bringing the potential savings closer to 22 percent.

DETAILING FOR FIRE RESISTANCE

An important yet little known piece of information for many designers is that there are many sources for tested assemblies that meet 1-hour and 2-hour fire-resistance ratings required for wood buildings—not just UL.

In addition to UL's Fire Resistance Directory, assemblies can be found in publications such as:



EL DORADO HIGH SCHOOL

Location: El Dorado, Arkansas
Architect: CADM Architecture
Structural Engineer: Engineering Consultants, Inc.

When the initial steel and masonry design for this 320,000-square-foot, Type IIIA high school came in well over budget, the project team evaluated alternative systems. The intent had always been to utilize exposed heavy timber in select areas. However, by changing approximately 40 percent of the nonexposed structural materials to wood framing, the team was able to save \$2.7 million.⁴

Photo: Costea; courtesy of LPA, Inc.



SOUTH TAHOE HIGH SCHOOL

Location: South Lake Tahoe, California
Architect: LPA, Inc.
Structural Engineer: LPA, Inc.
Size: 67,500 square feet

Fire resistance of exposed wood members can be calculated using the provisions of Chapter 16 of the NDS.

- Intertek Testing Services' *Directory of Listed Products*
- Gypsum Association's *Fire Resistance Design Manual*

They can also be selected from one of the prescriptive assemblies provided in IBC Section 721, which are based on ASTM E 119 or UL 263 test results, by calculating an assembly's fire resistance using IBC Section 722, or by other methods indicated in Section 703.3 of the code.

Assemblies tested by the wood industry are also available. AWC's *Design for Code Acceptance 3: Fire-Rated Wood Floor and Wall Assemblies* contains fire ratings of

wood-frame wall and floor/ceiling/roof assemblies. Other sources include APA – The Engineered Wood Association's *Fire-Rated Systems* (Form W305), and Wood Truss Council of America's *Metal Plate Connected Wood Truss Handbook*. Some manufacturer websites and catalogues also reference tested assemblies that include their products.

Designers also have the option of integrating exposed, fire resistance-rated heavy or mass timber structural members into their designs, adding warmth to interior spaces. Because these products are

thick and solid, they char on the outside at a slow and predictable rate, while retaining strength, slowing combustion, and allowing time to evacuate the building. The char protects the wood from further degradation, helping to maintain the building's structural integrity and reducing its fuel contribution to the fire.

Per IBC Section 722, the fire resistance of exposed wood members may be calculated using the provisions of Chapter 16 of the NDS. AWC's Technical Report No. 10: *Calculating the Fire Resistance of Exposed Wood Members*, contains full details of the NDS method as well as design examples.

ACOUSTICS

With spaces that vary from gyms to libraries (and every noise level in between), acoustic consideration is an obvious priority for school design. The IBC divides sound into two categories. Airborne sound is measured with sound transmission class (STC) ratings and is relevant both to wall and floor/ceiling assemblies. Structure-borne sound is measured through impact insulation class (IIC) ratings and only relates to floor/ceiling assemblies.

While the IBC requires STC and IIC ratings of 50 for assemblies in apartment buildings and hotels, it has no such requirements for educational facilities. However, many school districts have established their own minimum ratings, often with similar STC and IIC baselines.

Tested wood-frame assemblies are available to meet a wide variety of acoustic performance levels. This is illustrated in Figure 6, which shows the progression from single-stud through staggered stud and double-stud construction. Double-stud walls can achieve a rating of approximately STC 63 when insulated with batt insulation and covered with two layers of gypsum wallboard on the outside faces of the studs.

Beyond gypsum wallboard and insulation, options for improving performance include (among others) resilient channels in walls and floors, and concrete topping (or other similar material) on floor assemblies.

DESIGN RESOURCES: DETAILING

Tested assemblies for fire resistance: UL's *Fire Resistance Directory* (www.ul.com); Intertek Testing Services' *Directory of Listed Products* (www.intertek.com); Gypsum Association's *Fire Resistance Design Manual* (www.gypsum.org); IBC Section 721; AWC's *Design for Code Acceptance 3: Fire-Rated Wood Floor and Wall Assemblies* (www.awc.org); APA – The Engineered Wood Association's *Fire-Rated Systems (Form W305)* (www.apawood.org); Wood Truss Council of America's *Metal Plate Connected Wood Truss Handbook*

Acoustic detailing: *Acoustical Considerations of Mixed-Use Wood-Frame Buildings*, www.woodworks.org

Durability: "Designing for Durability," *Architectural Record* CEU, www.ThinkWood.com

For a more in-depth discussion of acoustic detailing, the WoodWorks paper, *Acoustical Considerations for Mixed-Use Wood-Frame Buildings*, is also relevant to the design of wood-frame schools.⁵

DURABILITY

There is a misperception that wood buildings require greater levels of maintenance than those made from other materials or don't last as long, and architects have cited this perceived limitation as a particular issue for schools. However, with proper design and detailing, wood schools can match the durability performance of schools made from any other material.

In the context of durability, there are two main concerns: areas of high traffic and high moisture.

In high-traffic areas, the structural material doesn't tend to be at risk unless the structure is also the finish material, as it often is with a CLT or other mass timber school. Common options for avoiding damage include high-durability finishes, such as hard tile, medium-density fiberboard, impact-resistant gypsum, and vinyl wall coverings. To make these finishes cost-effective, they are often added just to the lower portion of the wall (e.g., the bottom 6 feet) where the most wear and tear can be expected.

In high-moisture areas such as bathrooms

and labs, it is useful to both use durable finish materials and elevate the wall structure and finishes off the floor by installing a curb below the walls.

For information on durability detailing related to the building envelope, including moisture, fungi, and termite control, the *Architectural Record* CEU, "Designing for Durability," is available at www.ThinkWood.com.

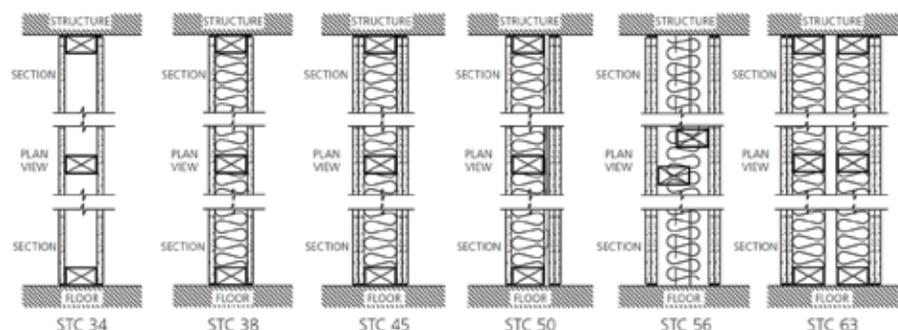
STRUCTURAL DESIGN

Schools offer unique design challenges, in part because of the great variety of spaces. Requirements include a mix of smaller spaces such as classrooms, offices, corridors, and bathrooms; medium spaces such as choir rooms and labs; and large spaces such as gyms, cafeterias, and libraries.

Although a detailed discussion of structural design options is beyond the scope of this course, this section will consider typical school requirements and demonstrate how they can be met with wood-frame construction, while at the same time reducing costs.

Many schools include long, rectangular classroom wings, separated from the gym and cafeteria, with classes that feed into a corridor from both sides. Classrooms are typically 800 to 1,100 square feet, sized to accommodate 20 to 30 students, and are square to slightly rectangular. Common classroom sizes include 28 by 30 feet, 30 by 30 feet, and 32 by 32 feet, while corridors tend to be

Figure 6: Acoustical Progression in Wood-Framed Walls



Source: *Acoustical Considerations for Mixed-Use Wood-Frame Buildings*, WoodWorks

DESIGN RESOURCE: MASS TIMBER

For current information on mass timber, the Think Wood website (www.ThinkWood.com) offers an expanding library of materials on products, research, and building examples, including developments related to tall wood buildings.

6 to 18 feet wide. Minimum ceiling height is typically 9 feet, with a floor-to-floor height of about 13 feet.

Structural Loads

An important aspect of the IBC is that it is scaled to reflect risk. Per IBC Table 1604.5, buildings are classified into risk categories based on use, from Risk Category I for those representing a low hazard to human life in the event of failure (such as storage buildings) to Risk Category IV for structures with greater consequences associated with their failure (such as hospitals). They are further defined based on the likelihood of a specific type of event occurring. Buildings constructed in regions known for hazards, such as hurricanes, earthquakes, or floods, are subject to design requirements that make them better able to withstand these events.

Educational facilities are generally Risk Category III and must be designed for structural loads that are 10 to 25 percent higher than buildings in lower risk categories. Common loadings include:

- Classroom floor live load = 40 pounds per square foot (psf)
- Corridor floor live load = 80 to 100 psf

This is where the relative light weight of wood-frame systems can be a cost advantage. Even a floor system detailed to meet objectives for fire resistance and acoustics—with gypsum wallboard, lightweight concrete topping, resilient channels, and insulation—results in a floor dead load of just 25 to 35 psf. For comparison, a structural steel system with cast-in-place concrete or a precast concrete slab would likely be twice that amount.⁷ Wood's light weight also has potential benefits in terms of foundation and seismic requirements (seismic force is relative to weight), which add to the savings.

It should be noted that the IBC allows reduced loads in certain cases that are relevant to school design. Where members are used to support a large surface of floor area, the code recognizes the unlikelihood that the entire area will be loaded to its maximum all the time. Per ASCE 7-10: Minimum Design Loads for Buildings and Other Structures, Section 4.7.2, exterior and interior columns and beams in spaces that meet minimum tributary area requirements may be designed for lower live loads. In a 32-by-32-foot classroom, for example, a column in the exterior wall can be designed for 23 psf live load instead of the standard 40 psf.

Floor Framing

Wood framing is a viable choice for floor spans of 25 to 32 feet, which are typical of classrooms. It can meet the same safety and

WOOD AND SCHOOL SAFETY: FIRE/SEISMIC/WIND

The IBC requires schools to perform to the same level of safety, regardless of materials, and wood buildings can be designed to meet rigorous standards of performance.

Fire protection: Effective fire protection involves a combination of active and passive features. Active fire safety features include fire detection or suppression systems that provide occupant notification, alarm transmittance, and the ability to suppress fire growth (sprinklers) until the fire service arrives. Passive features, which include fire-resistant floors and walls, help contain a fire and slow its spread. In the case of wood schools, the unique charring properties of heavy and mass timber can be another advantage. When exposed to fire, surface char insulates the member so it can continue to support its load, increasing the amount of time before the member fails.

Seismic performance: On the West Coast, where seismic design is a particular concern, wood-frame schools are common. Wood buildings that are properly designed and constructed to comply with code requirements have been shown to perform well during seismic events. This is often attributed to the following characteristics:

- **Light weight:** Wood-frame buildings tend to be lightweight, reducing seismic forces, which are proportional to weight.
- **Ductile connections:** Multiple nailed connections in framing members, used in shear walls and diaphragms of wood-frame construction, exhibit ductile behavior (the ability to yield and displace without sudden brittle failure).
- **Redundant load paths:** Wood-frame buildings tend to be comprised of repetitive framing attached with numerous fasteners and connectors, which provide multiple and often redundant load paths for resistance to seismic forces. Further, when wood structural panels such as plywood or oriented strand board (OSB) are properly attached to wood floor, roof, and wall framing, they form diaphragms and shear walls that are exceptional at resisting these forces.

Wind resistance: All buildings are at risk during high-wind events, and each structure, with its unique set of characteristics such as stiffness and strength, reacts differently to wind loads. However, wood is conducive to meeting the challenges of wind-resistant design. For example, one of wood's characteristics is that it can carry substantially greater maximum loads for short durations than for longer periods of time, as is the case during high-wind events. As with seismic design, the redundant load paths associated with wood framing are also useful in resisting wind forces.⁶

Photo: Lara Swimmer



VASHON ISLAND HIGH SCHOOL

Location: Vashon Island, Washington

Architect and Engineer: Integrus Architecture

Typical school corridors range from 6 to 18 feet. At this 84,000-square-foot, Type V school, dimension lumber, glulam, and light-frame trusses were used for the structure, reflecting the community's values and desire to promote thoughtful stewardship of natural resources.

Photo: Walsh Construction Company

AN EFFECTIVE CHOICE FOR STUDENT HOUSING

When Mahlum Architects won the bid to design a new 140,000-square-foot, 530-bed student residence hall at the University of Oregon, the university directed the design team to use wood-frame construction.

"We have seen a very strong trend toward the use of wood in student housing as a way to reduce costs for this project type and at this scale," says Beth Brett, project manager for Mahlum, which also designed a major wood-frame housing project for the University of Washington. "This has been a typical approach for some time in developed multifamily projects. Now, with the rising cost of construction, universities have been looking to this approach to help manage their project budgets."

The University of Oregon project required unique responses toward important neighboring buildings. To the north, the Many Nations Longhouse required unobstructed solar access on the winter solstice to their 'Expression Place.' Mahlum modeled the sun's path to ensure the building's unique form did not cast shadows on this ceremonial zone. To the west and east of the building, landscape areas help break down the building massing to ease the transition between institutional and residential scales. Through these and other design features, the new residence hall enhances the university's commitment to live/learn communities by co-locating a lecture hall, seminar room, and study spaces with an open lounge and kitchen and a maker-hacker space.



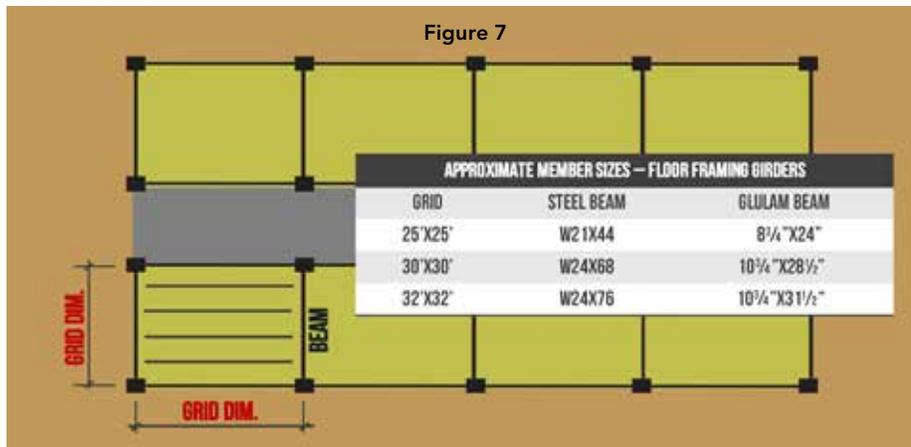
UNIVERSITY OF OREGON RESIDENCE HALL

Location: Eugene, Oregon

Architect: Mahlum

Structural Engineer: Froelich Engineers

Source: WoodWorks



Assumptions: Live load = 40 psf, wood dead load = 30 psf, steel dead load = 70 psf. Sizes shown are for illustration purposes. All member sizes should be provided by a project's structural engineer.

performance requirements, and follow essentially the same grid design as other materials, but often at much less cost. While savings vary by city, cost estimates performed by EQS Consultants based on RS Means data for 2016 Q2 indicated that, compared to steel and concrete, wood-frame floor systems offer the following savings based on a 32-by-32-foot grid:

- Orlando, Florida: \$4/square foot
- Los Angeles: \$4/square foot
- Washington, D.C.: \$3/square foot
- Houston: \$3/square foot
- Charlotte, North Carolina: \$2/square foot
- San Francisco: \$2/square foot

Options for classroom floor assemblies include I-joists and parallel chord trusses. (Dimension lumber is suitable for the smaller spans needed for corridor assemblies.) As shown in Figure 7, the required wood member sizes for a standard classroom design are similar to steel. The table is shown over a typical grid that includes columns in the exterior walls and corridor walls, all directly aligned with classroom separation walls.

While Figure 7 indicates that the glulam beams are typically 3 to 7 1/2 inches deeper than the steel beams, this difference could be 2 1/2 inches smaller than the beam depths would indicate. This is because the common steel option is an open-web joist, which includes a joist seat that drops the beam by about 2 1/2 inches. Glulam beams can be flushed to the top of the I-joist or truss, and a top flange hanger can be used to support the truss or joist from the beam.

Although the typical grid shown in Figure 7 can be accommodated with wood framing, taking a slightly different approach can reduce costs even further. For example:

- A designer may choose not to align columns in the exterior and corridor walls with the classroom separation walls, but rather shorten the floor spans by using a column spacing (along the corridor and exterior walls) of 20 to 24 feet. Although this would likely add an additional row of columns and beams, it would reduce their size and provide shallower floor joist members, allowing more room for mechanical, electrical, and plumbing in a dropped ceiling application. Column locations would need to be coordinated with openings in the exterior and corridor walls.
- By using wood-frame corridor walls and exterior walls as bearing walls, columns and beams could be eliminated. (See Wall Framing below.)

Although not a code criteria, floor design is often governed by vibration at the span ranges above, regardless of material. Options for floor vibration analysis include the use of higher

Photo: Dennis Ivy

deflection criteria to add stiffness (e.g., $L/480$ or $L/600$ instead of $L/360$ for live load), and proprietary assemblies that have been tested and rated for vibration. A research organization, FPInnovations, has also devised a method for evaluating complete floor systems (including solid sawn joists, I-joists, parallel chord trusses, sheathing, toppings, etc.) and calculating vibration performance.

Wall Framing

Options for wall framing include solid sawn and finger-jointed dimension lumber, glulam framing, and structural composite lumber (SCL) products.

It is common in steel and concrete buildings to frame walls, both interior and exterior, with non-load bearing studs. In a wood-frame school, it can be beneficial both from a construction schedule and cost perspective to frame all walls with wood, making them load bearing where necessary for structural purposes.

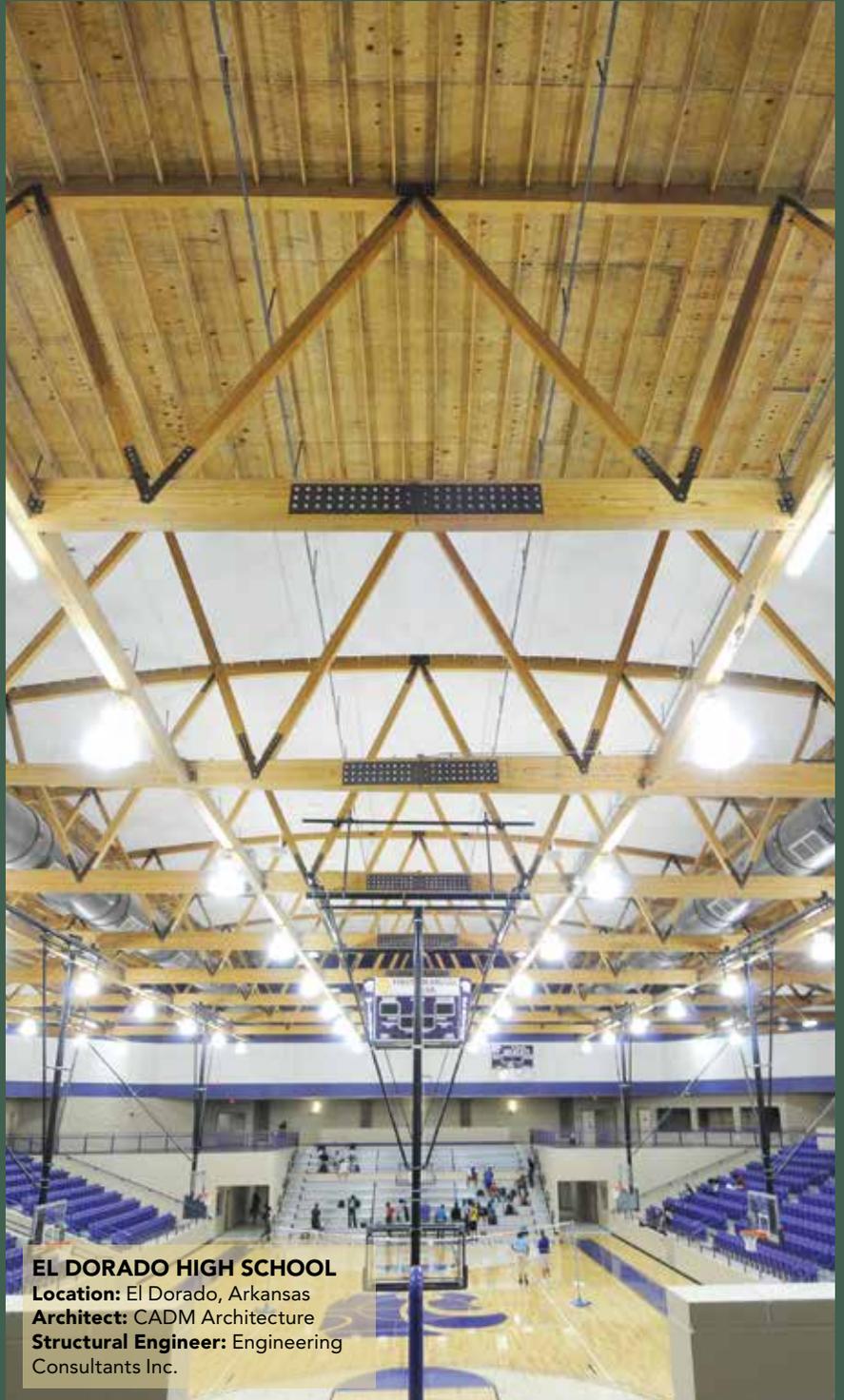
In a typical steel-frame school, the building's lateral stability against wind and seismic forces is usually provided by steel braced or moment frames or masonry shear walls. These systems may only be present in the building for the purpose of lateral load resistance. However, in a wood-frame school utilizing wood walls covered with sheathing, such as plywood or OSB, these walls can double as both gravity force-resisting members (bearing walls) and lateral force-resisting members (shear walls).

Wood-frame shear walls offer the advantages of light weight and ductility. For contrast, a typical masonry shear wall in a school might include 8-inch masonry walls with grout and reinforcing steel at 32 inches on center (o.c.). This combination has an average weight of 47 psf. A typical wood-frame shear wall in a school would be 2-by-6 studs at 16 inches o.c. with a layer of ½-inch plywood or OSB. This combination has an average weight of 12 psf.⁸

As noted, a building's seismic forces are directly tied to its mass, meaning that the seismic forces contributed by 8-inch masonry walls would be nearly four times greater than those of the wood-frame walls. Seismic forces on a building are also directly tied to the code-specified seismic response coefficient (R). As the R term is in the denominator of the seismic force equation, a larger R value results in lower seismic forces. For seismic load resistance, wood-frame shear walls are classified as "light-frame walls sheathed with wood structural panels rated for seismic resistance" ($R = 6.5$, per Table 12.2-1 of ASCE 7-10). This R value of 6.5 is greater than many steel and masonry lateral load-resisting systems, result-

ACHIEVING LONG SPANS WITH WOOD ROOFS

Spans of 60 to 160 feet are a common requirement for school assembly spaces, and there are numerous wood options for achieving these spans. They include, among others, trusses, glulam girders and sub-purlins, and mass timber panels.



EL DORADO HIGH SCHOOL

Location: El Dorado, Arkansas

Architect: CADM Architecture

Structural Engineer: Engineering Consultants Inc.

With seating for 2,200 people, this is one of the larger assembly spaces by high school standards. The roof is made from curved bowstring trusses spanning about 165 feet. Originally designed in structural steel, the switch to a bowstring truss wood roof saved the project \$60,000.

DESIGN RESOURCE: ESTIMATE THE CARBON BENEFITS OF WOOD BUILDINGS

The Wood Carbon Calculator for Buildings allows designers to compare the carbon benefits of their wood building projects. Users enter nominal wood volume information, and the calculator estimates the amount of carbon stored in the wood products, emissions avoided by not using fossil fuel-intensive materials, and amount of time it takes North American forests to grow that volume of wood. Recently updated to include more options for mass timber, this free tool is available at www.woodworks.org/carbon-calculator.

Photo: Richard Mandelkorn



BOLTON DINING COMMONS
Location: Athens, Georgia
Architects: Smith Dalia Architects, Bruner/Cott
Structural Engineer: Uzon + Case

In this 55,555-square-foot dining commons at the University of Georgia, glulam trusses and Douglas-fir structural roof decking respond to the client's desire for natural materials that evoke feelings of warmth and comfort.

ing in further reduction of seismic forces.

Tall Walls

It's common for schools to require 'tall walls'—20 feet and taller—to achieve desired interior heights for areas such as gymnasiums and cafeterias. Wood is both appropriate and effective in these applications.

Wood-frame tall walls offer the same benefits as other wood stud walls:

- They're able to resist snow loads on the roof and wind loads on the wall, without requiring an additional load-bearing frame.
- When wood sheathing is added to studs, the wall is effective at resisting the lateral racking loads caused by high-wind and seismic events.
- They can be easily insulated to provide excellent thermal resistance.
- They can be finished with a wide range of finishing materials.

For these spaces, larger lumber sizes and engineered wood products can be used to obtain the same strength for walls that are taller and longer. Shear walls and connections can be easily designed to provide the required lateral resistance. Thermal requirements can be achieved with insulation. And, by paying attention to details and selecting appropriate finishing materials, tall stud walls can meet or exceed stringent fire separation requirements.

ENERGY EFFICIENCY

For the Bethel School District, energy efficiency is an objective because of the cost savings. However, it underscores wood's benefits from a thermal performance perspective.

Between 2004 and 2011, the district reduced its energy use by more than 7.6 million kilowatts and saved \$4.3 million in utility costs—equivalent to the cost of electricity for 15 of its elementary schools for one year. It reported an 81 percent ENERGY STAR rating overall, and several of its 17 elementary and six junior high schools had a rating of between 95 and 98 percent. All of these schools are wood-frame.

Wood-frame building enclosures are inherently more efficient than steel-frame, concrete, or masonry construction—because of the insulating qualities of the wood structural elements, including studs, columns, and beams, and because wood stud walls are easy to insulate.⁹ Options also exist for insulating wood-frame buildings that aren't available for other construction types. For example, while requirements for lighting systems or mechanical systems do not change based on structural material, wood's versatility related to building envelope configuration gives designers more

Photo: Jerry Markatos



DUKE SCHOOL

Location: Durham, North Carolina
Architect: DTW Architects & Planners
Structural Engineer: DTW Architects & Planners

To create a welcoming environment, the Duke School library is framed with glulam arches that span the space. Between the arches are glulam beams and, above those, spanning in the opposite direction, exposed tongue and groove decking.

insulation flexibility.

Continuous insulation is often specified as a stand-alone prescriptive requirement or, alternatively, in conjunction with nominal insulation (e.g., between wood studs) in order to achieve higher effective R-values. Continuous insulation is necessary in structural systems using concrete and steel, which have high rates of thermal bridging, but is often avoidable in wood-frame envelopes.¹⁰

ENVIRONMENTAL PERFORMANCE

School boards, whether they receive funding from public or private sources, often include environmental performance in their objectives for school design.

In addition to the fact that wood grows naturally and is renewable, wood has a lighter carbon footprint than other common building materials.

As trees grow, they absorb carbon dioxide from the atmosphere, storing the carbon in their wood, roots, leaves or needles, and sur-

rounding soil, and releasing the oxygen back into the atmosphere. When trees start to decay, or when the forests succumb to wildfire, insects, or disease, the stored carbon is also released. However, when trees are harvested and manufactured into products, the products continue to store much of the carbon. In the case of wood buildings, this carbon is kept out of the atmosphere for the lifetime of the structure, or longer if the wood is reclaimed and manufactured into other products. In any of these cases, the carbon cycle begins again as the forest regenerates and young seedlings once again begin absorbing carbon dioxide.

The fact that manufacturing wood into products requires less energy than other materials (and very little fossil fuel energy) also contributes to its relatively light carbon footprint.¹¹

Life-cycle assessment (LCA) studies consistently show that wood outperforms other materials in terms of embodied energy, air and water pollution, and global

warming potential.¹² LCA is an internationally recognized method of evaluating the environmental impacts of materials over their life cycles, from extraction or harvest of raw materials through manufacturing, transportation, installation, use, maintenance, and disposal or recycling. It is increasingly being integrated into green building rating systems as a way to compare the impacts of alternate building designs.

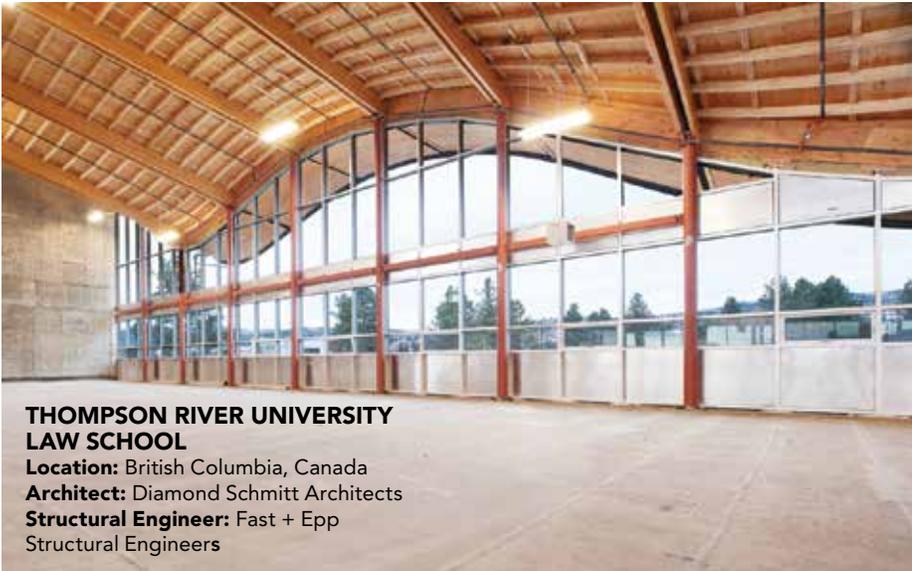
HEALTH AND WELL-BEING

As green building objectives have come to embrace human health issues, a growing number of studies have linked the use of exposed wood with occupant well-being.

For example, an Austrian study found that interior wood use in classrooms reduced pupils' stress levels, as indicated by criteria that included heart rate and perceived stress from interaction with teachers.¹⁴

Similarly, a 2012 study at the University of British Columbia and FPInnovations

Photo: Mathias Fast



THOMPSON RIVER UNIVERSITY LAW SCHOOL

Location: British Columbia, Canada

Architect: Diamond Schmitt Architects

Structural Engineer: Fast + Epp
Structural Engineers

Prefabricated panels for this 400-foot-long roof at Thompson River University Law School in British Columbia were erected in roughly six weeks. The glulam frame is supported by wood purlins made from trees killed by the Mountain Pine Beetle.

demonstrated that the presence of visual wood surfaces in a room lowered sympathetic nervous system (SNS) activation.¹⁵ The SNS is responsible for physiological stress responses in humans.

Building on this study, the 2015 report, *Wood as a Restorative Material in Healthcare Environments*, reviews available research on the human response to natural elements in the built environment.¹⁶ The report states: “In the small but growing volume of research on wood and health, the results that are emerging mirror results we have seen from exposure to other natural elements, such as views and plants. Lower stress reactivity in the autonomic nervous system is found when wood, plant, or nature views are present. Lower sympathetic activation and higher parasympathetic activation result in measurably lower heart rate, lower blood pressure, lower skin conductivity, and higher heart rate variability. These results have been linked to exposure to wood. However, lower stress activation due to views and plants have also been shown to increase the ability to concentrate, lower pain perception, and speed recovery times. Though these benefits have not been identified for wood, they are tied to the same automatic responses to nature seen with wood. Therefore, it is reasonable to expect that future research on wood will find many of these same results.”

One of the most promising areas of focus is evidence-based design, which involves using

information gained from the analysis of past buildings to build better new ones. Healthcare architects have been at the forefront of this effort, exploring the physiological benefits of good design on patient recovery and the well-being of staff and visitors. Among the results, an increasing number of health-care facilities are making use of natural daylight, views of nature, and exposed wood to create warm, natural aesthetics that support their healing objectives. These same techniques are also being used in schools and offices to improve performance, productivity, and occupant well-being.

CONCLUSION

If there is a generalization to be made about the design of educational facilities, it is that architects are often called upon to achieve many objectives with limited budgets. This may be wood’s greatest strength in the context of schools—that it typically costs less, while performing structurally and offering benefits that cover the gamut from design flexibility to carbon footprint to occupant well-being. This may also be the reason we see more wood schools over the next decade, as U.S. designers seek to satisfy the needs of a growing student population.

END NOTES

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⁷*ASC Steel Deck Floor Deck Catalogue*, <http://www.ascsd.com/files/floordeck.pdf>

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