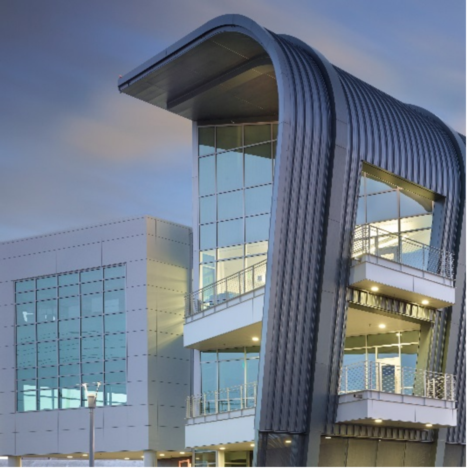
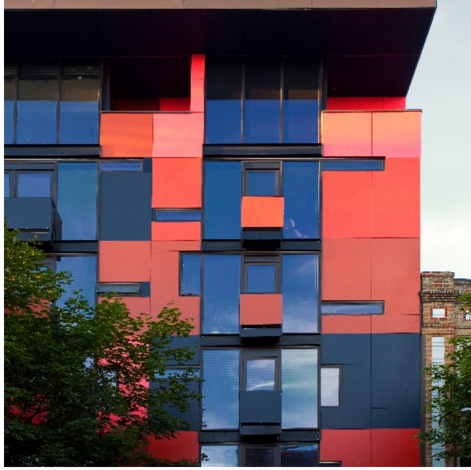


Selecting the Right Structural System for Your School Building

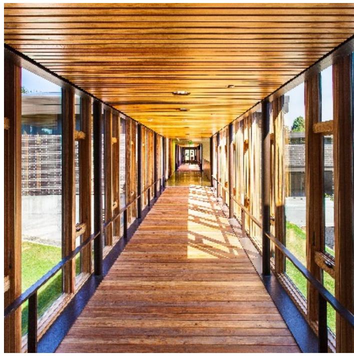
Bret Maddox, S.E. Associate Principal



Introduction

- Bret Maddox, S.E.
  - Associate Principal
  - BS Arch. Engineering, Univ. of Wyoming
  - 24 years experience in school design.

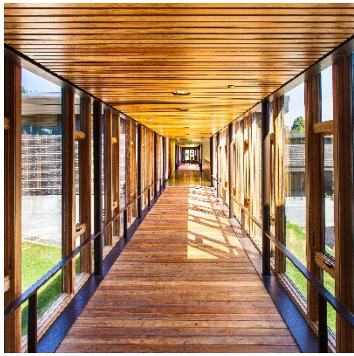
- PCS Structural *Solutions*
  - 50+ person firm with offices in Seattle and Tacoma
  - Founded in Tacoma 50 years ago
  - Responsible for over 1/3 of new schools in Washington
  - Beyond K-12 Projects, our markets include:
    - Adaptive Reuse/Historic Renovation, Medical, Higher Education, Civic/Museum, High-End Residential, Multi-family Residential, Parking Garages, Industrial and more…



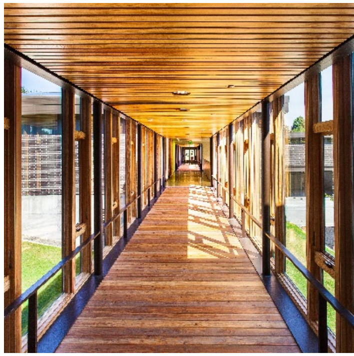
PCS Structural Solutions

Overview/Learning Objectives

- Understand the various factors that play into the selection of a Structural Systems.
- Identify the primary components of the structural system.
- Learn how the various structural materials can be combined to form building systems.
- Introduce some new innovations to the structural palette.

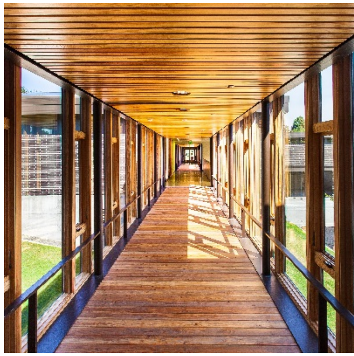


"Structural engineering is the art of molding materials we don't wholly understand, into shapes we can't fully analyze, so as to withstand forces we can't really assess, in such a way that the community at large has no reason to suspect the extent of our ignorance."



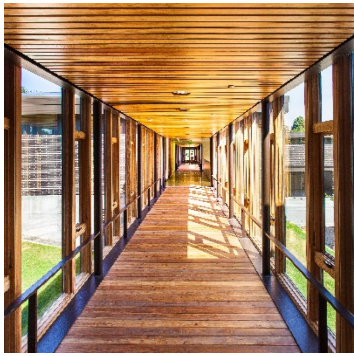
A number of factors can affect the choice of structural system.

- Loading Criteria
- Building Type
- Performance objectives
- Design Aesthetic
- Sustainability
- Budgets
- Location



Loading Criteria

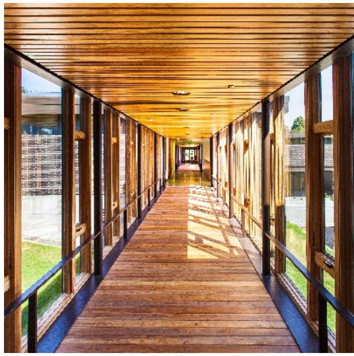
- Gravity Loads
  - "Dead Load" – weight of building materials
  - "Live Load" – weight of transient things
    - People, furniture, snow, rain, etc.
- Lateral Loads
  - Wind
    - main force resisting system
    - Components and cladding
  - Seismic
    - Areas of high seismicity will limit what systems are permitted.
    - Western Washington and Oregon are high seismic zones on par with areas in California.



PCS Structural Solutions

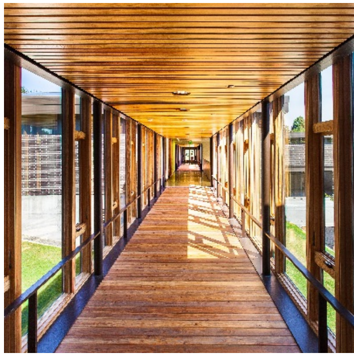
Building Area/Fire Separation

- Building Type:
    - Type I, II, III, IV or V?
    - Non-rated?
    - Sprinkled (not a choice)
- Limitations placed on specific types relating to combustibility of materials.
- Allowed areas are affected by structural materials and vice versa.



Performance Criteria and Objectives

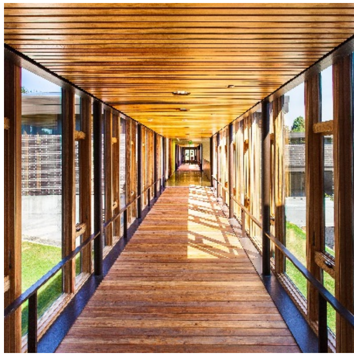
- Deflection and Vibration
- Durability and Long Term Maintenance
- Acoustics
- Future Flexibility



Design Aesthetic/Public Expectations

- Communities are Unique
  - Budgets vary greatly
  - Political pressures
  - Innovative Programs

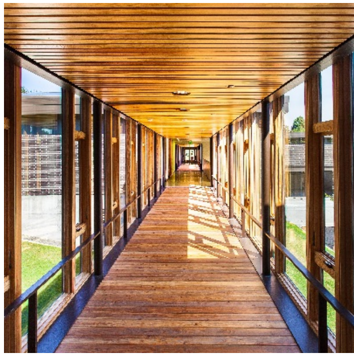
- Designers bring a vast variety of concepts and materiality.
  - Traditional vs. Modern designs



Sustainability Goals

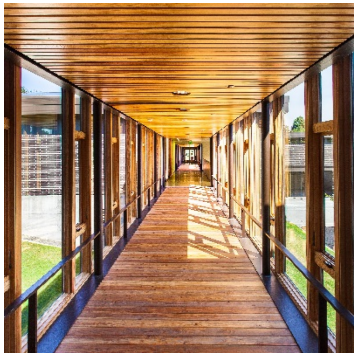
- Washington State Sustainable Schools Protocol (WSSSP).
- Sustainable Oregon Schools Initiative (SOSI)
- Leadership in Energy and Environmental Design (LEED).

- There isn’t a lot of opportunity to influence points through structural system choices
- Selection of structural materials can influence Energy Code compliance.
  - Thermal bridging.



Cost/Schedule/Value

- First cost versus long term maintenance costs.
- Consider the life of the building.
  - Beyond "50 year" life.
  - Structure is closest to permanent.
- Concept of "Value" varies based on who is speaking
  - Can very much be politically driven.
- Flexibility for future can be enhanced or constricted with choice of system.

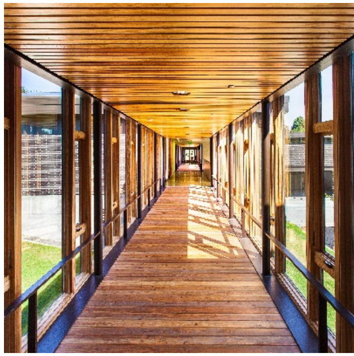


Structural Solutions

Geographic Location of Building Site

- Can limit what materials are available or affordable.
- Different climates can dictate material choices.
- Can limit what systems are allowed for use.
  - Seismic limitations

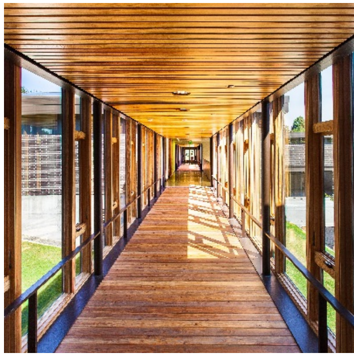
- We are spoiled in the Pacific NW to have good access to a full palette of choices.



Structural Basics

- Four basic materials commonly used:
  - Concrete
  - Masonry
  - Steel
  - Wood

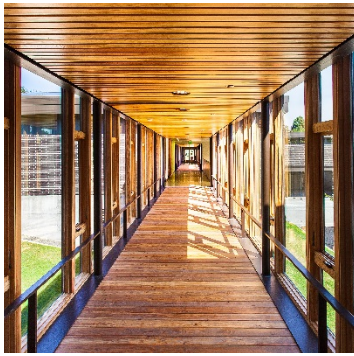
- Less common:
  - Aluminum
  - Composites
  - Rammed Earth
  - Tensioned Fabric



Basic Structural Systems

- Foundation Systems
- Vertical Load Systems – Dead and Live Loads
- Lateral Load Systems – Wind and Seismic
- Exterior Closure – Wind/Seismic and Weather

- A lot of variety exists in each of these categories.
  - Each could easily be it's own presentation.



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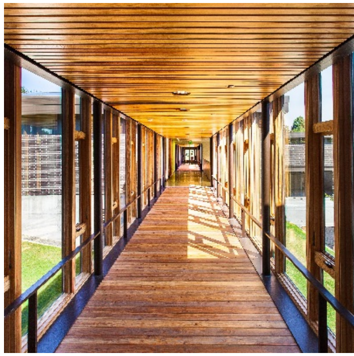
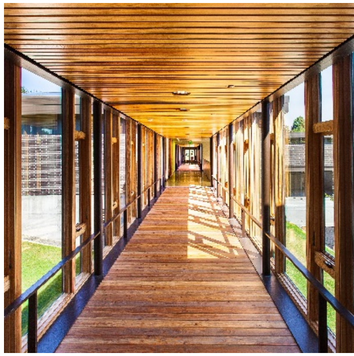
Foundations

- Two basic concepts:
  - Shallow Systems
    - Usually buried from 1-4 feet below ground level.
    - Must reach frost depth (varies geographically)
    - More conventional
    - Less expensive
    - Easier to construct



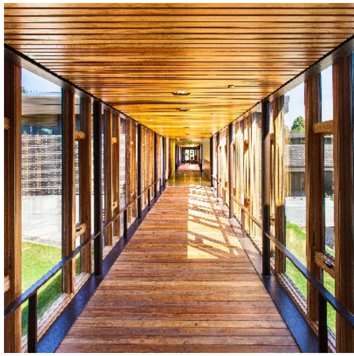
Foundations

- Two basic concepts:
  - Deep Systems: Piling, Soil Improvement
    - Piling can be:
      - Concrete (usually auguer-cast)
      - Steel (traditional pipe, H-pile, or pin)
      - Timber (less common, regionally specific)
    - Soil Improvement
      - Rammed Aggregate Piers
      - Pressure Grouting
      - A Variety of Other Options
      - Work Closely with Geotechnical Engineer or Contractor to determine the right choice.



Vertical Load Systems

- Components
  - Floor/Roof Decking
  - Floor Slabs
  - Joists, Beams and Girders
  - Columns and Bearing Walls
- Horizontal/Sloping Members
  - Typically wood or steel, but can be concrete
- Vertical Members
  - Any of the basic materials: concrete, masonry, steel or wood.



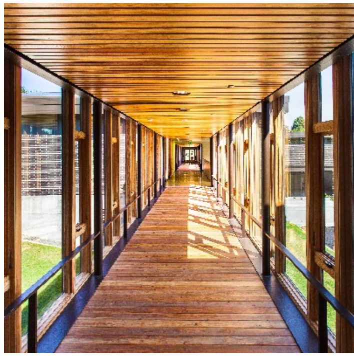
Lateral Load Systems

- Components
  - Floor/Roof Diaphragms

  - Joists, Beams and Girders
  - Columns and Bearing Walls

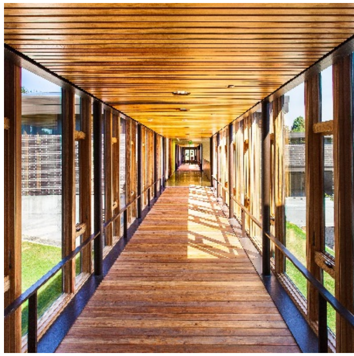
- Horizontal/Sloping Members
  - Typically wood or steel, but can be concrete

- Vertical Members
  - Any of the basic materials: concrete, masonry, steel or wood.



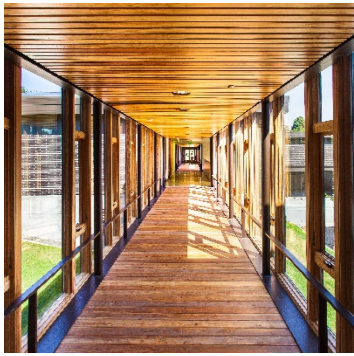
Lateral Load Systems

- Three basic systems to choose from
  - Shear walls
    - Can be plywood, masonry, concrete or light gage sheet steel.
  - Brace frames
    - Special Concentric, Ordinary Concentric, Buckling Restrained, Eccentric and Light Gage Strapping
  - Moment Frames
    - Special, Ordinary, Proprietary



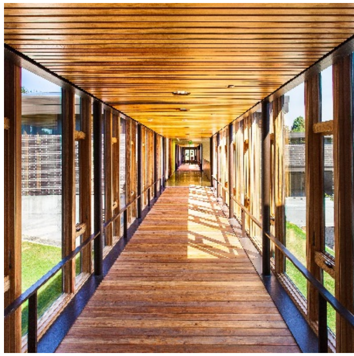
Structural Building Systems

- Wood Frame
- Steel Frame
- Hybrid Systems



Wood Frame Structures

- Typically one or two story.
- More common for elementary school projects, less common for MS and HS.
    - Related to building Type and allowable areas; Type V buildings.



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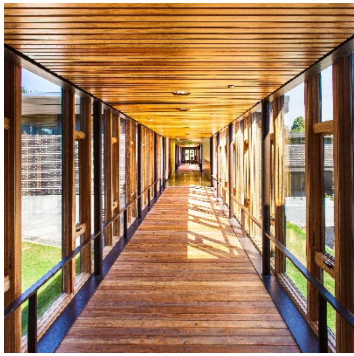
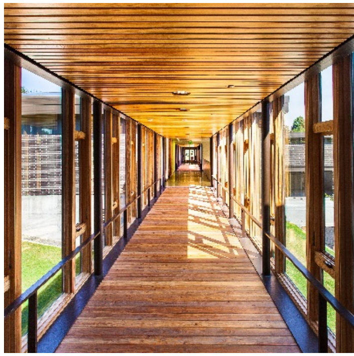


Wood Frame Structures

Typical Components

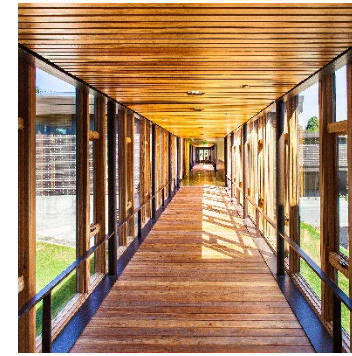
- Typically I-joists or open web wood joists with plywood sheathing.
- Glulam beams (steel in some cases).
- Wood stud bearing walls with plywood sheathing to act as shear walls.
- Combination of wood and steel columns.
- Foundations are determined by site characteristics, but typically conventional shallow foundations are used.
- Concrete slab on grade (with shallow foundation systems). Not truly structure.

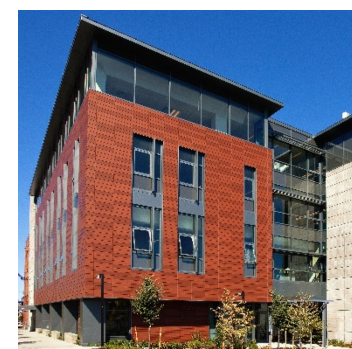


Wood Frame Structures

Pros

- For one and two story construction, current cost is generally less than other alternatives.
  - In the past, steel and wood have been neck and neck for pricing in two story structures; dependent on market forces.
- Labor generally more available – traditional material, lots of experience in the trades.
- Less detailing required
- Better overall energy performance; less thermal bridging
- Can be exposed very successfully; warm, comfortable material

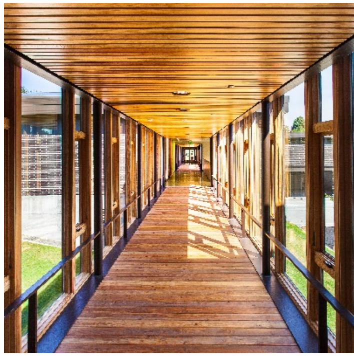




Wood Frame Structures

Cons

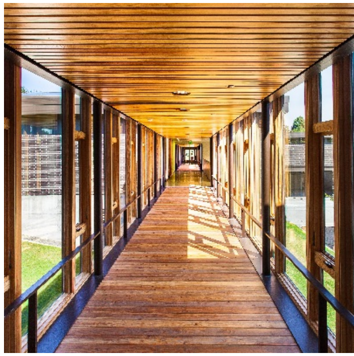
- Can result in higher floor to floor heights or reduced ceiling heights
- Harder to control noise and vibration for elevated floors
- Type V building area limitations – fire walls
- Can complicate routing of mechanical systems – taller floor to floor heights
- Perception of being "lesser" material or having shorter life span



Wood Frame Structures

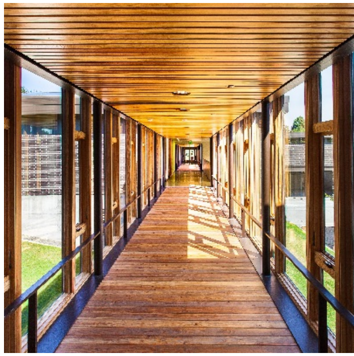
Variations

- CMU bearing/shear walls
  - Most commonly used around gymnasiums and other “big box” areas
  - Less common in rest of building higher seismic zones
  - Pros: durability, structural performance for tall walls
  - Cons: added cost, complicates structural with added mass and anchorage
- Heavy timber: exposed glulam/sawn beams and T&G decking
  - Not common, but used sporadically; mostly in more public spaces – Commons, Entries, etc.
  - Pros: Aesthetics – strong, traditional appearance
  - Cons: Costs (can be offset somewhat by serving dual purpose)



Steel Frame Structures

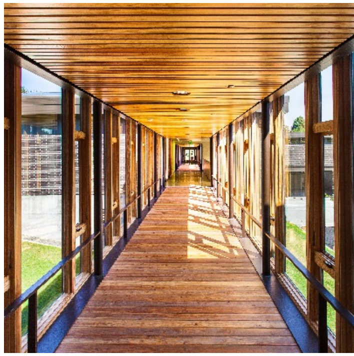
- Typically two or more stories. Can be single story
- Most common for HS and MS buildings. Becoming less common in single story elementary buildings. Type II buildings.



Steel Frame Structures

Typical Components

- Open web steel joists or structural steel joists with metal roof decking.
- Structural steel roof girders (some use of open web steel girders at large spaces)
- Structural steel floor framing (joists and girders) composite with concrete filled metal decking.
- Structural steel columns
- Steel Brace Frames
- Similar to Wood Frame, foundations are determined by site characteristics, but typically conventional shallow foundations are used.
- Concrete slab on grade.

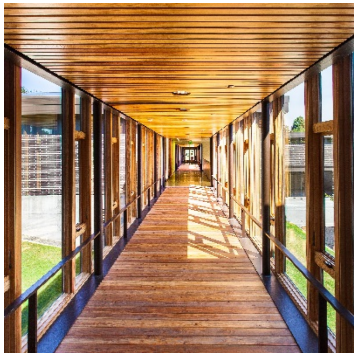


PCS Structural Solutions

Steel Frame Structures

Pros

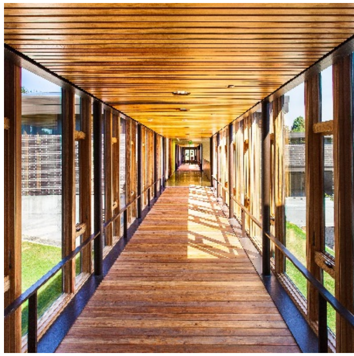
- Speed of erection
- Maximizes future flexibility
- Better control of vibration and noise in elevated floors
- More durable



Steel Frame Structures

Cons

- More costly for one and two story buildings
- More difficult to meet Energy Code; thermal bridging
- More detailing time
- More specialized labor requirements

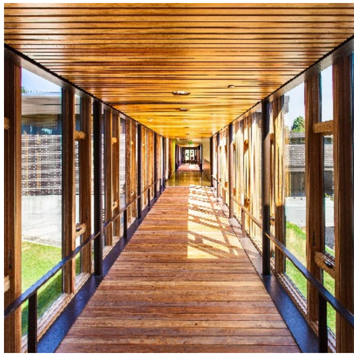


Steel Frame Structures

Variations

- Steel Moment frames
  - Not common in school construction; much more common in mid/high rise and medical
  - Pros: Provides maximum openness in design; no cross members or solid structural walls
  - Cons: Costs, larger columns to fit in plan, Post-Northridge proprietary frames, harder to control building drifts

- Masonry bearing/shear walls
  - Common around large “box” areas; gym, commons, etc.
  - Can be placed in similar quantity and length to brace frames; same basic footprint. Not a significant cost difference.
  - Pros: durability, structural performance in tall walls, smaller foundations than brace frames, can be exposed as finish material
  - Cons: Speed of erection, can limit future flexibility, energy code challenges for exterior walls

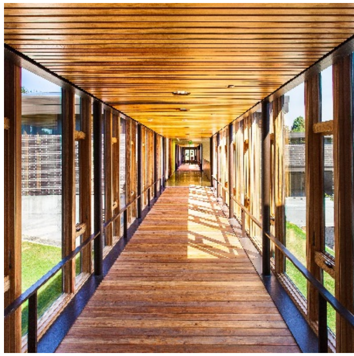


Steel Frame Structures

Variations

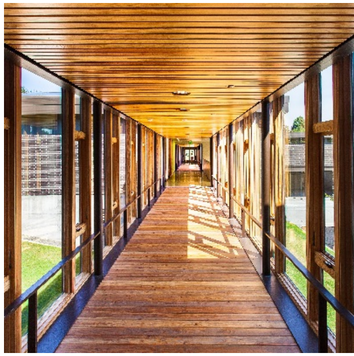
- Concrete bearing/shear walls
  - Similar to masonry, but significantly more expensive

- Pre-Cast (tilt-up) Concrete walls
  - Similar to masonry in characteristics
  - Pros: similar cost to CMU wall construction, speed of construction
  - Cons: aesthetics, less customizable, size limitations



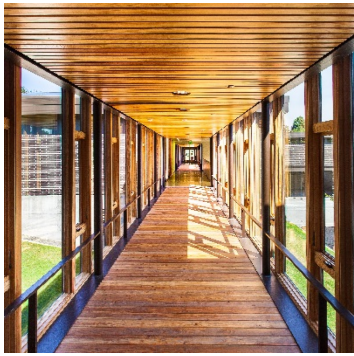
Hybrid Systems

- Steel Frame with Wood Stud Wall
  - Traditional steel frame superstructure
  - Substitutes wood stud in place of metal studs for exterior walls (interior okay also)
  - Can be done with various building types. Easier with Type V buildings.
  - Pros: easier energy code compliance (less thermal bridging), more “conventional” construction of walls
  - Cons: mixing of trades, “straightness” of lumber



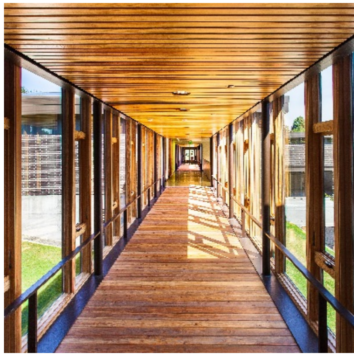
Hybrid Systems

- Mixed Lateral Systems
  - For buildings with two stories or more
  - Uses “stiff” lateral elements (brace frame, masonry/concrete shear walls) in lower story, “flexible” lateral elements in upper (plywood/light gage metal shear walls, moment frames).
  - Similar to 5-over-2 construction used in multi-family
  - Structural advantages in seismic design
  - Can save costs. Sloping and stepped roof buildings are good candidates.
  - Pros: primarily structural; reduction in seismic loading on upper level, can ease complication at sloping/stepped roofs.
  - Cons: mixing materials, shear walls systems can limit future flexibility



New and Emerging Technologies

- Cross Laminated Timber (CLT)
  - Essentially glulam floor/wall “slabs”
  - Sustainable; “captured carbon”, good thermal performance
  - Still working through U.S. Code approvals; for now, conservative designs
  - Targeted primarily for competing with PT concrete floors in mid-rise, multi-family markets.
  - Costs: conventional wood/steel < CLT < concrete
  - Walls require furring to conceal systems



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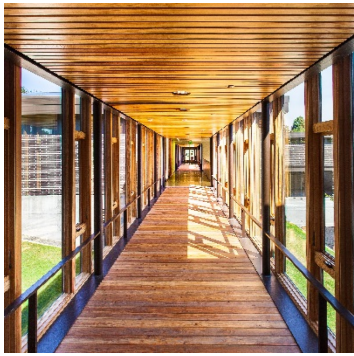
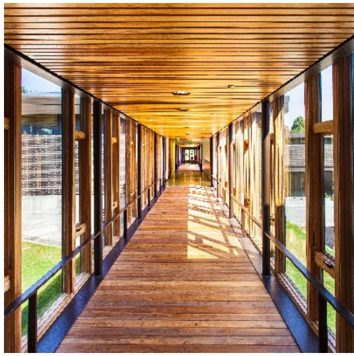
New and Emerging Technologies

- Buckling Restrained Brace Frames (BRB)
  - Slender steel rods contained in grout filled pipes or square tubes
  - Not common in school construction, yet?
  - More expensive than traditional brace frames for two story and less, economy shifts for three story and more.
  - Highly ductile. More predictable behavior under cyclic seismic loading
  - Reduced connection size and complexity
  - Reduced foundation requirements
  - Proprietary design build (similar to steel joists); multiple manufacturers exist



New and Emerging Technologies

- Modular Construction
  - “Code” for prefabrication
  - Not really new, but is finding traction in current markets
  - Can be applied to numerous materials/systems
  - Can result in lower costs and faster construction
  - Can limit flexibility in design



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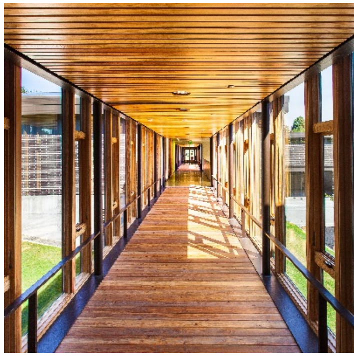
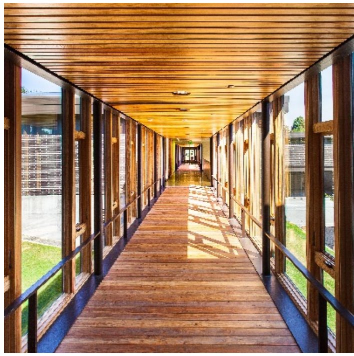


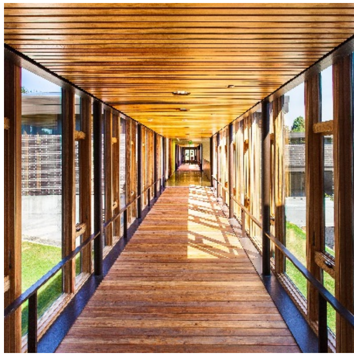
So, what is the "right" structural system?

It Depends…

As Engineers, we try to listen and to seek out a balance between all of the influencing factors.



Structural Solutions



Questions?