Project Overview

New engineering building
30,000 sqft
30’ above grade
Site Context

- High School
- Shopping Center
- Bus Stop
- Police Station
- SFSU Campus
- Lake Merced Blvd
- 4 Lane Freeway
- San Francisco
Hazards & Challenges - Earthquake Risk

Earthquake Outlook for the San Francisco Bay Region 2014–2043

72% probability of one or more $M \geq 6.7$ earthquakes from 2014 to 2043 in the San Francisco Bay Region.

UCERF3
Uniform California Earthquake Rupture Forecast (Version 3)

Three-dimensional perspective view of the likelihood that each region of California will experience a magnitude 6.7 or larger earthquake in the next 30 years. It matches the magnitude of the 1994 Northridge earthquake, and 30 years is the typical duration of a homeowner mortgage.

1/1000 1/100 1/10 1 10 100

30-year M ≥ 6.7 likelihood (percent)
Hazards & Challenges - Fires

Nov. 2018 Camp Fire
> 150,000 acres
> 18,000 structures destroyed
Climate & Challenges

The average annual max. temperature is: **64.04° F (17.8° C)**
The average annual min. temperature is: **50.9° F (10.5° C)**

The average annual amount of sunhours is: **3070.0 hours**

The average annual amount of rainy days is: **73.0 days**

The average annual percentage of humidity is: **75.0%**

The average amount of annual precipitation is: **600.0 mm (23.62 in)**

On average, the most wind is seen in **July**.
On average, the least wind is seen in **January**.

Conclusions:
- moderate climate
- low precipitation, max. volume in February.
- humidity at the morning due to the fog
- high number of sunny days
- winds from SW, max. 89 km/h
What is the name of our first big idea? (multiple answers possible)

7 odpowiedzi

- intersection: 6 (85.7%)
- green machine: 4 (57.1%)
- cone: 3 (42.9%)
- flower: 2 (28.6%)
- plant/leaf: 2 (28.6%)
- web/net/connections: 2 (28.6%)
- light beam: 1 (14.3%)
- puzzle: 0 (0%)
- transparency: 0 (0%)
- diagrid: 2 (28.6%)
- Avenir (French for future): 1 (14.3%)
INTERSECTION
Intersection - Big idea

- learning spaces
- computer labs
- atrium
- lounge
- cafe
- faculty offices

students

- trees on the site
- view to the lake
- green roof
- algae
- organic shapes
- program

nature

- faculty offices

teachers

building
Intersection - Concept evolution

- placing the footprint on the site
- creating atrium and two entrances
- moving atrium and adding cantilevers on one side
- developing structure and atrium
Intersection - Site plan

lake Merced

San Francisco State University

N
Intersection - View From Lakeside
Intersection - Program Layout

- Auditorium
- Lounge area
- Cafe
- Toilets
- Shafts+Elevator
- Mechanical Room
- Server Room
- Atrium
- Seminar Room

115' x 110' x 72'
Intersection - Program Layout

Instructional Lab
Small Classroom
Toilets
Atrium
Faculty Office
Department Chair’s Office
Senior Administration Office
Administrative Assistants
Intersection - What happens in the atrium?

Buildings of the future  ➤ Green buildings

VISION: ARCH  MEP  SE
Intersection - Atrium
Intersection - Section
Intersection - Arch + SE collaboration
Intersection - Main Entrance
Structural Design Process

1/18-1/20 Kickoff

First Concepts

Technology - Asterisk

Clashes,
Room sizes,
Brainstorming,
Landscaping,
User experience

2/22 Crit Session

10 Models - Optimal FL Height (Steel & Conc)
14 Models - Optimal Bay Size (Steel & Conc)

2/30 Cone Concept

Updated Floor Layout

8 Models - Optimal FL Height (Steel & Conc)
10 Models - Optimal Bay Size (Steel & Conc)

3/6 Diagrad

Communication & Collaboration

3/9 Larger Cantilevers

3/15 Winter Presentation
## Selection of Structural Material

<table>
<thead>
<tr>
<th></th>
<th>Steel</th>
<th>Concrete</th>
<th>Timber</th>
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<tbody>
<tr>
<td><strong>Cost (Case Study)</strong></td>
<td>$$</td>
<td>$$</td>
<td>$</td>
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<tr>
<td><strong>Prefabrication Availability</strong></td>
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<td><strong>Aesthetics</strong></td>
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<tr>
<td><strong>Weight</strong></td>
<td>490 pcf</td>
<td>150 pcf</td>
<td>35 pcf</td>
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</tbody>
</table>

### 3.2 COST ESTIMATION

#### 3.2.1 Project description

The project selected for the cost analysis was a performing arts center built in 2008 outside Napa, California. The 40,000 square feet building is divided in five areas: theater wing, music wing, main theater area, administrative area, and lobby area (Figure 1).

"CROSS-LAMINATED TIMBER VS. CONCRETE/STEEL: COST COMPARISON USING A CASE STUDY"

Maria Laguarda-Mallo and Omar Espinoza (University of Minnesota Twin Cities)
# Selection of Lateral System

<table>
<thead>
<tr>
<th></th>
<th>Moment Frames</th>
<th>BRBs</th>
<th>EBFs</th>
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<tr>
<td>Impact on Volume of Structural Elements</td>
<td>$$$</td>
<td>$</td>
<td>$$$</td>
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<tr>
<td>Labor</td>
<td>$</td>
<td>$</td>
<td>$$$</td>
</tr>
<tr>
<td>Resilience</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
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</table>

- **Moment Frames**: High volume of structural elements, high labor costs, no resilience.
- **BRBs**: Low volume, moderate labor costs, high resilience.
- **EBFs**: Moderate volume, high labor costs, high resilience.

Diagram: Buckling-Restrained Brace
Intersection - 2 Structural System Options

**System 1: “Natural”**
- Glulam
- CLT Shear Walls
- Glulam Diagrid w/ fuses
- CLT panels

**System 2: “Mixed”**
- Glulam
- Steel
- BRBs
- Glulam Diagrid w/ fuses
- CLT Composite

- Columns
- Beams
- Lateral
- Cantilever
- Slab
Intersection - Structural Design Solutions

**System 1:**
- **TIMBER - “NATURAL”**
  - Glued Laminated Timber, Cross Laminated Timber
  - Concealed steel connections
  - CLT shear walls
  - Exposed structure - natural look

**System 2:**
- **MIXED - “DIVERSE”**
  - Glulam columns, steel beams
  - CLT/Concrete/Steel composite flat slab
  - Buckling Restrained Braces
  - Exposed columns, concealed beams
Intersection - Typical Live Load Determination

- 40 psf
- 50 psf
- 80 psf
- 100 psf

<table>
<thead>
<tr>
<th>Live Load Determination</th>
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<tr>
<td>Classrooms</td>
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<td>Office</td>
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<tr>
<td>Corridors</td>
<td>80</td>
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<tr>
<td>Auditorium</td>
<td>100</td>
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<tr>
<td>Stairwell/Elevator</td>
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<tr>
<td>Deck</td>
<td>100</td>
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<tr>
<td>Storage</td>
<td>125</td>
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</tbody>
</table>

CBC Section 1607.1
Intersection - “Mixed” Structural Design

- BUCKLING RESTRAINED BRACES
- GLULAM COLUMNS
- CONCRETE RETAINING WALL
- STEEL BEAM
- COMPOSITE SLAB
- TIMBER DIAGRID
- LATERAL SYSTEM
- FRAMING
- FLOORS
Intersection - “Mixed” Option Framing Layout

16”x16” Glulam Columns
W14x53 Steel Framing
Timber & steel BRBs
Glulam Diagrid
12” Concrete Walls
Intersection - CLT Panel Layout

Manufacturing constraints:
- Max Width: 9' - 10½"
- Max Length: 40'
- Max Thickness: 12.4"
- Density: 30.3 pcf
Intersection - “Mixed” Option Framing Layout

- 16"x16" Glulam Columns
- W14x53 Steel Beams
- Timber & Steel BRBs
- Glulam Diagrid
- 12” concrete walls
Intersection - CLT Panel Layout

Manufacturing constraints:

- **Max width**: 9' - 10 ½"
- **Max length**: 40'
- **Max thickness**: 12.4”
- **Density**: 30.3 pcf
Intersection - Curved Glulam Beams
Intersection - “Natural” Structural Design

- CLT SHEAR WALL with HOLDOWN
- LATERAL SYSTEM
- CONCRETE RETAINING WALL
- FLOOR SYSTEM
- GLULAM COLUMNS
- FRAMING
- GLULAM BEAM
- CLT DECK
- TIMBER DIAGRID
Intersection - Typical “Natural” Option Framing

- 16”x16” Glulam Columns
- 6.75”x 16.5” Glulam Beams
- CLT Shear Walls
- Glulam Diagrid
Hazards & Challenges - Site Conditions

PGA: 2 percent in 50 years (Time Horizon: 2475 yrs)

Soil Conditions:
- Well sorted fine to medium sand
- Bearing Capacity: 3500psf
- Not in Liquefaction Zone
- Water Table: 14ft below grade

Base Shears:
- “Mixed” w/ Steel BRBs ~1500 kip
- “Natural” w/ CLT Shear Walls ~850 kip

Design Horizontal Response Spectrum

Soil Type C

Table of Design Parameters:

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Description</th>
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<td>$S_1$</td>
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<td>$S_{DS}$</td>
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<tr>
<td>$S_{D1}$</td>
<td>0.698</td>
<td>Numeric seismic design value at 1.0s SA</td>
</tr>
</tbody>
</table>

Soil Conditions:

- Well sorted fine to medium sand
- Bearing Capacity: 3500psf
- Not in Liquefaction Zone
- Water Table: 14ft below grade

Base Shears:

- “Mixed” w/ Steel BRBs ~1500 kip
- “Natural” w/ CLT Shear Walls ~850 kip
Intersection - Diagrid Gravity Load Path
Intersection - Butterfly Fuses & Collector Beams
Intersection - Auditorium Gravity Load Path
Intersection - Lateral Load Path

- **Compression**
- **Tension**
Intersection - Foundations

ISOLATED FOUNDATIONS 5’x 5’x16’’
STRIP FOUNDATIONS 7’x16’’
The nearest Energy Power Plants

- **Our building**
  - Used for electricity generation, with waste heat capture. This heat is captured in a hot water loop that reaches building and can be used for the MEP systems.

**Cogeneration possibility**

The nearest Energy Power Plants

- **L-SHAPE section**
  - Our building
  - Used for electricity generation, with waste heat capture. This heat is captured in a hot water loop that reaches building and can be used for the MEP systems.
Intersection - Design Strategies

- High thermal mass
- Sun shading devices
- Natural ventilation
- 50% Internal heat gains
- 20% Solar gains
Intersection - Insulation Materials

CORK SLAB
Thermal conductivity: $\lambda = 0.040$ to $0.042$ W/mK
Water absorption: 0.30 Kg/m2
Acoustic excellent insulation
Fire-safety Euro Class E
Aesthetic
Cost $5.50$ per square foot

SHEEP WOOL
Thermal conductivity: $\lambda = 0.034$ to $0.042$ W/mK
Water absorption: absorbing and desorbing against ~65% relative humidity
Acoustic Noise reduction coefficient of 0.90 to 1.15.
Fire-safety Conforms to Class A of the building code.

STRAW BALE
Thermal conductivity: 0.048 W/mK
Water absorption: soak up water and nutrients
Acoustic works very well
Fire-safety around 2h fire rating

HEMPCRETE
Thermal conductivity: 0.07 W/mK
Water absorption: 93% capabilities
Acoustic: absorbing sound and noises works like concrete
Fire-safety 0.75-1.5 h
# HVAC system options

## Multi System
- Allows different areas of the building to be simultaneously heated & cooled
- Decreases long term costs
- Increases the first costs

## A: Natural Ventilation
- Can not be use for a whole year
- Can not be easily controlled
- People can feel cold because of the inflow of fresh air
- Reduce the energy consumption
- Compromise between the full mechanical solution and natural ventilation to low energy consumption

## B: Displacement Ventilation
- High limitation
- More complex supply air ducting
- The diffusers are more expensive
- The neutral room temperature is higher
- Excellent for a high and big rooms
- Fewer diffusers and less ductwork necessary
- Higher ventilation effectiveness

## C: Variable Air Volume
+ Tolerance for variations - zone building
+a thermostat controls room temperature by regulating the volume of air supplied - occupant control
+ System has low first costs
+ System is economical to operate - energy conservation

## C: Hydronic system
- Long reaction time
- Expensive at first
- Works only with specific finish
- No noise
- Non-allergic
- Energy efficient
- Uniform heating
- Easily to connect with prefabrication parts
# HVAC primary & secondary system criteria matrix

## CRITERIA MATRIX

<table>
<thead>
<tr>
<th>Location of Building</th>
<th>San Francisco, CA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>Rooftop Package U</td>
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<tr>
<td></td>
<td>Geothermal Heat Pun</td>
</tr>
<tr>
<td></td>
<td>Chilled Beam</td>
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<tr>
<td></td>
<td>Radiant Floor</td>
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<tr>
<td></td>
<td>Window Unit</td>
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<tr>
<td>Size of System</td>
<td></td>
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<tr>
<td>----------------------</td>
<td>-------------------</td>
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<td>User Concern</td>
<td>User Concern</td>
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<td>VAV</td>
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<td>Maintenance Cost</td>
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<td></td>
<td>53,2</td>
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</table>
Intersection & Passage - System option #1

**PRIMARY SYSTEMS**

Variable volume system with AHU on the roof with heating and cooling coils and heat recovery unit

Water heater - Solar PV panels & water pump

Transformers, Generators, Switchgear energy from Solar PV

**SECONDARY SYSTEMS**

[offices, small class]- Supply duct & return air plenum
[auditorium, large class]- Displacement ventilation

BUILDING HEATING/COOLING
VAV with AHU on the roof

WATER HEATING

ELECTRICITY
### PRIMARY SYSTEMS

**GEOTHERMAL HEATING/COOLING**
- Rooftop air handler
- Ground source heat pump

**Water heater - geothermal energy & water pump**

- Transformers, Generators, Switchgear
  energy from Solar PV

### SECONDARY SYSTEMS

**[offices, small class] - Radiant slab/Chilled beams & natural ventilation**

**[auditorium, large class] - Displacement ventilation**

### BUILDING HEATING/COOLING
**HYDRONIC + NATURAL VENTILATION**

### WATER HEATING

### ELECTRICITY
Intersection & Passage - Sandwich Process

slab beam 2' 1 1/2” one main duct 3’ 2”

slab beam 2' 1 1/2” two main duct 2’1”

2’1” duct inside the beam 2’ 1 1/2”
Intersection & Passage - System Option #1

Auditorium & large classes -
displacement ventilation

foldable seats
+ more space for
additional purpose
+ additional rent space
- worst air flow
- storage space needed

sloped floor
+ less excavation

fix floor
- wasted space
Sandwich #2,3 option

Intersection + Passage:
construction: wood slab, wood beams
hvac: raised floor- return plenum, radiant ceiling heating and cooling

Offices & small classes-
hydronic radiant ceiling/ chilled beams

Intersection + Passage:
construction: composite floor: clt, concrete, steel
hvac: active chilled beams
Intersection - Zones

Zone 1 - temporarily use auditorium & large classes

Zone 2 - continuous use offices & small classes
Intersection - Duct Distribution

Return air by the grill in suspended ceiling

Supply

Exhaust

Shafts

MEP room

Chilled beam & natural ventilation + displacement ventilation

level 1

level 2

level 3
Intersection
Intersection - Algae Process

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<td>maintenance</td>
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<td>3</td>
<td>4</td>
</tr>
<tr>
<td>availability</td>
<td>2</td>
<td>3</td>
<td>4</td>
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ALGAE PROCESS
**Intersection - Energy Production and Storage**

**ENERGY PRODUCTION POTENTIAL**

- PV panel area: 962 m² = 10,354 sq ft
- Energy production: 202,000 kWh/year

**HARVESTING POTENTIAL**

- Annual rainfall = 600 mm/year
- Surface area of catchment = 1597 m²
- Run-off coefficient green roof = 0.8
- Mean rainwater supply: 168,500 gal
Intersection - PV and Natural Ventilation

LOUVRE WINDOW controlled by CO₂ sensors for appropriate natural ventilation control

SOUTH FACADE

PV PANELS & SHADING DEVICE
Intersection - Geothermal Possibilities

OPTION #1 water-air exchange

OPTION #2 water-to-water+solar collector
Passage - STV water target

02/21/2019

- normal WC: 1.6 gal/flush
- EcoVac - The extremely low-flush toilet 0.1-0.2 gal/flush

6 540 000 kg reduction to 531 000 kg
Up to 91.87% water
Cost: normal WC- $115
      EcoVac- $638

03/07/2019

- normal urinal: 0.5 gal/flush
- efficient no-flush urinal with BlueSeal liquid 0.0 gal/flush

Saves: 681 000kg reduction to 0kg
Up to 91.87% water
Cost: normal urinal- $157
      BlueSeal urinal- $500

03/10/2019
Intersection - STV

timber

![Performance Relative to Life Cycle Impact Targets for timber](image)

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<tr>
<th>Impact</th>
<th>Target</th>
<th>Project</th>
<th>%</th>
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<td>3,714 897</td>
<td>3,685 955</td>
<td>97%</td>
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<tr>
<td>Energy (MJ)</td>
<td>129,559 907</td>
<td>129,513 654</td>
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<tr>
<td>Water (kgH₂O)</td>
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<td>70,826 555</td>
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<td>Ozone (kgCFC11)</td>
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timber & concrete

![Performance Relative to Life Cycle Impact Targets for timber & concrete](image)

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<td>Ozone (kgCFC11)</td>
<td>-</td>
<td>1,038-01</td>
<td>-</td>
</tr>
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</table>
Passage - Big Idea

- height difference
- public area
- campus
- nature and building
Passage - Concept Evolution

GIVEN FOOTPRINT

WAY THROUGH

DIVISION

PASSAGE
Passage - Site Plan

Lake Merced

San Francisco State University

stadium
Passage - Main Entrance
Passage - Program Layout

- Auditorium
- Faculty Lounge
- Cafe
- Storage/Server Room
- Mechanical Room
- Shaft + Elevators
- Corridor
- Toilets
- Faculty Office
Passage - Program Layout
Passage - Program Layout

- Large Classroom
- Small Classroom
- Seminar Room
- Toilets
- Corridor
- Faculty Office
- Department Chair’s Office
- Senior Administration Office
- Administrative Assistants
Passage - Connections

- students
- faculty members
- visitors
- suppliers
Passage - Section
Passage - Lounge Area
Passage - Second Entrance
**Passage - Structural Design Solutions**

**TIMBER - NATURAL**
- Glued Laminated Timber, Cross Laminated Timber
- Concealed steel connections
- Rocking walls with *fuses* - resilient
- Exposed structure - natural look

**STEEL - INDUSTRIAL**
- Steel design with BONE structure solutions
- CLT/Concrete *composite* floor
- Buckling Restrained Braces - resilient
- Faster construction
- *Flexibility* in the future
Passage - Timber Structural Design Components

- CLT Rocking Walls
- Post-Tensioning Element
- Steel Braces
- Glulam Beam
- Glulam Column
- Clt Deck
- Lateral System
- Framing
- Floors
Passage - Timber Framing Plan

- Glulam columns 8’x 8’
- Glulam columns 14’x14’
- CLT shear rocking walls
- Glulam beams 8’x14’
- Glulam girders 12’x 32’
- Expansion joint
GLULAM BEAM TO RELIEVE SHEAR WALL FROM GRAVITY LOAD

KRAWINKLER BUTTERFLY FUSE

POST TENSIONED STEEL RODS

PANEL TO PANEL CONNECTION

STEEL CONNECTOR

GLULAM COLUMN
Passage - Steel Structural Design

- LATERAL SYSTEM
  - BRACED FRAMES
  - BUCKLING RESTRAINED BRACES

- FRAMING
  - STEEL BEAM

- FLOORS
  - COMPOSITE DECK
  - STEEL COLUMN
Prefabricated Steel Design

- No weld connections
- Prefabrication
- Zero-waste

Use traditional steel members with BONE manufacturing technologies for connection details.
Passage - Steel Framing Plan

- Steel columns W12x58
- Steel columns W14x109
- Buckling Restrained Braces
- Steel beams W14x53
- Steel girders W24x192
- Expansion joint

10’-6” 11’-3” 10’

18’ 18’

Cantilever
Passage - Load Path

GRAVITY LOAD

LATERAL LOAD

→ COMPRESSION
→ TENSION
Passage - Foundations

ISOLATED FOUNDATIONS 5’x 5’x16”
STRIP FOUNDATIONS 7’x16”
Timber Connection Details

- Steel column
- End-plate connection
- Concrete topping slab
- Slab reinforcing
- Composite floor screw
- Built-up steel beam
- CLT floor planks
Steel & Timber - Fire Hazards

Timber

FRR = 2.5 hrs


Steel

FRR > 2 hrs

WoodWorks presentation from David Barber at Arup
Passage - Design Strategies

- High thermal mass
- Sun shading windows
- Natural ventilation
- 50% Internal heat gains
- 20% Solar gains
Passage - Thermal Mass Materials

Thermal conductivity: \( \lambda = 1.05 \text{ W/mK} \)
Acoustic: reduce a noise
Aesthetic: support an idea without natural passage look

Thermal conductivity: 2.15 W/mK
Acoustic: reduce noise
Aesthetic: support an idea with natural passage look

Thermal conductivity:
Acoustic: does not reduce noises
Aesthetic: easy to maintain and hygienic

Thermal conductivity:
Acoustic: reduce a noise
Aesthetic: easy to Maintain
Hygienic

BRICK
STONE
TILES
CONCRETE
Passage - Living Wall

Green wall along the passage
ENERGY PRODUCTION POTENTIAL

PV panel area:
962 m² = 10,354 ft²

Energy production:
202,000 kWh/year

HARVESTING POTENTIAL

Annual rainfall = 600 mm/year
Surface area of catchment = 871 m² = 9,375 ft²
Run-off coefficient green roof = 0.8

Mean rainwater supply:
110,688 gal
Passage - Zones

Zone 1 - temporarily use-auditorium & large classes

Zone 2 - continuous use-offices & small classes
Passage - Duct Distribution

Return air by the grill in suspended ceiling
Supply
Exhaust

Shafts
MEP room

Overhead supply & plenum return + displacement ventilation
Passage - STV

Timber

Performance Relative to Life Cycle Impact Targets

<table>
<thead>
<tr>
<th>Impact</th>
<th>Target</th>
<th>Project</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon (kgCO₂e)</td>
<td>3,714,697</td>
<td>2,644,733</td>
<td>71%</td>
</tr>
<tr>
<td>Energy (MJ)</td>
<td>120,589,067</td>
<td>59,132,476</td>
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<tr>
<td>Water (lkg)</td>
<td>73,347,945</td>
<td>62,414,777</td>
<td>11%</td>
</tr>
<tr>
<td>Ozone (kgCFC11)</td>
<td>8,785,059</td>
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Steel

Performance Relative to Life Cycle Impact Targets

<table>
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<tr>
<th>Impact</th>
<th>Target</th>
<th>Project</th>
<th>%</th>
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<tr>
<td>Energy (MJ)</td>
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<tr>
<td>Water (lkg)</td>
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<tr>
<td>Ozone (kgCFC11)</td>
<td>-</td>
<td>1,12E-01</td>
<td>-</td>
</tr>
</tbody>
</table>
Intersection - Site Plan

EXCAVATION PHASE

- Excavation (-9 ft)
- Shoring of excavation pit
- Site storage (2200 sq. ft.)
- Tire washing station setup

LEGEND

- Site fence
- Silt fencing
- Rubble path
- Existing tree
- Site trailer (18 persons)
- Retaining wall
- Pedestrian/Bike traffic rerouting
- Site access gates
- Dewatering baker tanks
- Site route
- Excavated pit
- Shoring
- Excavator location
- Excavator reach
- Equipment parking
- Tire washing station
- Toilets
Intersection - Site Plan

FOUNDATION PHASE

- Concrete pump set up (30 ft x 30 ft)
- Lay down of transit mixer site path
- Dewatering using 1 Baker Tanks (2850 cum. ft.). Water released after desilting.
- Site storage (2200 sq. ft.)
- Secondary site storage setup (material laydown/worker shed) (1800 sq. ft.)
- Tire washing station setup
- Car parking (13 spots)/Equipment parking (1600 sq. ft.)

LEGEND

- Site fence
- Silt fencing
- Rubble path
- Existing tree
- Site trailer (18 persons)
- Retaining wall
- Pedestrian/Bike traffic rerouting
- Site access gates
- Dewatering baker tank
- Site route
- Second storage
- Concrete pump
- Pump storage
- Toilets
- Tire washing station
- Car parking
EXCAVATION PHASE

- Excavation (-9 ft)
- Shoring of excavation pit
- Site storage (2200 sq. ft.)
- Tire washing station setup

LEGEND

- Site fence
- Silt fencing
- Rubble path
- Existing tree
- Site trailer (18 persons)
- Retaining wall
- Pedestrian/Bike traffic rerouting
- Site access gates
- Dewatering Baker tanks
- Site route
- Storage
- Excavated pit
- Shoring
- Excavator location
- Excavator reach
- Equipment parking
- Tire washing station
- Toilets
Passage - Site Plan

FOUNDATION PHASE
- Concrete pump set up (30 ft x 30ft)
- Lay down of transit mixer site path
- Dewatering using 1 Baker Tanks (2850 cum. ft.). Water released after desilting.
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- Tire washing station setup
- Car parking (12 spots)/Equipment parking (1600 sq. ft.)

LEGEND
- Site fence
- Silt fencing
- Rubble path
- Existing tree
- Site trailer (18 persons)
- Retaining wall
- Pedestrian/Bike traffic rerouting
- Site access gates
- Dewatering baker tanks
- Site route
- Storage
- Excavated pit
- Shoring
- Excavator location
- Excavator reach
- Equipment parking
- Tire washing station
- Toilets
Intersection - Site Plan

STRUCTURE CONSTRUCTION PHASE
- Lay down of transit mixer site path
- Mobile crane location setup
- Site storage (5700 sq. ft.)
- Secondary site storage setup (material laydown/worker shed) (1800 sq. ft.)
- Tire washing station setup
- External car parking for office workers

LEGEND
- Site fence
- Rubble path
- Site trailer (24 persons)
- Retaining wall
- Pedestrian/Bike traffic rerouting
- Site access gates
- Mobile Crane locations
- Site route
- Storage
- Second storage
- Toilets
- Crane boom reach, 80ft (40ft ht.)
- Tire washing station
Passage - Site Plan

**STRUCTURE CONSTRUCTION PHASE**
- Lay down of transit mixer site path
- Mobile crane location setup
- Site storage (5700 sq. ft.)
- Secondary site storage setup (material laydown/worker shed) (1800 sq. ft.)
- Tire washing station setup
- External car parking for office workers

**LEGEND**
- Site fence
- Silt fencing
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- Existing tree
- Site trailer (24 persons)
- Retaining wall
- Pedestrian/Bike traffic rerouting
- Site access gates
- Mobile Crane locations
- Site route
- Storage
- Second storage
- Toilets
- Crane boom reach, 80ft (40ft ht.)
- Tire washing station
Equipment Selection

- Mobile Crane: Terex - T340 & LTM 1030-2.1
- Building Access: Telescopic forklifts, Electric forklifts & Stairs
- Dump trucks (5-6 m3)
- Baker tanks for dewatering process
- Excavator: 320D Hydraulic
- Transit mixers (5-6 m3)
Intersection - Schedule

| Site Preparation | 2 weeks |
| Excavation       | 3 weeks |
| Foundation       | 4 weeks |
| Super Structure  | 10 weeks|
| MEP              | 4 weeks |
| Exterior (Skin and facade) | 8 weeks |
| Interior (Finishing) | 6 weeks |
| Landscaping      | 6 weeks |
| Contingency      | 3 weeks |
| Close out        | 3 weeks |

**42 Week**
- Start of foundation. Transition from excavation logistic to foundation phase
- Finishing of 2nd Floor. Start of servicing installation phase
- Finishing of Facade and skin
- Parametric Cone

**41 Week**
- Start of foundation. Transition from excavation logistic to foundation phase
- Finishing of 2nd Floor. Start of servicing installation phase
- Finishing of Facade and skin
- Parametric Cone
### Passage - Schedule

| Week number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 |
|-------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Site Preparation | 2 weeks | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | }
Construction Cost Calculation

- BIM Model
- Quantity Take Off
- Data Entry

Target Value Design Sheet
Construction Cost Tracking

- Target Value: $8,900,000
- Budget: $8,350,000

Graph showing cost tracking over time with labels for different materials and phases:
- Target Value
- Budget
- Intersection Timber
- Intersection Mixed
- Passage Timber
- Passage Steel

Winter Presentation markers: $8,900,000 (Target), $8,350,000 (Budget)
Construction Cost Comparison

**Passage Steel**
- A Substructure: $7,450,000
- B Shell: $8,150,000
- C Interiors: $6,800,000
- D Services: $7,800,000
- E Equipment and Furnishings: $6,800,000
- F Specialty Construction: $8,150,000
- G Building Sitework: $7,450,000
- H General Conditions: $7,450,000

**Passage Timber**
- A Substructure: $7,450,000
- B Shell: $8,150,000
- C Interiors: $6,800,000
- D Services: $7,800,000
- E Equipment and Furnishings: $6,800,000
- F Specialty Construction: $8,150,000
- G Building Sitework: $7,450,000
- H General Conditions: $7,450,000

**Intersection Mixed**
- A Substructure: $7,450,000
- B Shell: $8,150,000
- C Interiors: $6,800,000
- D Services: $7,800,000
- E Equipment and Furnishings: $6,800,000
- F Specialty Construction: $8,150,000
- G Building Sitework: $7,450,000
- H General Conditions: $7,450,000

**Intersection Timber**
- A Substructure: $7,450,000
- B Shell: $8,150,000
- C Interiors: $6,800,000
- D Services: $7,800,000
- E Equipment and Furnishings: $6,800,000
- F Specialty Construction: $8,150,000
- G Building Sitework: $7,450,000
- H General Conditions: $7,450,000

Target Value: $8,900,000
## Overall Comparison

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Intersection Mixed</th>
<th>Intersection Timber</th>
<th>Passage Timber</th>
<th>Passage Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructability</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
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<tr>
<td>Schedule</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
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<tr>
<td>Cost</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Detailing</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td>Modularity</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
<td>⬤</td>
</tr>
<tr>
<td><strong>Total Points</strong></td>
<td><strong>8</strong></td>
<td><strong>12</strong></td>
<td><strong>9</strong></td>
<td><strong>13</strong></td>
</tr>
</tbody>
</table>

1  2  3
Why Life Cycle Costs Matter

Areas

[Diagram showing connections between areas and consumption]

MEP (STV)

Consumptions

CM (TVD)

Initial Costs

SE

Safety

O&M Costs

R&M Costs

Risk Costs

LCFM (LCC)

Rent, CashFlow, Financing, etc.
Risk Management Steps

Created Risk List
- Risks over different stages (planning, construction, etc.)
- Identify as many as possible

Calculated Risk Priority Figure
- Evaluate risks on consequences, occurrence- and discovery probability
- Identify main risks

Avoid
Eliminate Risks
- Reduce Probability or impact

Mitigate
- Build up reserves

Accept
- Third party takes responsibility (e.g. insurance)

Transfer
- Third party takes responsibility (e.g. insurance)

Calculate remaining risk costs for the project
→ Add to the Cash Flow

<table>
<thead>
<tr>
<th>#</th>
<th>Risk</th>
<th>Description</th>
<th>Consequences</th>
<th>Risk allocation</th>
<th>AEC Responsibility</th>
<th>Risk Management</th>
<th>Calculating RPZ</th>
<th>Risk Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Planning Stage</td>
<td>Wrong prediction of occupants needs regarding quality, quantity, flexibility or functionality</td>
<td>Replanning of the building layout, floorplans, used materials, etc. → extended planning time → additional costs</td>
<td>X</td>
<td>A, SE, MEP</td>
<td>Risk to the described clients requirements, work closely with owners</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>1.1</td>
<td>Requirement risk</td>
<td>No permissions granted or delayed permissions</td>
<td>Delayed start of construction → additional costs</td>
<td>X</td>
<td>All</td>
<td>Tight communication with the authorities, review stage of permission</td>
<td>4</td>
<td>4</td>
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</table>
Risk Maps before/after Risk Strategies

Lower risks through mitigation and transfer
## Life Cycle Cost and Resulting Rent

<table>
<thead>
<tr>
<th></th>
<th>Intersection Timber</th>
<th>Intersection Mixed</th>
<th>Passage Timber</th>
<th>Passage Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Cost</strong></td>
<td>7.57M $</td>
<td>7.58M $</td>
<td>6.93M $</td>
<td>7.94M $</td>
</tr>
<tr>
<td><strong>O&amp;M Cost</strong></td>
<td>8.59M $</td>
<td>8.74M $</td>
<td>6.73M $</td>
<td>7.77M $</td>
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<tr>
<td><strong>R&amp;M Cost</strong></td>
<td>0.71M $</td>
<td>0.72M $</td>
<td>0.95M $</td>
<td>0.59M $</td>
</tr>
<tr>
<td><strong>Risk Cost</strong></td>
<td>1.53M $</td>
<td>1.55M $</td>
<td>1.37M $</td>
<td>1.50M $</td>
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<tr>
<td><strong>Interest Cost</strong></td>
<td>2.21M $</td>
<td>2.21M $</td>
<td>2.03M $</td>
<td>2.32M $</td>
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<tr>
<td><strong>Total LCC</strong></td>
<td>20.62M $</td>
<td>20.81M $</td>
<td>18.01M $</td>
<td>20.12M $</td>
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<tr>
<td><strong>LCC p.a.</strong></td>
<td>0.83M $</td>
<td>0.83M $</td>
<td>0.72M $</td>
<td>0.81M $</td>
</tr>
<tr>
<td><strong>Owner Rent p.a.</strong></td>
<td>0.91M $</td>
<td>0.93M $</td>
<td>0.79M $</td>
<td>0.89M $</td>
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<tr>
<td><strong>Total Rent p.a.</strong></td>
<td>1.06M $</td>
<td>1.07M $</td>
<td>0.94M $</td>
<td>1.04M $</td>
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# Finance Summary

<table>
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<th>Intersection Mixed</th>
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<th>Passage Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WACC (Discount Rate)</strong></td>
<td>4.89%</td>
<td>4.89%</td>
<td>4.89%</td>
<td>4.89%</td>
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<tr>
<td><strong>Break Even Point</strong></td>
<td>2047</td>
<td>2047</td>
<td>2046</td>
<td>2048</td>
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<tr>
<td><strong>NPV</strong></td>
<td>2,647,000 $</td>
<td>2,756,000 $</td>
<td>2,670,000 $</td>
<td>2,672,000 $</td>
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<tr>
<td><strong>IRR</strong></td>
<td>15.78%</td>
<td>16.19%</td>
<td>16.81%</td>
<td>15.19%</td>
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<td><strong>Minimum DSCR</strong></td>
<td>1.35</td>
<td>1.37</td>
<td>1.52</td>
<td>1.49</td>
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<tr>
<td><strong>Minimum LLCR</strong></td>
<td>1.80</td>
<td>1.82</td>
<td>1.86</td>
<td>1.78</td>
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</table>
Decision Matrix Methodology

01 Find Decision Criteria

02 Weight Criteria Based on Owner input

03 Evaluate Alternatives

04 Decide on Alternative for Project Development

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Owners</th>
<th>Adrienne</th>
<th>Ewa</th>
<th>Hussein</th>
<th>Jure</th>
<th>Karolina</th>
<th>Renata</th>
<th>OWNERS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Weighting in %</td>
<td>Weighting in %</td>
<td>Weighting in %</td>
<td>Weighting in %</td>
<td>Weighting in %</td>
<td>Weighting in %</td>
<td>Weighting in %</td>
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<tr>
<td>Implementation Big Idea</td>
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<td>5%</td>
<td>6%</td>
<td>8%</td>
<td>8%</td>
<td>6%</td>
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<tr>
<td>Aesthetic Design</td>
<td></td>
<td>9%</td>
<td>8%</td>
<td>8%</td>
<td>7%</td>
<td>8%</td>
<td>10%</td>
<td>8%</td>
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</table>

<table>
<thead>
<tr>
<th>Agrocieka (A)</th>
<th></th>
<th>Weighting in %</th>
<th>DD 1 Timber</th>
<th>DD 2 Mixed</th>
<th>L1 Timber</th>
<th>L2 Street</th>
<th>Weighting in %</th>
<th>DD 1 Timber</th>
<th>DD 2 Mixed</th>
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<tbody>
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<td>Implementation Big Idea</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>6%</td>
<td></td>
<td></td>
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<tr>
<td>Aesthetic Design</td>
<td></td>
<td>8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8%</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Sara (JE)</th>
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<th>Weighting in %</th>
<th>DD 1 Timber</th>
<th>DD 2 Mixed</th>
</tr>
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<tbody>
<tr>
<td>Implementation Big Idea</td>
<td></td>
<td>6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aesthetic Design</td>
<td></td>
<td>8%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Comparison of Alternatives

**Intersection Timber**
- Implementation Big...
- Program Requirement
- User Experience
- Negative Carbon
- IT Integration
- DPR - Prefabrication
- Life Cycle Costs
- Construction Costs
- Construction Time
- Energy Demand
- Integrated AEC Design
- Aesthetic Design

**Intersection Mixed**
- Implementation Big...
- Program Requirement
- User Experience
- Negative Carbon
- IT Integration
- DPR - Prefabrication
- Life Cycle Costs
- Construction Costs
- Construction Time
- Energy Demand
- Integrated AEC Design
- Aesthetic Design

**Passage Timber**
- Implementation Big...
- Program Requirement
- User Experience
- Negative Carbon
- IT Integration
- DPR - Prefabrication
- Life Cycle Costs
- Construction Costs
- Construction Time
- Energy Demand
- Integrated AEC Design
- Aesthetic Design

**Passage Steel**
- Implementation Big...
- Program Requirement
- User Experience
- Negative Carbon
- IT Integration
- DPR - Prefabrication
- Life Cycle Costs
- Construction Costs
- Construction Time
- Energy Demand
- Integrated AEC Design
- Aesthetic Design
# Decision Matrix Summary

<table>
<thead>
<tr>
<th>Criteria Comparison Alternatives</th>
<th>Intersection Timber</th>
<th>Intersection Mixed</th>
<th>Passage Timber</th>
<th>Passage Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implementation Big Idea</td>
<td>1.14</td>
<td>1.01</td>
<td>1.71</td>
<td>1.39</td>
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<td>Aesthetic Design</td>
<td>1.58</td>
<td>1.92</td>
<td>2.17</td>
<td>2.00</td>
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<tr>
<td>Integrated AEC Design</td>
<td>2.03</td>
<td>2.47</td>
<td>2.21</td>
<td>1.68</td>
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<tr>
<td>Floorplan</td>
<td>1.88</td>
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<td>2.04</td>
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<td>Energy Demand</td>
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<td>1.02</td>
<td>2.43</td>
<td>1.96</td>
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<tr>
<td>CO² Footprint</td>
<td>1.82</td>
<td>1.99</td>
<td>2.60</td>
<td>1.56</td>
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<tr>
<td>Construction Time</td>
<td>1.02</td>
<td>0.87</td>
<td>1.35</td>
<td>1.64</td>
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<tr>
<td>Construction Costs</td>
<td>0.71</td>
<td>0.79</td>
<td>1.20</td>
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<td>Life Cycle Costs</td>
<td>1.62</td>
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<td>DPR - Prefabrication</td>
<td>1.23</td>
<td>1.23</td>
<td>1.67</td>
<td>1.73</td>
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<tr>
<td>IT Integration</td>
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<td>1.03</td>
<td>1.09</td>
<td>1.03</td>
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<tr>
<td>Negative Carbon</td>
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<td>1.68</td>
<td>1.92</td>
<td>2.32</td>
</tr>
<tr>
<td>User Experience</td>
<td>2.39</td>
<td>2.39</td>
<td>2.47</td>
<td>2.39</td>
</tr>
<tr>
<td>Program Requirement</td>
<td>0.99</td>
<td>1.11</td>
<td>1.54</td>
<td>1.67</td>
</tr>
<tr>
<td>Total</td>
<td>20.61</td>
<td>20.84</td>
<td>26.91</td>
<td>23.68</td>
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</tbody>
</table>
Technology and Communication
Coordination and Collaboration

- Trouble Shooting in IrisVR
- Ideation in Span
- ClashDetection in Glue
- Crowdsourcing with Forms
- When2meet
BIM Execution Plan

4.5 - Levels

Levels should be drawn in each discipline model to acquire level constraints as they cannot be acquired from linked models. Common levels should be positioned on top face of the structural floors, because the floor sandwich above the structural part (insulation, different finishes, …) can vary in thickness.

Example of wrong positioning of the floors:

Example of correct positioning of the floors:

Architectural floors should be positioned with an offset or with a help of additional level.

Naming Convention
Levels should be named in the following order: Discipline mark, position of level, description. Position 00 should mark the lowest level.

Example
S.01: First floor - meaning: Structure, Second lowest level, First floor.
Lessons Learned

**Pull Planning**
- Assigning Task / Responsibility
- Tracking

**Keeping Deadlines**
- Domino effect
- Pressure & Quality drop
- Stick to deadlines
- Break down task to subtasks
- Submission Lead
- Set reminders and remind others when you need data

**Rework**
- Uncommunicated changes
- Working in silos
- Use open office approach - shared voice conference - easy interactions and faster inquires
- Better integration of disciplines

**Team Meetings**
- Inefficient Meetings
- Time Track
- More meetings in VR!
- Preparation per Discipline / Lead
- Moderation / Lead
Back Up Slides
TVD Sheet - Intersection Timber

TARGET VALUE DESIGN WALL - Intersection Timber
Budget = $8,350,000

<table>
<thead>
<tr>
<th>PACIFIC TEAM</th>
<th>ESTIMATED VALUE</th>
<th>TARGET VALUE</th>
<th>VALUE DELTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>$8,659,000</td>
<td>$8,900,000</td>
<td>$1,240,000</td>
</tr>
</tbody>
</table>

Gross Square Footage: 36,570
Price = $209 /SF

TVD - SUMMARY

COST ESTIMATE

TVD - TARGETS BY CLUSTER

TVD - TRACKING TARGET OVER TIME
TVD Sheet - Intersection Mixed

TARGET VALUE DESIGN WALL - Intersection Mixed

Budget = $8,350,000

PACIFIC TEAM

<table>
<thead>
<tr>
<th></th>
<th>ESTIMATED VALUE</th>
<th>TARGET VALUE</th>
<th>VALUE DELTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>$8,500,000</td>
<td>$8,900,000</td>
<td>$590,000</td>
</tr>
</tbody>
</table>

Gross Square Footage: 36,570

Price = 229 $/SF

COST ESTIMATE

- G Building Sitework: $977,826 (13%)
- H General Conditions: $744,000 (5%)
- A Substructure: $312,147 (4%)
- F Specialty Construction: $271,025 (4%)
- C Interiors: $1,285,568 (13%)
- D Services: $1,723,365 (21%)
- E Equipment and Furnishing: $200,150 (2%)

TVDSUMMARY

TOTAL $590,000

TVD - TARGETS BY CLUSTER

- TARGET VALUE
- ESTIMATED VALUE
- VALUE DELTA

TVD - TRACKING TARGET OVER TIME

TARGET

ESTIMATE

DELTA

ESTIMATE QUANTITY RELIABILITY

- HIGH 0%
- MEDIUM 100%
- LOW 0%

ESTIMATE COST DATA RELIABILITY

- HIGH 0%
- MEDIUM 100%
- LOW 0%

ESTIMATE OVERALL RELIABILITY

- HIGH 0%
- MEDIUM 100%
- LOW 0%
## TVD Sheet - Passage Steel

### Target Value Design Wall - Passage Steel

**Budget = $8,350,000**

<table>
<thead>
<tr>
<th>PACIFIC TEAM</th>
<th>ESTIMATED VALUE</th>
<th>TARGET VALUE</th>
<th>VALUE DELTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>$7,683,000</td>
<td>$8,900,000</td>
<td>$1,216,000</td>
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</tbody>
</table>

### TVD Summary

- **TVD - SUMMARY**
  - Total Estimated Value: $7,683,000
  - Total Target Value: $8,900,000
  - Value Delta: $1,216,000

### TVD - Targets by Cluster

- **COST ESTIMATE**
  - A Substructure: $941,860 (11%)
  - B Shell: $933,333 (11%)
  - C Interiors: $1,264,012 (22%)
  - D Services: $1,273,105 (22%)
  - E Equipment and Furnishing: $1,188,800 (15%)
  - F Speciality Construction: $826,718 (10%)
  - G Building Stenwork: $124,910 (9%)
  - H General Conditions: $695,821 (9%)

- **TVD - Tracking Target Over Time**

- **Gross Square Footage**: 30,470
- **Price**: 252 $/SF

### Estimate Quantity Reliability
- Low: 0%
- High: 0%
- Medium: 0%

### Estimate Cost Data Reliability
- Low: 0%
- Medium: 100%
- High: 0%

### Estimate Overall Reliability
- Low: 0%
- Medium: 100%
- High: 0%
SE - Sizing Structural Columns (Timber)

WOOD COLUMNS

WOOD COLUMNS—NORMAL HEIGHT

WOOD COLUMNS—TALL

THE ARCHITECT’S
STUDIO COMPANION
RULES OF THUMB FOR PRELIMINARY DESIGN

Third Edition

Edward Allen and Joseph Iano
SE - Sizing Structural Beams (Timber)

The Architect's Studio Companion
Rules of Thumb for Preliminary Design

Third Edition

Edward Allen and Joseph Iano
**SE - Base Shear Calcs**

### "Mixed" Intersection

<table>
<thead>
<tr>
<th>W_Floor 1</th>
<th>1730.632 kip</th>
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<tbody>
<tr>
<td>W_Floor 2</td>
<td>1730.632 kip</td>
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<tr>
<td>W_Total</td>
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<tr>
<td>Sds</td>
<td>1.45</td>
</tr>
<tr>
<td>R</td>
<td>4</td>
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<tr>
<td>Ie</td>
<td>1.25</td>
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<tr>
<td>Cs</td>
<td>0.453125</td>
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<tr>
<td>V</td>
<td>1568.385 Kip</td>
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--- Obtained from USGS Seismic Design Tool

--- Steel BRBs

\[
C_s = \frac{S_{eq}}{2} I_e
\]  

(12.8.2)

where

- $S_{eq}$ is the design spectral response acceleration parameter in the short period range as determined from Section 11.4.5 or 11.4.8;
- $R$ is the response modification factor in Table 12.2-1; and
- $I_e$ is the Importance Factor determined in accordance with Section 11.5.1.

### "Natural" Intersection

<table>
<thead>
<tr>
<th>W_Floor 1</th>
<th>1501.408 kip</th>
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<tbody>
<tr>
<td>W_Floor 2</td>
<td>1501.408 kip</td>
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<tr>
<td>W_Total</td>
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<tr>
<td>Sds</td>
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<td>R</td>
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<td>Cs</td>
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<tr>
<td>V</td>
<td>837.3237 Kip</td>
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</tbody>
</table>

--- Obtained from USGS Seismic Design Tool

--- CLT Shear walls

### 12.8 EQUIVALENT LATERAL FORCE (ELF) PROCEDURE

#### 12.8.1 Seismic Base Shear

The seismic base shear, $V$, in a given direction shall be determined in accordance with the following equation:

\[
V = C_s W
\]  

(12.8.1)

where

- $C_s$ is the seismic response coefficient determined in accordance with Section 12.8.1.1; and
- $W$ is the effective seismic weight per Section 12.7.2.
# Structural Materials - Cost Case Study

<table>
<thead>
<tr>
<th>Element</th>
<th>Concrete/Steel option</th>
<th>CLT options</th>
<th>Basic CLT option 1</th>
<th>Basic CLT option 2</th>
<th>Green option 1</th>
<th>Green option 2</th>
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</thead>
<tbody>
<tr>
<td>Structural Walls</td>
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<td>$624,417</td>
<td>$414,901</td>
<td>$414,901</td>
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<td>Concrete Slab</td>
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<td>Interior Walls*</td>
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<td>$155,304</td>
<td>$155,304</td>
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<td>Steel Beams</td>
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<tr>
<td>Glulam Beams</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Extra CLT Walls</td>
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<td>$595,241</td>
<td>$654,768</td>
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<td>$654,768</td>
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<td>Extras for CLT**</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>TOTAL $</td>
<td>$2,590,950</td>
<td>$2,565,763</td>
<td>$2,217,777</td>
<td>$2,105,506</td>
<td>$2,027,091</td>
<td>$2,027,091</td>
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<tr>
<td>SQFT</td>
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<td>40.065</td>
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<td>$64</td>
<td>$64</td>
<td>$55</td>
<td>$60</td>
<td>$50</td>
<td>$50</td>
</tr>
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</table>

* Interior walls for concrete and basic CLT options are in light-steel frame construction. Interior walls for CLT Green options are in wood-frame construction.

** Extras for CLT includes labor cost and connectors for CLT

[https://www.researchgate.net/publication/320739097](https://www.researchgate.net/publication/320739097)
# CrossLam® CLT Panel Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Details</th>
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<tbody>
<tr>
<td>Maximum Panel Size</td>
<td>9’10.5” x 40.0’</td>
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<tr>
<td>Maximum Thickness</td>
<td>12.42”</td>
</tr>
<tr>
<td>Minimum Thickness</td>
<td>3.43”</td>
</tr>
<tr>
<td>Production Widths</td>
<td>7’10.5” &amp; 9’10.5”</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>12% (+/-3%) at time of production</td>
</tr>
<tr>
<td>Glue Specifications</td>
<td>Purbond polyurethane adhesive</td>
</tr>
<tr>
<td>Glue Type</td>
<td>Weatherproof, formaldehyde free foaming PUR</td>
</tr>
<tr>
<td>Species</td>
<td>SPF, Douglas-fir</td>
</tr>
<tr>
<td>Lumber Grades</td>
<td>SPF #2 &amp; Btr, SPF #3, Dfir L3, MSR 2100</td>
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<tr>
<td>Stress Grades</td>
<td>V2M1.1, V2.1, E1M4, E1M5</td>
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<tr>
<td>Manufacturing Certification</td>
<td>APA PRG 320 Product Report PR-L314</td>
</tr>
<tr>
<td>Density</td>
<td>30.3 lbs/ft³ (shipping weight at time of manufacturing)</td>
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</table>
Timber - Fire Hazards

Glulam Performance in Fire

Glulam performs very well in the intense heat of a fire, where temperatures can achieve 1,650°F or higher. Unprotected steel members typically buckle and twist in such high temperatures, causing catastrophic collapse of both the roof and supporting walls.

Wood ignites at about 450-500°F, but charring may begin as low as 300°F. Wood typically chars at a rate of 1/40 inch per minute. Thus, after 30 minutes of fire exposure, only the outer 3/4 inch of the glulam will be damaged. It is important to note that the adhesives used in the manufacture of a glulam beam burn at about the same rate as the wood and do not affect the overall fire performance of the member. The char that develops insulates the glulam member and, hence, raises the temperatures it can withstand. Most of the cross section of a large glulam will remain intact when exposed to fire, and the member will continue to support load.

Thus, depending on the severity of the fire and after a structural re-analysis by a qualified design professional, it is often possible to salvage the glulam members by merely removing the fire-damaged material and refinishing the surface of the member.

“The char protects the load-carrying ambient temperature wood, allowing the member to be designed to carry applied forces, given the rate of charring is highly predictable.”

Structurlam is pleased to announce that the mass timber manufacturer has received accreditation from Intertek Testing Services, certifying that the CrossLam® cross laminated timber (CLT) product has qualified under ASTM E119-16a and CAN/ULC S101 Standard Test Methods for Fire Tests of Building Construction and Materials. The product achieved a fire resistance rating of 150 minutes (2 1/2 hrs).

On February 22, 2017, Intertek conducted testing on Structurlam’s CrossLam® CLT Un-restrained Load-Bearing Floor/Ceiling Assembly. The fire resistance test evaluates the duration for which a building material can be exposed to fire and maintain its structural integrity.

The fire endurance test took place over 2 1/2 hours, during which CrossLam® CLT paneling was exposed to fire reaching extremely high temperatures. Based on the test results, the product sustained total load of 4.35 kPa (90 psf) throughout the test duration. No flaming was observed on the exposed side of the panel for the duration of the test. This resulted in a fire resistance rating of 150 minutes.