Team Members’ Location

- **Geffen (Apprentice)**
  - USA

- **Klara (CM)**
  - Iraq

- **Liu Xi (SE)**
  - China

- **Stavros (MEP)**
  - Greece

- **Robert (A)**
  - Slovenia

- **Sio Chong (SE)**
  - China

- **Han (CM)**
  - Singapore
Effective Cyber Collaboration on Terf
Weekly Meetings
Communication

EXPRESS

SE
CM
A
MEP
SE
CM
App
Bi-Weekly Subgroup Meetings

Building Systems Integration

SE  App  MEP

Cost

A  CM  CM
Flush with less water than in a beer can

Smart systems control the water usage
Agile IPD ↔ Subgroup Meetings
Set Deadlines
Weekly 2-min surveys to Reflect

1. Reduce inefficiencies
2. Minimize latency
3. Add value for time
4. Measure KPIs
EXPRESS

Water Challenge

Rainwater Catchment

Geo-Polymer Concrete

Green Roof

Green Wall

Less is More

Charmin®
- 300 000 Inhabitants
  - 50 000 University students
- Oceanic climate - 1400mm
- Ljubljana basin - Fog 65 days

- Earthquakes
- Marshland ground dryout
- High groundwater
- Floods
EXPRESS

FLOODING WAVE
Big Idea - Concept

Koliščarji - Marshlanders
Le Corbusier - Center of Visual Arts

Green roof/wall

Canalla Disco - Vailo + Irigaray

Gymnasium Markt Indersdorf

Cloud House
Ideas for Inbetween Spaces

STUDY AND GO

LOGGIA

MULTIPURPOSE STAIRS
First Floor Plan

- **Circulation / Lounge**
- **Auditorium**
- **Seminar Rooms**
- **Vertical Shaft**
- **Study’N’Go**
- **Restrooms**
- **Large Classroom**
- **Offices/Staff**
- **Small Classroom**
- **Fire Stairs / Storage**

**View on Auditorium**
- Controlling air humidity
- Acoustics diffusor
- Water filter
- Bringing nature closer to students
- Filtered water is saved in water tank
Water Tank

Largest aquarium in Europe - Berlin

Lounge / Cafe
View on the Entry Plaza
- \( S_1 = 0.20g \)
- \( S_s = 0.55g \)

- Data from USGS, Worldwide Seismic Design Tool.
- Assume the seismic condition in Ljubljana is very similar to Trieste, Italy (One-hour driving distance).
Earthquake Base Shear

Use *Equivalent Lateral Force Procedure*, desired in the ASCE Standard

<table>
<thead>
<tr>
<th></th>
<th>Symbol</th>
<th>Concrete Building</th>
<th>Steel Building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead Load per floor</td>
<td>W</td>
<td>1000 kips</td>
<td>700 kips</td>
</tr>
<tr>
<td>(Roughly Estimated)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>S_D1</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>S_DS</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Fundamental Natural</td>
<td>$T = C_t h_n^x$</td>
<td>0.341s</td>
<td>0.425s</td>
</tr>
<tr>
<td>Period of Building</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Response Modification</td>
<td>R</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Factor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Occupancy Importance</td>
<td>I</td>
<td>1.25</td>
<td></td>
</tr>
<tr>
<td>Factor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Shear</td>
<td>V</td>
<td>275 kips</td>
<td>154 kips</td>
</tr>
<tr>
<td></td>
<td>V_max</td>
<td><strong>258 kips</strong></td>
<td>180 kips</td>
</tr>
<tr>
<td>Base Shear Max</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Shear Min</td>
<td>V_min</td>
<td>91 kips</td>
<td>64 kips</td>
</tr>
</tbody>
</table>

Use a simplified format based on the provisions of the ASCE Standard

\[ \text{Wind Pressure} \ P = 0.00256V^2IK_zK_{zt}K_dGC_p = 8.6 \text{psf} \]

• Assume basic wind speed \( V = 85 \text{ mph} \) (same with CA).
• School -> Occupancy Level 3 -> \( I = 1.15; \)
• Exposure Category B & Low-rise Building -> \( K_z = 0.7 \) for all levels;
• Building on ground level -> \( K_{zt} = 1.0; \)
• Main Lateral-Resisting System -> \( K_d = 0.85; \)
• Rigid Structure -> \( G = 0.85; \)
• Windward Wall -> \( C_p = 0.8. \)
<table>
<thead>
<tr>
<th>Load Type</th>
<th>Level</th>
<th>Concrete Structure</th>
<th>Steel Structure</th>
</tr>
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<tbody>
<tr>
<td>Wind</td>
<td>All Level</td>
<td>8.6 psf (0.41 kN/m²)</td>
<td></td>
</tr>
<tr>
<td>Seismic Base Shear</td>
<td>Base</td>
<td>258 kips (58 kN)</td>
<td>154 kips (35 kN)</td>
</tr>
<tr>
<td>Seismic Floor Distributed Load</td>
<td>Level 1</td>
<td>43 kips (9.7 kN)</td>
<td>15.4 kips (5.8 kN)</td>
</tr>
<tr>
<td></td>
<td>Level 2</td>
<td>86 kips (19.3 kN)</td>
<td>51.3 kips (11.7 kN)</td>
</tr>
<tr>
<td></td>
<td>Level 3</td>
<td>129 kips (29 kN)</td>
<td>77 kips (17.5 kN)</td>
</tr>
<tr>
<td>Occupancy or Use</td>
<td>Uniform (psf)</td>
<td>Uniform (kN/m²)</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>---------------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td>Rooms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classroom</td>
<td>40</td>
<td>1.92</td>
<td></td>
</tr>
<tr>
<td>Office</td>
<td>50</td>
<td>2.40</td>
<td></td>
</tr>
<tr>
<td>Computer Lab</td>
<td>100</td>
<td>4.79</td>
<td></td>
</tr>
<tr>
<td>Auditorium (Stage Floor)</td>
<td>150</td>
<td>7.18</td>
<td></td>
</tr>
<tr>
<td>Corridor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corridors above Ground Floor</td>
<td>80</td>
<td>3.83</td>
<td></td>
</tr>
<tr>
<td>Corridors on Ground Floor</td>
<td>100</td>
<td>4.79</td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof</td>
<td>20</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>Roof for Promenade Purpose</td>
<td>60</td>
<td>2.87</td>
<td></td>
</tr>
<tr>
<td>Concentrated Load</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevator / Machine Room grating (on area of 4 in² [2,580 mm²])</td>
<td>300 pound</td>
<td>1.33 kN</td>
<td></td>
</tr>
</tbody>
</table>

Ref: [http://www.ce.udel.edu/courses/CIEG407/ASCE003c04_p09-14.pdf](http://www.ce.udel.edu/courses/CIEG407/ASCE003c04_p09-14.pdf)
Wave Structure Model 1 - Concrete Model
First Floor Grid Legend

- **Shear Wall - 10’ x 1’**
- **Hollow Core PT Slab - 8” + 1.5”**
- **Interior Column - D 24”**
- **Exterior Column - 18” x 18”**
- **Shallow PT Beam - 8”(H) x 10”(W)**
  - Max Span: 13’
- **Normal PT Beam - 16”(H) x 10”(W)**
  - Max Span: 30’
- **Long PT Beam - 30”(H) x 12”(W)**
  - Max Span: 52’
**MEP at First Floor Ceiling**

- **Shear Wall** - 10' x 1'
- **Hollow Core PT Slab** - 8” + 1.5”
- **Interior Column** - D 24”
- **Exterior Column** - 18” x 18”
- **Shallow PT Beam** - 8”(H) x 10”(W)
  - Max Span: 13’
- **Normal PT Beam** - 16”(H) x 10”(W)
  - Max Span: 30’
- **Long PT Beam** - 30”(H) x 12”(W)
  - Max Span: 52’
Roof Floor Plan

Roof Grid Legend

- **Red**: Shear Wall - 10' x 1'
- **Green**: Hollow Core PT Slab - 8” + 1.5”
- **Gray**: Interior Column - D 24”
- **Gray**: Exterior Column - 18” x 18”
- **Orange**: Shallow PT Beam - 8”(H) x 10”(W) Max Span: 13’
- **Blue**: Normal PT Beam - 16”(H) x 10”(W) Max Span: 30’
- **Purple**: Long PT Beam - 30”(H) x 12”(W) Max Span: 52’
Hollow Core PT Slab Values

Popular in Northern and UAE socialist countries of Eastern Europe, because of following,

(1) Light Weight Building
(2) Long Span
(3) Excellent Fire Resistance
(4) Excellent Sound Transmission Characteristics
(5) Flexible in Floor Opening

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Design Span</td>
<td>30 foot</td>
</tr>
<tr>
<td>Allowable Superimposed Load</td>
<td>180 psf</td>
</tr>
<tr>
<td>Self-Weight</td>
<td>70 psf</td>
</tr>
<tr>
<td>Concrete Grade</td>
<td>5000 psi</td>
</tr>
<tr>
<td>Prestress (D 0.5”)</td>
<td>175 ksi</td>
</tr>
</tbody>
</table>

Values for using hollow core PT slab

- Excellent Fire Resistance
- Long Span

At the span of 30 ft (9m), the max allowable superimposed load is 180 psf (8.5kPa).

% Concrete Weight = \( \frac{70 \text{psf}}{150 \text{pcf} \times 8\"} = 70\% \)

Ref: Hollow Core Concrete Detailing Manual, Hollow Core Concrete Pty. Ltd.
Values for using hollow core PT slab

- **Excellent Fire Resistance**
  - Rating from 1.5 hours to 4 hours

- **Excellent Sound Transmission Characteristics**
  - High Sound Transmission Loss Rate (STC - 50) and Impact Isolation Class Rate (IIC - 73)

Values for using hollow core PT slab

● **Flexibility in Floor Opening**
  
  - Core Hole less than 6” in diameter simply drilling through core on site
  
  - Large Opening for staircase, etc. Trimmer Beam

Ref: Hollow Core Concrete Detailing Manual, Hollow Core Concrete Pty. Ltd.
Fly Ash-based Geopolymer Concrete

- Hardening of geopolymer cement through Geopolymerization chemistry. Request no water at end product.

- Very minor CO_2 emission during manufacturing.

<table>
<thead>
<tr>
<th></th>
<th>Geopolymer Concrete</th>
<th>Portland Cement Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement (lbs)</td>
<td>0</td>
<td>560</td>
</tr>
<tr>
<td>Fly Ash (lbs)</td>
<td>667</td>
<td>0</td>
</tr>
<tr>
<td>Coarse Aggregates (lbs)</td>
<td>1,863</td>
<td>1,760</td>
</tr>
<tr>
<td>Fine Aggregates (lbs)</td>
<td>1,193</td>
<td>1,100</td>
</tr>
<tr>
<td>Admixtures (lbs)</td>
<td>0</td>
<td>1.4</td>
</tr>
<tr>
<td>Water (lbs)</td>
<td>0</td>
<td>290</td>
</tr>
<tr>
<td>8 mol. NaOH solution (lbs)</td>
<td>300</td>
<td>-</td>
</tr>
</tbody>
</table>
Real Life Example of Building made with Geopolymer Concrete

Queensland’s University GCI Building.
World’s first successful building made with Geopolymer Concrete

This building comprises 3 suspended geopolymer concrete floors involving 33 precast panels.

Slab - Beam Connection

Ref: Hollow Core Concrete Detailing Manual, Hollow Core Concrete Pty. Ltd.
Preliminary Column Design

Column Interaction Diagrams
for rectangular, tied columns with symmetric reinforcement

<table>
<thead>
<tr>
<th>Material Properties</th>
<th>Compression</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f'_c$</td>
<td>5,000 psi</td>
</tr>
<tr>
<td>$f'_t$</td>
<td>60,000 psi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Column Dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$b$</td>
<td>18 in</td>
</tr>
<tr>
<td>$h$</td>
<td>18 in</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reinforcement Requirements</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>$A_{s,min}$</td>
<td>3.24 in$^2$ OK</td>
</tr>
<tr>
<td>$A_{s,max}$</td>
<td>25.92 in$^2$ OK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Shear Reinforcement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ties</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reinforcement Detail</th>
<th># of Bars</th>
<th>Bar Size</th>
<th>Line Depth (in)</th>
<th>$A_s$ (in$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>8</td>
<td>8</td>
<td>1</td>
<td>6.32</td>
</tr>
<tr>
<td>Line 2</td>
<td>8</td>
<td>8</td>
<td>6</td>
<td>6.32</td>
</tr>
<tr>
<td>Line 3</td>
<td>8</td>
<td>8</td>
<td>12</td>
<td>6.32</td>
</tr>
<tr>
<td>Line 4</td>
<td>8</td>
<td>8</td>
<td>17</td>
<td>6.32</td>
</tr>
<tr>
<td>Line 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Design Loads

<table>
<thead>
<tr>
<th>Pu, k</th>
<th>Nu, k-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC I</td>
<td>288</td>
</tr>
<tr>
<td>LC II</td>
<td></td>
</tr>
</tbody>
</table>

$\varepsilon_s$ = strain in steel layer furthest from compression side
+ve = tension

Column Interaction Diagram
Gravity Load Path
Truss Member: W12x26

Cantilever Load Path
Lateral Load Path - NS Direction

Lateral Resisting System Legend

- **Shear Wall - 10’ x 1’**
- **R.C. Rigid Diaphragm - 1.5”**
Lateral Load Path - EW Direction

Lateral Resisting System Legend

- Shear Wall - 10’ x 1’
- R.C. Rigid Diaphragm - 1.5”

North
Wave Structure Model 2 - Steel Model
First Floor Plan

First Floor- Grid Legend

- Column HW 400*400*15*15
- Beam HN 350*175*6*9
- Column HW 400*400*15*15 (ONLY from ground floor to first floor)
- Steel shear wall 200mm
- Bracing HN 200*100*5.5*8
Gravity Load Path
Spring Dam

Flooding Protection Measure
Soil Profile Diagram

- **A**: Human Soil - Non Bearing
- **B**: Clay with Pebbles CU/GC, $Q_u = 100$ kPa
- **C**: Stiff Compact Sedimentary River Gravel GW/GP, $Q_u = 290$ kPa

Surface

Water Table
- Excavate for 0.5m to remove the non-bearing human soil.
- 4" slightly R.C. Slab-on-grade at 0.5m below ground level.
- Isolated Footing at 1.5m below ground level.
Weather

Daily High and Low Temperature

- Jan 5: 36°F
- Feb 28: 45°F
- Mar: 26°F
- Apr: 48°F
- May 26: 71°F
- Jun: 79°F
- Jul 26: 70°F
- Aug: 56°F
- Sep 9: 70°F
- Oct: 50°F
- Nov 18: 45°F
- Dec: 32°F

Temperature ranges:
- Cold: 10°F - 20°F
- Warm: 23°F - 40°F
- Cold: 41°F - 90°F
EXPRESS

Orientation

18_Mar_08:00am
07_May_08:00am
26_Jun_08:00am
15_Aug_08:00am
04_Oct_08:00am
03_Dec_08:00am
<table>
<thead>
<tr>
<th></th>
<th>Delivered energy</th>
<th></th>
<th>Demand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kWh</td>
<td>kWh/m²</td>
<td>kW</td>
</tr>
<tr>
<td>Lighting, facility</td>
<td>8459</td>
<td>9.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Electric cooling</td>
<td>30298</td>
<td>32.4</td>
<td>26.56</td>
</tr>
<tr>
<td>HVAC aux</td>
<td>27346</td>
<td>29.3</td>
<td>3.34</td>
</tr>
<tr>
<td>Total, Facility electric</td>
<td>66103</td>
<td>70.8</td>
<td></td>
</tr>
<tr>
<td>Fuel heating</td>
<td>28233</td>
<td>30.2</td>
<td>20.35</td>
</tr>
<tr>
<td>Domestic hot water</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total, Facility fuel*</td>
<td>28233</td>
<td>30.2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>94336</td>
<td>101.0</td>
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<tr>
<td>Equipment, tenant</td>
<td>25375</td>
<td>27.2</td>
<td>8.1</td>
</tr>
<tr>
<td>Total, Tenant electric</td>
<td>25375</td>
<td>27.2</td>
<td></td>
</tr>
<tr>
<td>Grand total</td>
<td>119711</td>
<td>128.1</td>
<td></td>
</tr>
</tbody>
</table>

*heating value
Central Plant
  a. Chilled Water Pump
  b. Hot Water Heat Exchanger

Ground-Source Heat Pump
## Decision Matrix

<table>
<thead>
<tr>
<th></th>
<th>Central Plant</th>
<th>Ground Source Heat Pump</th>
<th>Weight</th>
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<tbody>
<tr>
<td>Cost</td>
<td>9</td>
<td>5</td>
<td>0.33</td>
</tr>
<tr>
<td>Constructibilty</td>
<td>8</td>
<td>5</td>
<td>0.22</td>
</tr>
<tr>
<td>Maintenance</td>
<td>10</td>
<td>9</td>
<td>0.11</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>7</td>
<td>9</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8.20</strong></td>
<td><strong>6.90</strong></td>
<td></td>
</tr>
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</table>
## Airflow Ducts

<table>
<thead>
<tr>
<th>Room</th>
<th>Quantity</th>
<th>Occupants [sqft/occupant]</th>
<th>SqFt Each Room</th>
<th>Occupants</th>
<th>Airflow (cfm)</th>
<th>Diameter Round Duct (inches)</th>
<th>Diameter Equivalent Rectangle Duct (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faculty Offices</td>
<td>20</td>
<td>100</td>
<td>180</td>
<td>2</td>
<td>42</td>
<td>4.9”</td>
<td>6” x 3”</td>
</tr>
<tr>
<td>Department Chair’s Office</td>
<td>1</td>
<td>100</td>
<td>300</td>
<td>3</td>
<td>65</td>
<td>4.9”</td>
<td>6” x 3”</td>
</tr>
<tr>
<td>Senior Administration Office</td>
<td>2</td>
<td>100</td>
<td>150</td>
<td>2</td>
<td>40</td>
<td>4.9”</td>
<td>6” x 3”</td>
</tr>
<tr>
<td>Administrative Assistants</td>
<td>4</td>
<td>100</td>
<td>75</td>
<td>1</td>
<td>20</td>
<td>4.9”</td>
<td>6” x 3”</td>
</tr>
<tr>
<td>Faculty Lounge</td>
<td>1</td>
<td>15</td>
<td>1000</td>
<td>25</td>
<td>440</td>
<td>4.9”</td>
<td>6” x 3”</td>
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<tr>
<td>Student offices</td>
<td>20</td>
<td>50</td>
<td>60</td>
<td>2</td>
<td>34</td>
<td>4.9”</td>
<td>6” x 3”</td>
</tr>
<tr>
<td>Auditorium</td>
<td>1</td>
<td>10</td>
<td>3000</td>
<td>300</td>
<td>4654</td>
<td>16.4”</td>
<td>12” x 18”</td>
</tr>
<tr>
<td>Large Classrooms</td>
<td>2</td>
<td>20</td>
<td>800</td>
<td>40</td>
<td>648</td>
<td>8.2”</td>
<td>6” x 9”</td>
</tr>
<tr>
<td>Small Classrooms</td>
<td>4</td>
<td>20</td>
<td>500</td>
<td>25</td>
<td>405</td>
<td>6.6”</td>
<td>6” x 5”</td>
</tr>
<tr>
<td>Seminar Rooms</td>
<td>4</td>
<td>20</td>
<td>200</td>
<td>10</td>
<td>162</td>
<td>4.9”</td>
<td>6” x 3”</td>
</tr>
<tr>
<td>Instructional Labs</td>
<td>2</td>
<td>40</td>
<td>1000</td>
<td>13</td>
<td>262</td>
<td>5.7”</td>
<td>6” x 5”</td>
</tr>
</tbody>
</table>
**Air Handler Type**: VAV with Economizer

**Cooling Type**: Direct Evaporative Cooling

**Size**: 8 x 5 x 18.5 (ft) [(w)x(h)x(l)]

**Capacity**: ~17 Cooling Tons
Distribution Trees
Overhead Mixing

2nd Floor

Vertical Shafts
Supply Air Ducts
Return Air Ducts
Supply Diffusers
Return Diffusers
Distribution Trees
Overhead Mixing

1st Floor

Vertical Shafts
Supply Air Ducts
Return Air Ducts
Supply Diffusers
Return Diffusers

A E MEP CM
Distribution Trees
Overhead Mixing

Ground Floor

Vertical Shafts
Supply Air Ducts
Return Air Ducts
Supply Diffusers
Return Diffusers
Exhaust Heat Recovery

OA → Heat Recovery → RA → SA

Server Room
<table>
<thead>
<tr>
<th>HVAC System</th>
<th>Overhead VAV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Concrete</td>
</tr>
</tbody>
</table>
Distribution Trees

UFAD

2nd Floor

Vertical Shafts

Supply Air Ducts

Swirl VAV Diffuser

Swirl CAV Diffuser

Perimeter Linear

Diffusers with Integrated Heater
Distribution Trees

Ground Floor

- Vertical Shafts
- Supply Air Ducts
- Swirl VAV Diffuser
- Swirl CAV Diffuser
- Perimeter Linear
- Diffusers with Integrated Heater

UFAD
### 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 (kg CO2e)</td>
<td>4,664.724</td>
<td>4,633.177</td>
<td>99%</td>
</tr>
<tr>
<td>Energy (MJ)</td>
<td>163,196.824</td>
<td>113,194.613</td>
<td>68%</td>
</tr>
<tr>
<td>Water (kg H2O)</td>
<td>1,466,958,904</td>
<td>436,978,032</td>
<td>29%</td>
</tr>
<tr>
<td>Ozone (kg CFC11)</td>
<td>-</td>
<td>1.65E-01</td>
<td>-</td>
</tr>
</tbody>
</table>

---

### Sustainable Target Value

**Concrete & Overhead**

**Steel & UFAD**
**Construction Methods**

**Substructure**

All Alternatives:
- No basement
- Excavate to 5 ft., level, install strip footings, square footings
- Cast-in-place slab on grade

**Structure**

Wave Steel:
- Continuous prefab steel columns > beams on columns > lightweight concrete on steel deck > pour and cure topping slab

Wave Concrete:
- Precast concrete columns > corbels > beams on columns > precast concrete slab > pour and cure topping slab
Construction Methods

Slab
Steel Structures:
- Light Weight Concrete on Steel Deck
- UFAD cuts through steel beams

Concrete Structures:
- Hollow Core Slab

All Alternatives:
- 2 in. R.C. Topping for Rigid Diaphragm

Installation Sequence
Wave Steel and Concrete:
- Beams Laid on Continuous Columns, Support Cantilevered Slab
- “Curved” Steel Frame Supported on Beams and Columns, easily installed
### Mobile Crane

<table>
<thead>
<tr>
<th>Model</th>
<th>t</th>
<th>m</th>
<th>kW PS</th>
<th>Standard Option</th>
<th>kW PS</th>
<th>min - max</th>
<th>min - max</th>
<th>max</th>
<th>max</th>
<th>max</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTM 1200-5.1</td>
<td>200</td>
<td>3</td>
<td>370</td>
<td>10 x 6 x 10</td>
<td>145</td>
<td>13.2 - 72</td>
<td>5.4 - 36</td>
<td>101</td>
<td>1.9</td>
<td>80</td>
<td>1.3</td>
</tr>
</tbody>
</table>

**Engine Model**

Cat® C7.1 ACERT™

**Net Flywheel Power**

203.0 hp

**Operating Weight**

64831.0 lb (32 tons)

---

**MATERIAL TRANSFER VEHICLES**

**Radius of 12 feet (4m)**

Eliminates dumping materials on ground and rehandling.

**MASABA SIDE DUMP TRUCK UNLOADER**
Steel Access:
(1) Acroni Steel (Closest, 62.3km, 40min)
(2) Begrad Steel

Concrete Access:
(1) Lafarge Cement (53 min)
(2) Granit DD
(3) Varis Lendava (Prefab Toilet)
**TVD - Wave Steel**

**Estimate:** $8.9 million

**Target:** $9.0 million

---

**ESTIMATE AND TARGET VALUE - SUMMARY**

<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>$8,900,000</td>
<td>$9,000,000</td>
<td>$100,000</td>
</tr>
<tr>
<td>A Substructure</td>
<td>$140,000</td>
<td>$830,000</td>
<td>$690,000</td>
</tr>
<tr>
<td>B Shell</td>
<td>$1,800,000</td>
<td>$1,800,000</td>
<td>$0</td>
</tr>
<tr>
<td>C Interiors</td>
<td>$1,100,000</td>
<td>$1,370,000</td>
<td>$270,000</td>
</tr>
<tr>
<td>D Services</td>
<td>$3,750,000</td>
<td>$2,200,000</td>
<td>$(1,550,000)</td>
</tr>
<tr>
<td>E Equipment and Furnishing</td>
<td>$50,000</td>
<td>$700,000</td>
<td>$650,000</td>
</tr>
<tr>
<td>F Specialty Construction</td>
<td>$350,000</td>
<td>$580,000</td>
<td>$230,000</td>
</tr>
<tr>
<td>G Building Sitework</td>
<td>$350,000</td>
<td>$700,000</td>
<td>$350,000</td>
</tr>
<tr>
<td>H General Conditions</td>
<td>$1,300,000</td>
<td>$700,000</td>
<td>$(600,000)</td>
</tr>
</tbody>
</table>

**Target:** $9.0 million

**Estimate:** $8.9 million
TVD - Wave Concrete

**ESTIMATE AND TARGET VALUE - SUMMARY**

<table>
<thead>
<tr>
<th></th>
<th>ESTIMATED VALUE</th>
<th>TARGET VALUE</th>
<th>VALUE DELTA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL</strong></td>
<td>$8,850,000</td>
<td>$9,000,000</td>
<td>$150,000</td>
</tr>
<tr>
<td>A Substructure</td>
<td>$140,000</td>
<td>$930,000</td>
<td>$790,000</td>
</tr>
<tr>
<td>B Shell</td>
<td>$1,860,000</td>
<td>$1,800,000</td>
<td>$(60,000)</td>
</tr>
<tr>
<td>C Interiors</td>
<td>$1,100,000</td>
<td>$1,270,000</td>
<td>$270,000</td>
</tr>
<tr>
<td>D Services</td>
<td>$3,700,000</td>
<td>$2,200,000</td>
<td>$(1,500,000)</td>
</tr>
<tr>
<td>E Equipment and</td>
<td>$50,000</td>
<td>$700,000</td>
<td>$650,000</td>
</tr>
<tr>
<td>F Specialty</td>
<td>$350,000</td>
<td>$580,000</td>
<td>$230,000</td>
</tr>
<tr>
<td>G Building</td>
<td>$350,000</td>
<td>$700,000</td>
<td>$350,000</td>
</tr>
<tr>
<td>H General</td>
<td>$1,300,000</td>
<td>$700,000</td>
<td>$(600,000)</td>
</tr>
</tbody>
</table>

**COST ESTIMATE - Wave Concrete**

- **G Building Sitework**: $350,000 (4%)
- **F Specialty Construction**: $350,000 (4%)
- **E Equipment and Furnishing**: $50,000 (0%)
- **D Services**: $3,700,000 (42%)
- **H General Conditions**: $1,300,000 (15%)
- **A Substructure**: $140,000 (2%)
- **B Shell**: $1,860,000 (21%)
- **C Interiors**: $1,100,000 (12%)

**Target**: $9.0 million

**Estimate**: $8.9 million

A E MEP CM
Inspirations - Big Idea

Faculty of Biotechnology, Ljubljana

Honeycomb

Beehive
wood composite facade

wood curtain wall
Honeycomb → Modularity → "IDEA" → Connecting - Building → Transportation Limitation

Concept Development
Express

View on Entry Plaza
Motivation:

- Collaborate the beehive idea from the Arch aspect into the structure.
- Take advantage of the honeycomb shape to minimize the amount of structure material to reach minimal weight and minimal material cost without losing the strength.
- Take advantage of the outstanding compression capacity of honeycomb structure to resist gravity load.
- Allows the framework to be pre-fabricated in modules.
- The structure is separated into small modules.
- All modules are pre-fabricated off-site for time efficiency & better quality control.
- Individual Modules are combined on site.
Express Honeycomb in Modules

First Floor Grid Legend

- **Column** - W 14 x 43
- **Beam** - W 14 x 30
- **Brace** - W 8 x 10
- **Composite Slab** - 3” Steel Deck + 2” L.W. Concrete
Honeycomb in Modules

Second Floor Grid

Legend

- **Column** - W 14 x 43
- **Beam** - W 14 x 30
- **Brace** - W 8 x 10
- **Composite Slab**
  - 3” Steel Deck + 2” L.W. Concrete
Lateral Load Path

Moment Frame (Unit: Foot)
Concrete Structure Overview
First Floor Plan

First Floor- Structure System

- Column - 300*300mm
- Shear Wall - 200mm
- Beam - 150*300mm
- Beam - 120*200mm
- PT Slab - 150mm
Gravity Load Path
Lateral Resistance

- **Shear Wall** - 200mm
- **PT Slab** - 150mm
# Energy Analysis

<table>
<thead>
<tr>
<th></th>
<th>Delivered energy</th>
<th>Demand</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>kWh</td>
<td>kWh/m²</td>
</tr>
<tr>
<td>Lighting, facility</td>
<td>7052</td>
<td>7.3</td>
</tr>
<tr>
<td>Electric cooling</td>
<td>30618</td>
<td>31.6</td>
</tr>
<tr>
<td>HVAC aux</td>
<td>28330</td>
<td>29.3</td>
</tr>
<tr>
<td><strong>Total, Facility electric</strong></td>
<td><strong>66000</strong></td>
<td><strong>68.2</strong></td>
</tr>
<tr>
<td>Fuel heating</td>
<td>31549</td>
<td>32.6</td>
</tr>
<tr>
<td>Domestic hot water</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total, Facility fuel</strong></td>
<td><strong>31549</strong></td>
<td><strong>32.6</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>97549</td>
<td>100.8</td>
</tr>
<tr>
<td>Equipment, tenant</td>
<td>21154</td>
<td>21.9</td>
</tr>
<tr>
<td><strong>Total, Tenant electric</strong></td>
<td><strong>21154</strong></td>
<td><strong>21.9</strong></td>
</tr>
<tr>
<td>Grand total</td>
<td>118703</td>
<td>122.6</td>
</tr>
</tbody>
</table>

*heating value*
Distribution Trees

Ground Floor

- Supply Air duct
- Exhaust Air Duct
- Supply diffuser

Displacement Ventilation

- Auditorium 2nd Floor
  - Supply Air duct: 4500 cfm
  - Skipped wall

- Entry

- Inst. lab
  - Air flow 260 cfm

- Small classrooms
  - Air flow 405 cfm
  - Air flow 405 cfm

- Server room
  - Air flow 200 cfm

- Tech support
  - Air flow 200 cfm
**HVAC System**
Displacement Ventilation / Radiant Ceiling for Heating and Cooling

**Structure**
Concrete
Ground Floor

- Supply Air duct
- Return Air Duct
- Supply Air diffuser
- Return Air Diffuser
Floor Sandwich

<table>
<thead>
<tr>
<th>HVAC System</th>
<th>UFAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Steel</td>
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</table>
**Sustainable Target Value**

Concrete & DV

**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>4,654.724</td>
<td>4,202.038</td>
<td>90%</td>
</tr>
<tr>
<td>Energy (MJ)</td>
<td>163,196,824</td>
<td>106,250,690</td>
<td>65%</td>
</tr>
<tr>
<td>Water (kgH2O)</td>
<td>1,466,958.904</td>
<td>435,837,177</td>
<td>30%</td>
</tr>
<tr>
<td>Ozone (kgCFCl3)</td>
<td>-</td>
<td>1,31E-01</td>
<td>-</td>
</tr>
</tbody>
</table>

Steel & UFAD

**Performance Relative to Life Cycle Impact Targets**

<table>
<thead>
<tr>
<th>Impact</th>
<th>Target</th>
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<th>%</th>
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</tr>
<tr>
<td>Ozone (kgCFCl3)</td>
<td>-</td>
<td>1,31E-01</td>
<td>-</td>
</tr>
</tbody>
</table>
### Secondary Systems Decision Matrix

<table>
<thead>
<tr>
<th></th>
<th>Overhead</th>
<th>DV</th>
<th>UFAD</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>9</td>
<td>7</td>
<td>7</td>
<td>0.25</td>
</tr>
<tr>
<td>Constructibility</td>
<td>10</td>
<td>9</td>
<td>6</td>
<td>0.083</td>
</tr>
<tr>
<td>Ceiling Height</td>
<td>9</td>
<td>10</td>
<td>6</td>
<td>0.25</td>
</tr>
<tr>
<td>Comfort</td>
<td>10</td>
<td>7</td>
<td>8</td>
<td>0.17</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>7</td>
<td>10</td>
<td>9</td>
<td>0.25</td>
</tr>
<tr>
<td>Total</td>
<td>8.75</td>
<td>8.67</td>
<td>7.30</td>
<td></td>
</tr>
</tbody>
</table>
All Alternatives:
- Modular Construction
- “Just-In-Time” Delivery
- A/E/C Specially Designed Modules for Beehive

Beehive Steel
- 3 Types of Modular Units
- Prefabricated, Assembled on Site
- Moment Connections

Beehive Concrete
- Modular Concrete Sections
- Prefabricated, Attached on Site
Equipment Selection

Big (but small) modular transporting trucks

ExpressBeehive
Detail, fabricate and deliver steel

Steel, roofing, elevator, plumbing, electric, HVAC

Install temporary power
Install temporary water service
Set up offices

Prepare site—lay down and temporary fencing

Install exterior fire and building fire riser

Erect building batter boards and layout building
# Schedule (Some Key Milestones)

<table>
<thead>
<tr>
<th>Scheduling</th>
<th>Beehive- steel</th>
<th>Honeycomb- Concrete</th>
<th>Wave- steel</th>
<th>Wave- concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start (2019-09-30)</td>
<td>14 days</td>
<td>12 days</td>
<td>16 days</td>
<td>20 days</td>
</tr>
<tr>
<td>Detail/fabricate/deliver</td>
<td>60 days</td>
<td>74 days</td>
<td>94 days</td>
<td>101 days</td>
</tr>
<tr>
<td>Installations on site</td>
<td>13 days</td>
<td>12 days</td>
<td>17 days</td>
<td>18 days</td>
</tr>
<tr>
<td>Foundations</td>
<td>397 hours= 50 days</td>
<td>63 days</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Computer labs</td>
<td>2020-07-16 ready</td>
<td>2020-07-20 ready</td>
<td>Rent</td>
<td>Rent</td>
</tr>
<tr>
<td>Finish</td>
<td>286 days (+14)</td>
<td>307 days</td>
<td>Aug-20</td>
<td>Sep-20</td>
</tr>
<tr>
<td>Approx. Total weeks</td>
<td>38-40 weeks</td>
<td>43-44 weeks</td>
<td>47-49 weeks</td>
<td>50 weeks</td>
</tr>
</tbody>
</table>
EXPRESS BEEHIVE

Cost Estimate - Beehive

COST ESTIMATE - Beehive Steel

- G Building Sitework: $350,000 (4%)
- F Specialty Construction: $250,000 (3%)
- E Equipment and Furnishing: $50,000 (0%)
- D Services: $4,000,000 (42%)
- C Interiors: $1,100,000 (12%)
- B Shell: $2,300,000 (24%)
- A Substructure: $120,000 (1%)

Total: $9.45 million

COST ESTIMATE - Beehive Concrete

- G Building Sitework: $350,000 (4%)
- F Specialty Construction: $700,000 (8%)
- E Equipment and Furnishing: $50,000 (0%)
- D Services: $3,700,000 (40%)
- C Interiors: $1,100,000 (12%)
- B Shell: $2,000,000 (22%)
- A Substructure: $140,000 (1%)

Total: $9.2 million
Cost Estimate Comparison

- **EXPRESS**
- **BEEHIVE**

**COST ESTIMATE - Beehive Steel**
- G Building Sitework: $350,000 (14%)
- H General Conditions: $1,300,000 (4%)
- F Specialty Construction: $250,000 (3%)
- E Equipment and Furnishing: $50,000 (0%)
- D Services: $4,000,000 (42%)
- C Interiors: $1,100,000 (12%)
- B Shell: $2,300,000 (24%)

Total: $9.45 million

**COST ESTIMATE - Beehive Concrete**
- G Building Sitework: $350,000 (13%)
- H General Conditions: $1,200,000 (4%)
- F Specialty Construction: $700,000 (8%)
- E Equipment and Furnishing: $50,000 (0%)
- D Services: $3,700,000 (42%)
- C Interiors: $1,100,000 (12%)
- B Shell: $2,000,000 (22%)

Total: $9.2 million

**COST ESTIMATE - Wave Steel**
- G Building Sitework: $350,000 (16%)
- H General Conditions: $1,400,000 (4%)
- F Specialty Construction: $350,000 (8%)
- E Equipment and Furnishing: $50,000 (0%)
- D Services: $3,750,000 (42%)
- C Interiors: $1,100,000 (12%)
- B Shell: $1,800,000 (20%)

Total: $8.9 million

**COST ESTIMATE - Wave Concrete**
- G Building Sitework: $350,000 (15%)
- H General Conditions: $1,300,000 (2%)
- F Specialty Construction: $350,000 (4%)
- E Equipment and Furnishing: $50,000 (0%)
- D Services: $3,700,000 (42%)
- C Interiors: $1,100,000 (12%)
- B Shell: $1,860,000 (21%)

Total: $8.9 million
## Discussion of Alternatives

<table>
<thead>
<tr>
<th></th>
<th>Wave Steel</th>
<th>Wave Concrete</th>
<th>Beehive Steel</th>
<th>Beehive Concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A</strong></td>
<td>+ Water integration</td>
<td>+ Water challenge</td>
<td>+ Latency challenge</td>
<td>+ Interesting structure and facade</td>
</tr>
<tr>
<td></td>
<td>+ Fluid</td>
<td>+ Fluid</td>
<td>+ Interesting structure and facade</td>
<td>- No flexibility</td>
</tr>
<tr>
<td></td>
<td>+ Open floorplan, views</td>
<td>+ Open</td>
<td>+ Modules reuse</td>
<td>- Latency challenge</td>
</tr>
<tr>
<td></td>
<td>- Hard to establish grid</td>
<td>- Hard to establish grid</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SE</strong></td>
<td>+ Innovative steel design</td>
<td>+ Green concrete</td>
<td>+ Uniformity</td>
<td>+ Green concrete</td>
</tr>
<tr>
<td></td>
<td>- Irregular beam system</td>
<td>+ Light concrete weight</td>
<td>+ Flexibility</td>
<td>+ Light concrete weight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ Long span fewer beams</td>
<td>- Moment connections</td>
<td>+ Long span fewer beams</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ Good for the room layout</td>
<td>- Overdesigned</td>
<td>- Less lateral resistance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Cantilever Challenge</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C</strong></td>
<td>+ Within target values</td>
<td>+ No big modular trucks</td>
<td>+ Finish early</td>
<td>+ Modular concept good</td>
</tr>
<tr>
<td></td>
<td>- Curved components</td>
<td>+ Within target values</td>
<td>- No good spaces in site for trucks</td>
<td>- A lot to handle for fabrication</td>
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<td>- Curved components</td>
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<td><strong>MEP</strong></td>
<td>+ Larger ceiling height</td>
<td>+ Thermal mass</td>
<td>+ More efficient system</td>
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<td>+ More efficient system</td>
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<td>+ More efficient system</td>
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<tr>
<td></td>
<td>- Holes in slab</td>
<td>- Coordination issues</td>
<td>+ Lots of duct work</td>
<td>- Lots of duct work</td>
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<td></td>
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<td>Energy Efficiency</td>
<td>Sustainability</td>
<td>Health</td>
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Wave Concrete Design
Questions? Any advice? Thank You

In may..