The Sustainable Attributes of Portland Cement Concrete

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Sustainable Development

“Development that meets the needs of the present generation without compromising the needs of future generations.”

The World Commission on Environment and Development
Triple Bottom Line

- Social
- Environment
- Economic

- Bearable
- Equitable
- Sustainable
- Viable
Environmental Impacts

- Climate Change
- Indoor Environmental Quality
- Resource Depletion
- Human Health Criteria
- Water Intake
- Human Health-Cancerous
- Ecotoxicity
- Eutrophication
- Habitat Alteration
- Human Health-Noncancerous
- SMOG Formation
- Ozone Depletion
- Acidification

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Measuring Green Infrastructure
Cradle to Cradle Perspective

Material Acquisition
Manufacturing
Construction
Operation
Reuse/Recycling

Life Cycle
Material Acquisition Phase

- Material Acquisition
- Manufacturing
- Construction
- Operation
- Reuse/Recycling
Impact of Extracting Materials

- Extraction of any raw material has impact on the environment
- Natural Resources Canada compared impacts in research study
  - Logging (wood)
  - Iron ore mining (steel)
  - Aggregate quarrying (concrete)
- Extracting aggregate for concrete has lower impact than other materials
## Impact Index

<table>
<thead>
<tr>
<th>Resource Impact Index</th>
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<tbody>
<tr>
<td>1.00</td>
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<tr>
<td>1.50</td>
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<tr>
<td>2.25</td>
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<tr>
<td>2.50</td>
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<tr>
<td>3.25</td>
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</table>

**Concrete**
- Aggregate Quarrying
- Limestone Quarrying

**Steel**
- Iron Ore Mining

**Wood**
- Boreal Timber Harvesting
- Coastal Timber Harvesting

Source: Natural Resources Canada
Logging for Wood

- Disruption per unit of building material is high
- Renewal takes generations
- Stream damage from landslides is common

Source: Natural Resources Canada
Iron Ore Mining for Steel

- Very deep open pit mining
- Mines are rarely restored
- Duration of disruption may be forever

Source: Natural Resources Canada
Aggregate & Limestone Quarrying

- Closely contained and temporary
- Restored within 1 to 2 years
- Most abundant materials on earth

Source: Natural Resources Canada
Carbon Dioxide

- Most materials require little processing
- Low energy of production
- Manufactured and harvested locally
- Low transportation energy
- Contributes to local economy
Does cement manufacturing generate CO\(_2\)?

- As with all industrial processes, cement generates CO\(_2\).
- Made from natural minerals:
  - calcium (60%) from limestone
  - silicon (20%)
  - aluminum (10%)
  - iron (10%)
- Heated in large kiln to 1500° C
- Converts raw materials to clinker
- CO\(_2\) generated from two sources:
  - Fossil fuels in burning process
  - Calcination - calcium carbonate broken down to calcium oxide with release of CO\(_2\)
U.S. Cement CO$_2$ Emissions

Does concrete manufacturing produce CO$_2$?

- Water, sand, stone or gravel and other ingredients make up about 90% of concrete.
- Mining sand and gravel, crushing stone, combining the materials and transportation concrete requires very little energy.
- Emits a relatively small amount of CO$_2$.
- Amounts of CO$_2$ embodied in concrete primarily function of cement content.
- Structures are built with concrete and not cement.
CO$_2$ Reabsorbed by Concrete

- CO$_2$ reabsorbed into concrete through carbonation
- 33% to 57% of CO$_2$ emitted from calcination is reabsorbed through carbonation over 100-year life

How does concrete compare to other building materials?

- Concrete has low energy consumption and CO₂ emissions compared to:
  - Steel
  - Wood
  - Asphalt
Concrete vs. Wood Frame

- Thermal mass systems save energy
- Lower CO2 emissions
- Concrete systems reduced energy by 17%

2x12 (R 38) = 6” ICF

Compared 5-story office building

- Steel frame with light frame exterior walls
- Concrete frame with solid concrete exterior walls

Energy of Production

![Bar chart showing production energy for various materials]

Concrete Frame vs. Steel Frame

- Study compared the CO$_2$ emissions of concrete and steel framed buildings
  - Concrete frame accounted for 550 kg of CO$_2$ per square meter of floor area
  - Steel frame accounted 620 kg of CO$_2$ per square meter of floor area

Concrete vs. Asphalt Pavements

Concrete vs. Asphalt Pavements

<table>
<thead>
<tr>
<th></th>
<th>Results based on driving on concrete vs. asphalt pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum 0.8%</td>
</tr>
<tr>
<td>Fuel Savings (liters)</td>
<td>377,000</td>
</tr>
<tr>
<td>Dollar Savings ($)</td>
<td>338,000</td>
</tr>
<tr>
<td>CO₂ Reductions (t)</td>
<td>1,039</td>
</tr>
</tbody>
</table>
Concrete vs. Asphalt

- LCA on concrete and asphalt roadways
- Construction and maintenance over 50-year life cycle for high volume highway
- Asphalt required 3 times more energy
- Global Warming Potential (CO2 equivalents)
  - Asphalt = 738 t/km
  - Concrete = 674 t/km

What is concrete industry doing?

- Committed to continuous environmental improvement
- P2P Initiative (Prescriptive to Performance Specifications for Concrete)
- The P2P Initiative removes limits on materials
- Allows producers to meet performance requirements
- Minimize environmental impact

www.nrmca.org/P2P
Recycled Industrial Byproducts

- Uses of industrial byproducts
  - Fly ash
  - Blast furnace slag
  - Silica fume
- Supplement a portion cement
- Otherwise end up in landfills
- Called supplementary cementitious materials (SCMs)
- Improves strength and durability
- Reduces CO$_2$ embodied in concrete
  - Typical values 15% to 40%
  - As much as 70%
Construction Phase

Material Acquisition
Manufacturing
Construction
Operation
Reuse/Recycling
Concrete Construction

- Made specifically for each order
- Little to no waste is generated
- Short transport
- No shipping carton or wrapping
- Leftovers
  - landscaping blocks
  - Traffic barriers
Returned Concrete Options

Batch fresh materials
Reship

Paving at plant

Truck wash, batch plant or discharge after treatment

Solids to landfill

Reclamation
Windrow & Crush
Blocks

Settling pond
Operational Phase

Material Acquisition
Manufacturing
Construction
Operation
Reuse/Recycling
Thermal Mass

- Increase thermal lag
  - Off peak demand
  - Lower energy costs
- Lower peak energy
  - Smaller, more efficient HVAC equipment
- Reduce temperature swings
  - Less heating and cooling energy required
High Performance Wall Systems

- Tilt-up Concrete Walls
- Insulating Concrete Forms
- Removable Form Systems
Urban Heat Island Effect

- Residential zones are 3° warmer
- Downtown areas are 7° warmer
- Due to dark-colored roofing and pavement

Source: Lawrence Berkeley National Laboratory
Urban Sprawl

- NASA Thermal Images of Atlanta

1973 1979 1983

Cool Communities

- Use light colored roofing and cladding
- Use light colored pavements
- Landscape shading
- Reduce air temperatures by 5°
- Reduce air conditioning by 18%
Roofing and Cladding

- Concrete roofing and cladding
  - Light colored
  - Highly reflective
- Research shows 40% reduction in cooling energy
Pavement and Landscaping

- Concrete pavement and landscaping
- Article in MIT Technology Review
  - “…blacktopping should be discontinued…”
  - Use light-colored pavements
  - Concrete costs slightly more but has a lower life cycle cost
Concrete Pavement
Reduced Lighting Requirements

- Asphalt requires 24% more poles
- Asphalt costs 24% more
  - Initial costs
  - Maintenance costs
  - Energy costs

Stormwater Management

- Pervious Concrete
  - 15-25% voids
  - Rainwater percolates through the slab
  - Minimizes runoff to surrounding streams and lakes
  - Functions like retention basins
  - Recharges groundwater supplies
Pervious Concrete Applications
### Indoor Air Quality

<table>
<thead>
<tr>
<th>Building Material</th>
<th>VOC Emission (mg/m³h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl flooring</td>
<td>2.3</td>
</tr>
<tr>
<td>Particle board</td>
<td>2.0</td>
</tr>
<tr>
<td>Plywood</td>
<td>1.0</td>
</tr>
<tr>
<td>Acrylic Latex Paint</td>
<td>0.43</td>
</tr>
<tr>
<td>Linoleum</td>
<td>0.22</td>
</tr>
<tr>
<td>Carpet</td>
<td>0.080</td>
</tr>
<tr>
<td>Gypsum board</td>
<td>0.026</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Source: University of Western Ontario
Reduce VOC Emissions

- Use exposed concrete:
  - Decorative floors
  - Textured walls
  - Exposed ceiling
Durability and Versatility

- Most widely used building material
- Extremely durable
  - Doesn’t rot
  - Doesn’t rust
  - Doesn’t burn
- Low maintenance
- 2000 year track record of performance
Reuse/Recycling Phase

Material Acquisition
Manufacturing
Construction
Operation
Reuse/Recycling
Supplementary Cementitious Materials

- **Fly ash**
  - From coal-fired electrical power plants
- **Blast furnace slag**
  - From steel manufacturing
- **Silica Fume**
  - From silicone manufacturing
Key to high performance

- High Performance
  - Improves durability
  - Increases strength
  - Improves constructability

- Environmental Benefits
  - Reduces waste
  - Reduces raw material extraction
  - Reduces energy of production
  - Reduces CO₂
Recycled concrete

- Fills and bases
- Roadways and parking areas
- Driveways and sidewalks
- Shoulders, curbs, gutters
- Landscaping features
- Foundations
- Some Concrete Structures
## Summary

<table>
<thead>
<tr>
<th>Concrete Feature</th>
<th>Environmental Benefit</th>
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<tr>
<td>Most ingredients require little processing</td>
<td>Minimizes energy of production</td>
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<tr>
<td>Most materials harvested and manufactured locally</td>
<td>Minimizes transportation energy</td>
</tr>
<tr>
<td>Building systems combine insulation and thermal mass</td>
<td>Homes and buildings more energy efficient</td>
</tr>
<tr>
<td>Long service life</td>
<td>Minimizes reconstruction, repair and maintenance</td>
</tr>
<tr>
<td>Pavement and exterior cladding are light in color</td>
<td>Minimizes urban heat island effect</td>
</tr>
<tr>
<td>Incorporates recycled industrial byproducts</td>
<td>Reduces the energy required for manufacturing</td>
</tr>
<tr>
<td>Absorbs CO₂ throughout its lifetime through carbonation</td>
<td>Reduces carbon footprint</td>
</tr>
</tbody>
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Thank you

Feel free to contact me with questions or comments at:

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