Between a rock and a hard place: options for reducing the carbon emissions associated with the use of cement and concrete

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Global figures (2010 estimate)

- \((a)\) 40 GT of products
- \((b)\) 37 GT of CO\(_2\)e

<table>
<thead>
<tr>
<th>Material</th>
<th>Per year</th>
<th>A = % of (a)</th>
<th>CO(_2)e / yr</th>
<th>B = % of (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced Concrete</td>
<td>22 GT</td>
<td>56%</td>
<td>3.4 GT</td>
<td>9.1%</td>
</tr>
<tr>
<td>Steel*</td>
<td>0.95 GT</td>
<td>2.4%</td>
<td>3.0 GT</td>
<td>8.1%</td>
</tr>
<tr>
<td>Timber</td>
<td>2.2 GT</td>
<td>5.6%</td>
<td>5.1 GT**</td>
<td>14%**</td>
</tr>
</tbody>
</table>

10% of CO$_2$ emissions
>3,000,000,000,000,000 kg/year

40% energy: 60% CaCO$_3$ $\rightarrow$ CaO + CO$_2$
Options

• Use non-carbonate feedstocks
• Use less concrete for the same function
• Use wastes to replace cement
• Improve processing energy efficiency
• Use existing concrete better
• Keep what we have already made in service longer: longevity*, maintenance and reuse
  – *A (brief) rant: “what have the Romans ever done for us?”
Non-carbonate feedstock

Calcium minerals:
- *Sense of scale: Limestone use for cement* 5000 Mt p.a.
- Gypsum: 263 Mt (5%)
- Fluorite: 6 Mt (0.1%)

Magnesium minerals:
- *Magnesite, dolomite:* >10GT reserves but carbonates
- Talc: 8 Mt (0.2%)
- Carnalite, Brucite: <1 Mt (<0.1%)
- USGS: *Resources from which Mg compounds can be recovered range from large to virtually unlimited [inc] seawater* – but the process requires Ca(OH)$_2$ derived from limestone!

Source: USGS and BGS. Production figures.
Less concrete

Sources for images used as basis for illustrations:
https://fet.uwe.ac.uk/conweb/commercial/armley2.jpg;
https://www.gracesguide.co.uk/File:JD_Manchester_Bridges29.jpg;

Ratio of skilled labour to material prices (tonnes/year):
1830s: 8
2010s: 150

27% less concrete
Using wastes

• PFA
  – 0.7 Gt pa (17%)
  – Coal use being phased out: *less ash*
  – Partial co-firing with biomass and/or refuse-derived fuels (50% at Drax): *low quality ash (chlorides)*
  – Importing PFA: *higher ash prices*

• GGBS
  – 0.4 Gt pa (9%)
  – Move away from basic oxygen furnaces to electric arc furnaces/direct reduction of iron: *less slag, low quality slag (low Si)*
  – Importing slag: *higher slag prices*

Improving process energy

• Average: \( \approx 5 \text{ GJ/t} \)
• Theory: \( \approx 2 \text{ GJ/t} \)
• **Best practice**: \( \approx 3 \text{ GJ/t} \)
• Much closer than aluminium, steel
• Limited scope
  – *Waste heat recovery for urban home heating?*
  – *Using wastes/biomass for fuel?*

Better existing concrete

Reducing slump and using SPs can have as large an effect as using PFA.

Longevity

Longevity

A. Wald, 1943

• Survival bias: the logical error of concentrating on things that made it past some selection process and overlooking those that did not.

B. Fletcher, A History of Architecture (17th Ed)

• Timespan: 300+ years

• Alternate layers of rubble and mortars compressed [p168]

• The important parts of the work were done by skilled craftsmen... the purely mechanical tasks were performed by local slaves [p175]

• Labour to price ratio = 0

https://en.wikipedia.org/wiki/Survivorship_bias; https://pdfs.semanticscholar.org/5dcc/ab070b8f9c5d03e8a0d3a9e92327dbd31c44.pdf
Longevity

- A product of Roman labour economics and statistics applied to prestige buildings made from a different material, not application of arcane knowledge.

Characteristic strength of Roman concretes

Investigator reported in Brune, 2010

<table>
<thead>
<tr>
<th>Investigator</th>
<th>Characteristic Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamprech</td>
<td>6.5</td>
</tr>
<tr>
<td>Ferreti</td>
<td>1.0</td>
</tr>
<tr>
<td>Giavarini</td>
<td>2.5</td>
</tr>
<tr>
<td>Jackson*</td>
<td>13.0</td>
</tr>
</tbody>
</table>

*calculated from point tensile test results

Longevity

Google Ngram – “concrete cancer”

Steel: 12%
Mixed: 9%
Timber: 22%
Unknown: 8%

Steel: 12%
Concrete: 42%
Mixed: 9%
Timber: 22%
Iron: 5%
Masonry: 1%
Unknown: 1%

Data: https://en.wikipedia.org/wiki/List_of_bridge_failures
Maintenance

• “Prevention is cheaper than cure. Waiting for the bridge to collapse is much more expensive than buttressing before it collapses. Deferred maintenance is a debt burden on the next generation.” L. Summers (Harvard)

• “You get a lot of new press for a new project. You don’t get a lot of press for maintaining the HVAC system in the school.” E Glaeser (Harvard)

• The Tyranny of the ribbon

Source: https://www.brookings.edu/blog/up-front/2017/01/31/the-case-for-spending-more-on-infrastructure-maintenance/;
Maintenance

Annual state spending on road expansion versus repair, 2009–2011
All dollar figures in billions.

- $20.4
- $16.5

- 99% of roads
- 1% of roads

Spend £Bn/year (2015/6-2020/1)

- 2.5
- 0.75
- 0.3
- 0.26% of asset valuation

New schemes (127)
Resurfacing programme
Normal maintenance

Reuse

- Recovery of **function and components** not resource and material

• Cast-in-situ concrete has no joints between members.
• Section capacity, component length and connection details usually bespoke.

Deconstruction
• Reclamation of components from existing structures

Adaptive reuse
• Reuse of the basic structure and/or fabric of the building

Design for deconstruction
• Whole life-cycle consideration at planning stage

Design for reuse
• Reuse of components mined from existing structures in new ones

Design for manufacture & assembly
• Design and manufacture of construction products off-site
**Information:** identify value

**Market:** distribute value

**Business models:** exploit value and effect change

Conclusions

<table>
<thead>
<tr>
<th>Reducing CO₂</th>
<th>Upper bound</th>
<th>Optimistic Real? (“expert” est.)</th>
<th>Potential +/-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-carbonate Ca sources</td>
<td>6%</td>
<td>2%</td>
<td>↑</td>
</tr>
<tr>
<td>Structural (shape) optimisation</td>
<td>13%</td>
<td>5%</td>
<td>↑</td>
</tr>
<tr>
<td>Use of pozzolanic wastes</td>
<td>23%</td>
<td>10%</td>
<td>↓</td>
</tr>
<tr>
<td>Energy efficiency (cement manufacture)</td>
<td>24%</td>
<td>16%</td>
<td>~</td>
</tr>
<tr>
<td>Strength (material) optimisation</td>
<td>36%</td>
<td>18%</td>
<td>↑</td>
</tr>
<tr>
<td>Lifespan extension/reuse</td>
<td>90%</td>
<td>50%</td>
<td>↑</td>
</tr>
<tr>
<td><strong>Total (allowing for interactions)</strong></td>
<td>97%</td>
<td>71%</td>
<td></td>
</tr>
</tbody>
</table>

- There is no silver bullet – we must advance on all fronts – but design interventions are more powerful than materials interventions
- Think about how technical factors interact with economic and cultural factors