Innovations in concrete construction: Some past, present and future influences on durability and sustainability

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Concrete - the most extensively used construction material in the world:
About 1m³ per person per year
Global Warming - the Challenge of the 21st Century

Despite being an intrinsically low energy material;

The enormous volume of concrete used means that cement production accounts for 5-8% of global CO₂ emissions

[Concrete values should be a range of estimates]

Source: K Scrivener, Future Cementitious Materials and Durability, International Workshop on the Service Life Aspects of Concrete Structures; 13-14 May 2010, Shenzhen Durability Centre for Civil Engineering, Guangdong, China
World cement production

![Graph showing world cement production with data points for various regions including China, India, and OECD: Other industrial nations.](image)

- **Billions of tonnes of CO₂**
  - 0.65 – 1.0 tonne CO₂ / tonne cement often quoted

Source: K Scrivener, *Future Cementitious Materials and Durability*, International Workshop on the Service Life Aspects of Concrete Structures; 13-14 May 2010, Shenzhen Durability Centre for Civil Engineering, Guangdong, China
Some contemporary challenges
Some contemporary challenges

- Profound changes in the standards for new buildings in response to climate change and related issues

- UK examples of these drivers of change include:
  - UK Climate Change Act: 26% reduction in CO₂ by 2020, 80% by 2050
  - Introduction of *The Code for Sustainable Homes*
  - Ongoing requirement to reduce energy usage – i.e. current evolution in Part L the UK Building Regulations.

  **Zero operational carbon new residential buildings: 2016**
  **Zero operational carbon for other new buildings: 2019**

- There are considerable future implications for both new and existing buildings and the associated building envelope
Aspects of present developments
Some aspects of present developments

• Environmental assessment methodologies (e.g. BREEAM, LEED, etc) – Leave for today

• Incremental change in concrete materials:
  – Ongoing reductions in CO₂ emissions in Portland binder manufacture
  – Greater use of secondary cementitious materials
  – Greater use of recycled aggregates, etc

• Design of lower impact and low / zero operational energy concrete buildings, such as:
  – Housing (e.g. Barratt Green House, Hanson EcoHouse etc)
  – Office buildings (e.g. Tooley Street offices, London etc)
BRE Innovation Park - at BRE site, Garston, UK

- Prototype / exemplar / experimental buildings
- Demonstration of next generation technologies
- Low impact buildings which are intelligent and green
- Relates to strongly to the requirements of the UK Code for Sustainable Homes:
  - Evolving industry response to these goals
  - Wide industry involvement
  - Acts as learning platform
Code for Sustainable Homes - Assessment Categories

- Energy and CO₂ emissions, 36.4%
- Water, 9.0%
- Waste, 6.4%
- Pollution, 2.8%
- Health and well being, 14.0%
- Ecology, 12.0%
- Management, 10.0%
- Materials, 7.2%
- Surface water run off, 2.2%

Current focus on operational energy / CO₂ emissions
Current extent: 10 buildings
Current BRE Innovation Park
Hanson Ecohouse
- Large panellised concrete wall system
Barratt Green House

Has concrete walls (Celcon) with external insulation to achieve a U-value = 0.11 W / m²K.
Manufacturers have adopted different approaches to concrete wall construction.

Large panellised concrete wall system (Hanson EcoHouse) and insulated formwork solutions help reduce problems onsite, reduce waste and to achieve better thermal and / or airtightness performance.
Housing - Other forms of wall construction

Aggregate Industries Enviroblock:
Produced from selected waste raw materials, manufactured in ISO 14001 compliant factories, with up to 50% recycled content.

Ibstock Ecoterre Earth Bricks:
100% recovered clay, dried with 100% recycled heat from the kiln, low carbon footprint, local manufacture – can be used for internal walling
Attention to detail in design is key for high performance building envelopes

Enhancing system behaviour requires consideration of component interactions and ‘buildability’ on site is key to good overall performance
Other forms of construction: Hemp-lime walls

• Need to ensure longevity and performance
• Testing / certification have a role with new products
Learning experiences: BRE Innovation Park

• Numerous companies involved
• BRE publications on learning:
  – Information Papers and reports
  – Describe what went well / what did not
  – Experiences at meeting requirements to Code for Sustainable Homes

• Many visitors to the BRE Innovation Park (600 – 1000 / month)
• Feedback to the next generation of buildings
  – More focus on passive measures (e.g. insulation, etc)
  – Less focus of active measures (e.g. photovoltaics, etc)
The Innovate Green office, Thorpe Park, Leeds, UK
Gained very high BREEAM score
Office does not look particularly green, but the building emits 80% less CO₂ than a typical conventionally air-conditioned office, producing only 22kg of carbon dioxide per m² per year. This equates to a saving of 350 tonnes of CO₂ a year.
Tooley Street, London – the lean office

- Precast concrete soffit panels of 3m x 3m x 50mm were used as permanent formwork with a 300mm post-tensioned slab cast directly onto them
- Storey-height hollow columns were precast off-site to assure quality
- Fair-faced concrete that received no decoration upon completion
- Exposed concrete is used to maximise the efficiency of the ventilation strategy, thereby saving up to 7% of the total building energy consumption
- Achieved BREEAM Very Good rating & Energy Performance Certificate ‘B’ rating
Tooley Street, London – the lean office

Ventilation strategy
Embodied CO\textsubscript{2} of forms of floor construction: Another driver of change and innovation?

Potential difference: 300 tonnes of embodied CO\textsubscript{2} / 1000m\textsuperscript{2} of floor

Specification: Modification of the material specification.
Method: Variability in the calculation of eCO\textsubscript{2} due to estimates and unknowns.

Courtesy: The Concrete Centre
Refurbishment of existing structures: The buildings that exist today will form over 50% of the buildings in 2050

- Big challenges
- Opportunities for innovation

The Stable Block to Bucknalls House (BRE) c. 1850’s
But, what of the future?

Current developments: the now
Future possibilities: the near horizon
the far horizon
Current developments / Future possibilities: The now and the near horizon

- As operation energy / CO₂ usage reduces in buildings etc – there will be an increasing focus on embodied CO₂ of materials

- Developments in contemporary concrete structure design and construction practices can improve durability and sustainability:
  - The role of codes of practice in promoting good practice in service life design and sustainable solutions (e.g. fib Model Code 2010, the CEN and ISO Execution Standards, ISO standards on design for durability, environmental assessment etc)

- Implications for developments in concrete materials include:
  - Further reductions in CO₂ emissions from current Portland binders
  - Use of other binders, such as calcium sulfoaluminate cements, etc
  - Innovative design with new concrete materials
## CO₂ emissions for some UK concrete mixes

<table>
<thead>
<tr>
<th>Concrete type</th>
<th>Description of typical concrete use</th>
<th>ECO₂ (kgCO₂ / m³) for mix</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CEM 1</td>
</tr>
<tr>
<td>GEN 1</td>
<td>Blinding, mass fill, strip footings, mass foundations</td>
<td>170 - 185</td>
</tr>
<tr>
<td>RC30</td>
<td>Reinforced concrete &amp; foundations</td>
<td>320</td>
</tr>
<tr>
<td>RC35</td>
<td>Ground floors</td>
<td>315</td>
</tr>
<tr>
<td>RC40</td>
<td>Structural in-situ floors, superstructure, walls, basements</td>
<td>375</td>
</tr>
<tr>
<td>RC50</td>
<td>Higher strength mix</td>
<td>435</td>
</tr>
</tbody>
</table>

- Other issues to consider – toxicity etc
- Other wider basis of evaluation - Ecopoint values
CO₂ emissions for some other concrete mixes

- Ultra high performance concrete (reactive powder concrete)
- Geopolymer concrete

<table>
<thead>
<tr>
<th></th>
<th>RPC: 1.5% steel fibres</th>
<th>RPC: 2.0% steel fibres</th>
<th>Grade 60: 15% PFA</th>
<th>Grade 40: 15% PFA</th>
<th>Geopolymer: Grades 40 &amp; 60</th>
<th>Strands &amp; Rebar</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 year Global Warming Potential: ECO₂ (kgCO₂ / m³)</td>
<td>2454</td>
<td>2537</td>
<td>985</td>
<td>905</td>
<td>318</td>
<td>34392</td>
</tr>
</tbody>
</table>

Ref: Ng, Voo and Foster: 2010

Note different values to previous slide but relativities here are the point
CO₂ emissions for structures made from various concrete mixes: 40m span bridge

Ref: Ng, Voo and Foster: 2010
CO₂ emissions for structures made from various concrete mixes: 1.5m high retaining wall

Ref: Ng, Voo and Foster: 2010
CO$_2$ emissions for concrete mixes

- London Olympic using sustainable concrete mixes
- GGBS mix (high replacement)
- PFA mix (high replacement)
- Inclusion of silica fume
- Inclusion of metakaolin
- Four powder mixes
- Reactive powder concrete (UHPFRC)
- Geopolymer concrete
- Etc

- Other issues apart from CO2 – toxicity etc
- Ecopoint values

Need more information for better analysis
To maximise sustainability benefits there is a need to target ‘ordinary’ concretes

Concrete grades produced in Europe
[European Ready Mix Concrete Organization, 2009]
Portland cement manufacture

- Manufacturing CO₂ emissions are the sum of various contributions:

\[
\dot{C}_\text{total} = \dot{C}_\text{raw materials} + \dot{C}_\text{fuels} + \{\dot{C}_\text{electric power}\} \text{ etc}
\]

- ≈ 1 tonne CO₂ / tonne cement often quoted; industry best practice data claims ≈ 0.65 tonnes of CO₂ / tonne Portland cement (PC) achieved

- ≈ 0.45 tonnes CO₂ / tonne from decalcination of limestone (chemical CO₂)

- Fuel-derived CO₂ emissions will diminish slowly for economic and other reasons (e.g. burning of shredded waste vehicle tyres)

What about possible replacements of PC?
Reducing “chemical” CO$_2$ in cement

Reducing “chemical” CO$_2$ from decalcination will change the composition of cement therefore its reactions and properties!
Cement substitutes / supplementary cementitious materials

Availability of supplementary cementitious materials

- Metakaolin
- Rice husk ash
- Silica fume
- Burnt shale
- Natural pozzolana
- Blast furnace slag
- Fly ash
- Cement
- Limestone

Source: K Scrivener, *Future Cementitious Materials and Durability*, International Workshop on the Service Life Aspects of Concrete Structures; 13-14 May 2010, Shenzhen Durability Centre for Civil Engineering, Guangdong, China
Activated binder products - High value, low CO₂

Concrete paving slabs and Hardrow® slates made from activated binders (Courtesy of Marshals and CRH)

Research promoting the use of new alkali activated binders in concrete production, reducing carbon dioxide (CO₂) emissions associated with the manufacture of pre-cast concrete products and site mixed concretes through the development of new low CO₂ concretes in which Portland cement is replaced by alkali-activated binders.
Future possibilities – the far horizon?

World cement production

Source: K Scrivener, Future Cementitious Materials and Durability, International Workshop on the Service Life Aspects of Concrete Structures; 13-14 May 2010, Shenzhen Durability Centre for Civil Engineering, Guangdong, China
Possible future sources world cement production
One hypothetical scenario

Source: K Scrivener, Future Cementitious Materials and Durability, International Workshop on the Service Life Aspects of Concrete Structures; 13-14 May 2010, Shenzhen Durability Centre for Civil Engineering, Guangdong, China
Possible CO₂ implications of future sources of world cement production: A hypothetical scenario

![Chart showing possible CO₂ implications of future sources of world cement production.](chart.png)

**Optimistic scenario?**

Perhaps possible to reduce future CO₂.
Possible future sources world cement production
A hypothetical scenario

Source: K Scrivener, *Future Cementitious Materials and Durability*, International Workshop on the Service Life Aspects of Concrete Structures; 13-14 May 2010, Shenzhen Durability Centre for Civil Engineering, Guangdong, China
Possible CO₂ implications of future sources of world cement production: A hypothetical scenario

![Graph showing possible CO₂ implications over time with various sources and scenarios](image)

- Increased clinker substitution
- Others
- Alkali-activated materials
- New substitutes
- Higher strengths
- New clinker
- Portland cement

Perhaps possible to limit future CO₂

Less optimistic scenario?
Summarising

Sustainability may potentially be improved by greater use:

- Current clinker substitutes
- Waste materials as substitutes for clinker and fuel
- Supplementary cementitious materials and alternative clinkers
- Other measures

This could involve:

- A diverse range of cementitious materials
- Adapting concrete composition to locally available materials

The uptake of such developments will require understanding of performance and durability of materials (i.e. test data for users to have confidence in the many potential solutions)
Remembering the lessons from the past
Lessons from the past:
Overall performance of buildings - Many studies

- Paterson study of general building defects (1984)
- Confidential reporting on structural safety - CROSS spotlight on failures (2007)
- Performance of concrete structures and remedial interventions
  - Idorn study of the durability of concrete structures in Denmark (1967)
  - Study by Clark et al on the quality of UK concrete construction (1997)
  - Remedial interventions on concrete structures - CONREPNET (2007)
Lessons from the past: Basic issues

• Design and specification issues / errors
• Detailing issues / errors
• Construction issues / errors [workmanship]

• Important new drivers for buildings
• Climate change issues
• Greatly improved energy efficiency / air tightness
  (Code for Sustainable Homes etc)
How can we remember the lessons from the past as we pursue future innovations and developments in concrete?
Could this be part of the future role of fib?

Basic industry groups / potential fib target audience

- **fib target audience**
  - Top 10 - 15%

- 5%: aware, proactive, forefront adopters

- 20%: followers, but early adopters

- 50%: main bulk, late adopters

- 25%: don’t do anything before it becomes a mandatory (legal) requirement
Concluding remarks:
Concrete - its contribution to sustainable structures

Many areas for development and innovation:

- **Innovative use of concrete to minimise energy (CO$_2$) in use**
- **Structural design with innovative materials to lower CO$_2$ footprint**
- **Low energy cements (new binders and materials) – lower embodied CO$_2$**
- **Use of waste / secondary materials from other sources / industries**
- **Better tools for service life design, sustainability evaluation and whole life costing**
- **Minimisation of waste on site**
- **Re-use of existing assets**
- **Design for deconstruction, etc**
Concluding remarks:
Concrete – A durable and sustainable material

• Sustainability - A multi-faceted objective
• Concrete is a family of materials ( <2N/mm² to >200N/mm² )
• Concrete is a material which has the capability to further improve it’s sustainable performance
• Various material possibilities can be pursued
• New design possibilities will arise

• Need to be mindful of potential implications of changes in durability, as well as in performance and buildability
• Should not forget lessons from the past
Thanks for listening

Questions?

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