Innovation on concrete structures

Miguel Ferreira and Edgar Bohner
VTT Technical Research Centre of Finland Ltd
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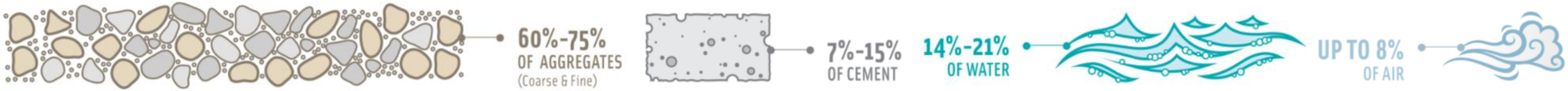
Outline

- What is driving concrete innovation?
- Novel material solutions for concrete
  - New cement chemistries
  - Alternative aggregates
- Special concretes
- Concrete technology – Digitalization
- Concrete construction
- Improved understanding of concrete ageing
- Concrete related EURATOM project – ACES
- Final remarks



What is concrete?

- **Concrete is most used manmade material in the world**
  - More than 7 billion m^3 of concrete are produced every year
  - ≈ 4.1 Gt of cement/year [1] and 4.7 Gt of cement/year by 2050 [2]
- **Why use concrete?**
  - It's mechanical properties, versatility, ease of production, worldwide availability, cost
- **Concrete sustainability**
  - Production of 4.1 Gt of cement/year worldwide → 3.8 Gt of CO_2 released – ≈ 8% of CO_2 emissions worldwide [3] (very energy intensive)
  - The Circularity problem – decoupling the development from consumption of finite resources
  - Durability of existing (and new) concrete structures

Finnsementti, Parainen, (industryhack.com)

[1] www.statista.com/statistics/219343/cement-production-worldwide/ (January 2021) [2] Reaching zero carbon emissions from Cement (2018) Energy Transitions Commission. [3] Lehne, J., & Preston, F., (2018) Making concrete change - Innovation in low-carbon cement and concrete. Chatham House Report, 138p.

What is driving concrete innovation?

- **Legislation & Policy**
  - Advancing the policies of Sustainable Development – Carbon neutrality (carbon-neutral concrete by 2050 pledge [1]), Circular Economy, etc.
- **Improved safety & quality** of concrete structures
  - Digitalisation of materials/process, automated quality control, structural health monitoring, non-destructive testing, …
- **Increase sustainability** – lower carbon footprint
  - Decarbonizing roadmaps, Portland cement replacements
- **Address scarcity of (non-renewable) resources**
  - Increase circularity (e.g. recycled aggregates), upcycling, use of industry waste, etc.
- **Company ethics/strategy and economics**
  - Zero waste concepts, monetization of mineral side streams/waste
  - Marketing, PR

policyoptions.irpp.org/magazines/september-2019/our-move-to-zero-emissions-must-use-nuclear-energy/

[1] https://gccassociation.org/news/concrete-the-worlds-most-widely-used-material-targets-carbon-neutral-future

Novel material solutions for concrete

- **New binder chemistry** [1]**:**
  - Extending the use of SCMs in cement to further reduce Portland clinker content – combined addition of calcined clay, limestone, biomass ashes and natural pozzolan
    - SCMs from 15-25% → 50%; Fillers from 6% → how much?
    - *E.g.: LC^3 has lower creep and delay in shrinkage strains compared to plain cement, resisting chloride ingress and expansion from ASR is outstanding* [2]
  - Belite-ye'elimite-ferrite (BYF) is a Non-Portland clinker – presents substantial CO_2 reductions relative to Portland clinker (but has higher raw materials costs)
  - Alkali-activated binders (AAM) – potential zero-cement composite
    - Requires e.g. BFS but global supplies are limited (as conventional SCMs)

[1] Scrivener, K., (2014) Options for the future of cement. Indian Concrete Journal 88(7):11-21 [2] Scrivener, K., *et al.* (2019) Impacting factors and properties of limestone calcined clay cements (LC^3). Green Materials. 7(1): 3-14

Novel material solutions for concrete

- **Alternative aggregates:**
  - Recycled aggregate from concrete demolition – Upgraded use, smart crushing [1]
  - Use of other waste materials as replacement of aggregate (slag granules, plastic, agroindustry, etc.)
  - Manufacturing artificial aggregates from clay or other mineral deposits (e.g. bottom ash, mining tailings)
- **Circular economy: how to promote circularity ?**
  - Reuse of aggregates well known, but reuse of binders would be big step towards lower CO_2 emissions and industry circularity – separate binder/sand/ rock aggregates for high quality reuse
  - Reuse aspects – design for disassembly, integration of design information and service life engineering through digital technologies (tracking/tracing)
  - Process demolition waste – promote the carbonation of concrete waste

Unground copper slag (BAM)

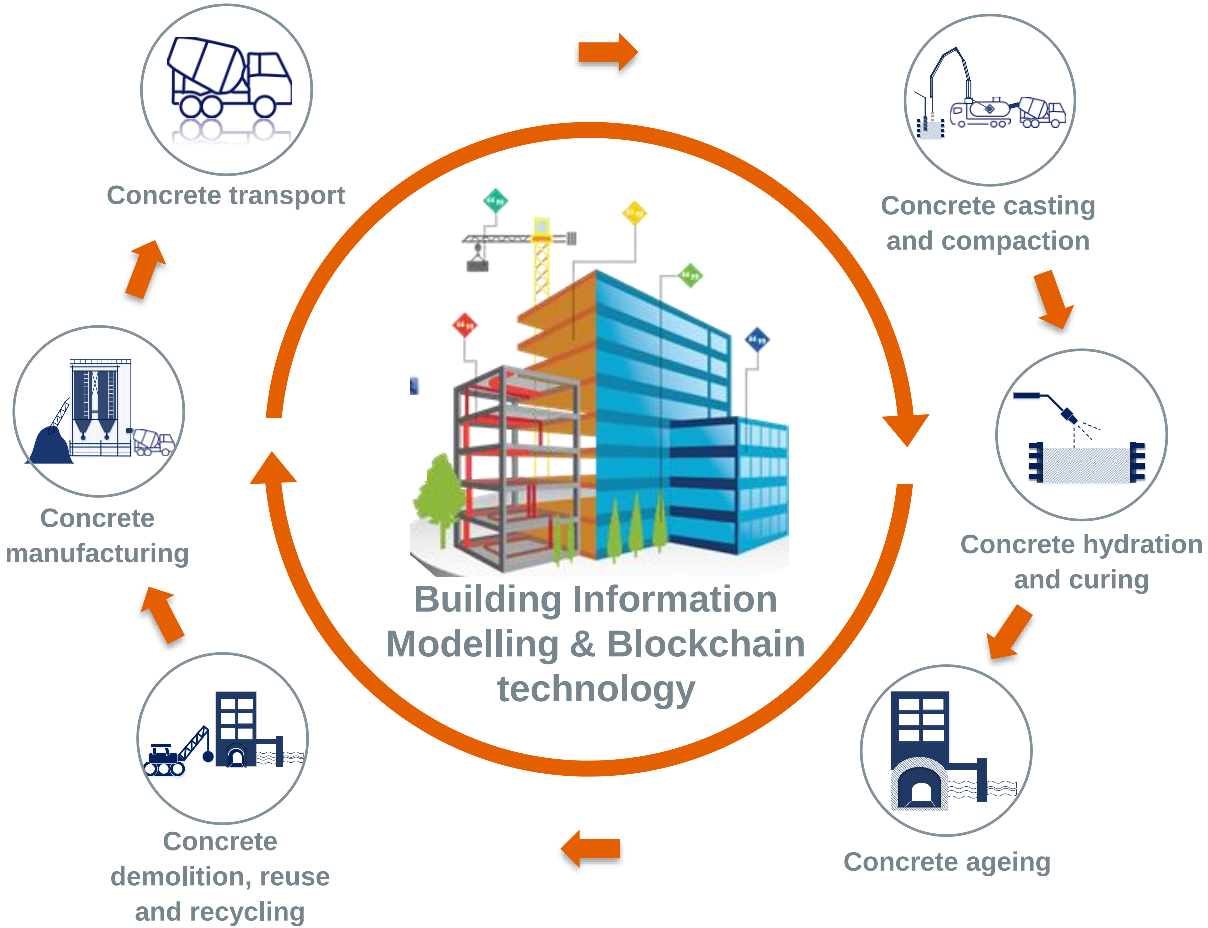
[1] Reaching zero carbon emissions from Cement (2018) Energy Transitions Commission

Special concretes

- **Self-healing concrete** [1] – using microcapsules containing ‘healing’ agents – such as calcium carbonate forming bacteria, super absorption polymers, epoxy, polyurethane, etc. – which can be added to building materials to allow self-repair of small cracks which develop over time
- **Self-sensing concrete** [2] – ability to sense such conditions as stress, strain, cracking and damage, temperature/relative humidity, and store electrical charge – functional fillers (carbon fibre, steel fibre, carbon nanotube, nickel powder, polymer composites, etc.)
- **CO_2 capture** [3, 4] – based on CO_2 mineralization – conversion of gaseous CO_2 into solid mineral carbonates (e.g., $CaCO_3$) within the concrete products – reducing CO_2 footprint
- **Engineered living materials** [5] – microbes to build inert structural materials – desired properties usually found in biological systems: self-power, self-heal, response to biosignals, etc.

[1] HEALCON - https://cordis.europa.eu/project/id/309451/reporting [2] Han, B., Yu, X., Ou, J., (2015) Self-Sensing Concrete in Smart Structures, Butterworth-Heinemann, 398p. [3] www.co2concrete.com [4] www.vttresearch.com/en/about-us/invest-innovation/vtt-launchpad/co2crete [5] www.sciencemag.org/news/2020/02/living-cement-medicine-delivering-biofilms-biologists-remake-material-world

Concrete technology - Digitalization



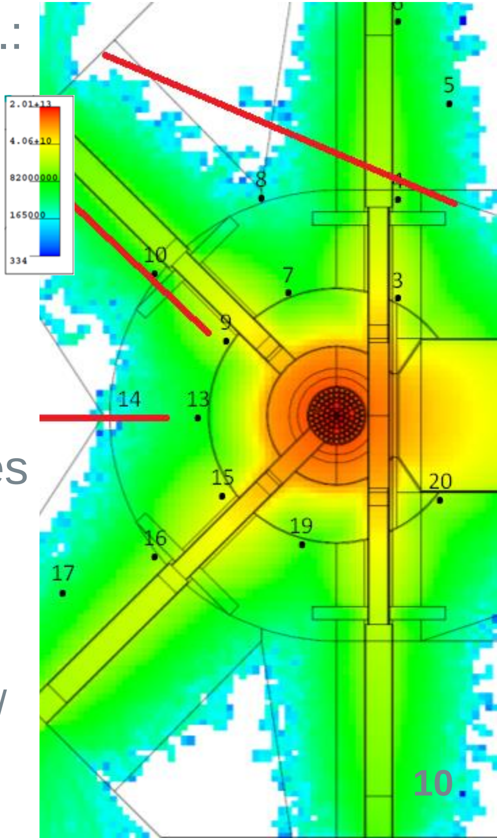
Concrete construction

- **SC modular construction**
  - Continuous steel plates are used on the surfaces of concrete walls/slabs, having both the roles of formwork and tensile reinforcement
  - Used in key buildings, to achieve higher levels of prefabrication and economy (time & money)
  - Several elements of the AP1000 plant design – high potential for SMR design
- **Additive manufacturing (3DP)**
  - Concrete deposited by 3D printer layer by layer without any formwork support and vibration process
  - Previous studies have shown that construction with 3DP technology can reduce 30–60% of construction wastes, 50–80% of labour costs and 50–70% of production time [1]

[1] Zhang, j., et al. (2019) A review of the current progress and application of 3D printed concrete. Composites Part A: Applied Science and Manufacturing. Vol. 125, 105533

Improved understanding of concrete ageing

- Research focused on ”concrete ageing” knowledge gaps, e.g.:
  - Effect of radiation (neutron & gamma) on concrete properties
  - Internal swelling reactions, creep & shrinkage of containment, embedded liner corrosion
- Integrated structural health monitoring systems, that include:
  - Monitoring (e.g. wireless technology), integrated data collection
  - Decision making tools (machine learning/AI data analysis)
- Effective NDE of concrete for unique NPP structural typologies
- Holistic ageing management systems
  - Proactive system that includes planning and monitoring activities during each of the phases in the life of NPP: design, construction, operation (maintenance, inspection and intervention), and demolition/ decommissioning.



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Concrete related EURATOM project – ACES

- **Towards improved Assessment of Safety Performance for LTO of nuclear Civil Engineering Structures (ACES)**
  - **Participants**: Consortium of 11 partners from 7 countries
  - **Duration**: 4 years (September 2020 - August 2024)
  - **Budget**: 5.4 M€ total, of which EC contribution of 3.99 M€
  - **Reply to**: Euratom NFRP 1: Ageing phenomena of components and structures and operational issues (RIA)
  - **Objective:** Advance the assessment of safety performance of NPP safety-critical concrete infrastructure by addressing remaining scientific and technology gaps for safe and LTO
- **End User Group Seminar** (public event) **– 3 March 2021**

Register at: https://www.lyyti.in/ACES_End_User_Seminar_030321

Final remarks

- Currently no clear alternative to structural concrete for new NPPs
- There is innovation – industry support and commitment needed for uptake
- Need for alternative cement and concrete chemistries – including carbon use innovations in the cement, concrete and aggregate value chain
- Uptake of innovations enabling better recycling/reuse of both cement and concrete (upcycling vs. downcycling)
- Need for digital technologies across entire concrete process chain (construction to demolition) → close to error free construction and QC processes
- Development of new construction methodologies/typologies that enhance the economy of the construction process.

beyond
the obvious

Miguel Ferreira & Edgar Bohner
miguel.ferreira@vtt.fi & edgar.bohner@vtt.fi
+358 401 380 546 & +358 401 969 081