A CONCRETE EDUCATION: FUTUREPROOFING FOR THE DIGITAL WORLD

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ABSTRACT. Concrete technology is arguable at a cross roads with regards to education and research. As the construction industry embraces the digital world, engineers, scientists and educators must look towards how concrete will develop as a material and how it can adapt to fit with rapid advances. Design, specification and construction techniques are being informed by such developments as Building Information Modelling and the use of Artificial Intelligence and Big Data and within these digital realms, concrete will play a vital part in future. The unique nature of concrete as a construction material compared to its competitors mean that the fundamentals still need to be taught through traditional education programmes and continuing professional development events but research and innovation needs to engage more with the engineering community to ensure we are all future proofed for the digital world.

Keywords: Education, Building Information Modelling, Artificial Intelligence, Big Data

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INTRODUCTION

Concrete is arguably facing its biggest challenge as the world's primary construction material. Ensuring that the material is fit for purpose in terms of the range of demands that continue to be placed on concrete is one such challenge, however, as the construction industry moves to embrace radical changes in digital technology, concrete and its users must also keep pace and adapt thought processes and use novel education methods to ensure that we continue to exploit the inherent properties of the constituent materials (in particular cements, both Portland and non-Portland) and concrete as a composite material to meet future performance demands (strength, durability) and energy requirements (including sustainability). The synergy between research and application is now even more important as digital technologies such as Building Information Modelling (BIM), Big Data and Artificial Intelligence (AI) drive other industries forward and education and the construction industry must work together to ensure that they are *driving* advancements, not *being driven by* advancements. However, we continue to need a range of options for concrete, not all of which will be at the higher technological end of the scale [1].

Education, training and research in construction materials remains a core element in many degree programmes across the world at both undergraduate and postgraduate level however it is now crucial that current education in concrete technology not only deals with understanding the fundamentals of what is a very complex, technologically dynamic construction material, but also recognises the role in which the digital environment is changing the way engineers design and build, supply chains plan and deliver and most importantly clients develop briefs for projects. Whilst it is recognised that engineering in its broadest sense is being driven by advances in digital design and sustainability, concrete technology must continue to develop but in order to do so, engineers must understand the fundamentals and dispel the many myths surrounding the material.

This paper aims to highlight some important considerations for concrete technology education, which is at somewhat of a crossroads. Although many education programmes exist globally, in further education, and higher education institutions and through continuing professional development (CPD) programmes delivered by professional bodies (eg the Institute of Concrete Technology in the UK, Indian Concrete Society, American Concrete Institute), advancements in digital technology within the construction industry mean that educational programmes must evolve to ensure that whilst basic knowledge of concrete technology is important, we must embrace concrete's role within the digital era.

THE IMPORTANCE OF CONCRETE AS A CORE SUBJECT FOR EDUCATION

Concrete technology forms a fundamental materials science and design thread through many undergraduate civil and structural degree programmes across the world. However, the way engineers and architects design and construct buildings and infrastructure is changing rapidly in the digital era. Increasing pressures are being placed on engineers to not only consider traditional parameters such as strength, durability and cost, but other parameters such as sustainability (including specifying non-traditional constituents), structural efficiency (including light-weighting of structural elements) and maximising other concrete characteristics (e.g. thermal mass). In order to take full cognisance of influencing factors, it is vital that engineers must have a competent understanding of how "traditional" concrete functions to enable them to modify and adapt the material accordingly. This forms the basis for many early year's civil engineering materials modules at Universities and is often the basis for many CPD programmes delivered to those within the construction industry.

Dispelling the Myths and Mysteries of Concrete

Whilst understanding the basics of concrete technology, many misunderstandings and mysteries and myths which surround concrete have arisen over the years. An unnamed major concrete producer was recently seen advertising concrete that "dries out quicker" to allow rapid construction which in the author's mind would appear to be promoting not having to provide moist curing (or any form of curing membrane), going against the very basis of how hydraulic materials work at a fundamental level! Whilst it is recognised that curing can be a time consuming and costly part of the construction process, those with a basic understanding of how the constituent materials work, recognise that it is absolutely necessary to enable the concrete to achieve not only its desired strength and engineering properties, but also its durability and sustainability potential.

The Concrete Society UK have recently published a series of short "Concrete Myths" to help dispel some of these misunderstanding, backed up by research and field evidence. These are very useful nuggets of information which can be utilised by both students and experienced engineers alike to ensure that they have a fully grounded understanding of the basics of concrete technology.

Some recent examples from 2017-18 are:

- *"Concrete has no tensile strength – and it plays no part in design"* [2]
- *"Concrete can't be too strong"* [3]
- *"Chlorinated water can lead to chloride-induced corrosion of reinforcement"* [4]
- *"You can't have too much cover to your reinforcement"* [5]

Standards and Specification: The Perils of Execution and Workmanship

Concrete is one of an ever expanding range of construction materials which are currently used by the construction industry. It not only competes with materials such as steel, timber and composite, but compliments these by often working in tandem both structural, aesthetic, economic and environmental purposes. Whilst it is argued that the basics of construction material knowledge is often grouped together for good reasons (eg in understanding the mechanics and strength of materials, it is useful to compare relationships between different types of materials), it can be argued that concrete is a very different beast when we look beyond the basics of mechanical behaviour.

Concrete is a material which can be manufactured offsite or onsite and hence is often at the mercy of those executing the work. This is often seen in the case of concrete durability for example. Whilst durability provisions lie within structural codes for many countries, standards have been developed around the world for dealing solely with specifying materials to ensure concrete durability e.g. EN 206-1 [6] across Europe and associated national standards (eg BS 8500 [7], DIN 1045-2 [8]) or ACI 201.2R-16 [9] in the USA. This single facet of concrete technology highlights the importance of knowledge and education and indeed is further evidenced by the fact that standards for *Execution of Concrete Structures* now also exist (eg ISO 22966 [10], EN 13670 [11]). Table 1 shows some of the key parts of the standard and again stresses the need for education of the basics of concrete technology for all involved in all parts of the construction process.

Table 1 Summary contents of EN 13670 Execution of Concrete Structures

TOPIC	COVERAGE
Execution Management	Documentation, Execution specification, Quality Plan and Management, Execution Classes, Inspection and Non-conformity
Falsework and Formwork	Release Agents, Design and Installation, Inserts and Embedded Components, Removal
Reinforcement	Materials, Bending and Cutting, Transportation and Storage
Prestressing	Post tensioning Systems, Sheaths, Anchorage, Tendon Supports, Grouts, Installation, Pretensioned Tendons, Grouting Operations.
Concreteing	Specification, Pre-concrete operations, Delivery, Reception and Site Transportation, Placing and Compaction, Curing, Post Concrete Operations, Surface Finishes.
Execution of Precast Elements	Factory and Site Manufactured Elements, Handling and Storage, Placing, Compaction, Curing.
Geometrical Tolerances	Bases, Columns, Walls, Beams, Slabs, Surfaces and Edges, Holes and Inserts

Within many education establishments at degree level, more specialist concrete technology knowledge such as durability is often left to the postgraduate curriculum. This further highlights and pedagogical problem for construction related education such as civil and structural engineering programmes. Rapid developments in technology mean that pressures are placed on educators to deliver a wider range of subjects and as such, many are now being seen as “specialist”. There is a danger that education is trying to shoehorn in many subjects which may appear to be attractive to students at the expense of basic knowledge which is still required. In the UK there are currently only three Master’s programmes which have the word *Concrete* in their title:

- Structural Engineering and Concrete Materials (University of Dundee)
- Advanced Concrete Technology (University of Leeds)
- Concrete Structures (Imperial College London)

Many other civil engineering related degree programmes encompass concrete as part of the wider programme, however there remains a danger that concrete will increasingly be seen as just another construction material without the real need for any specialist education. Professional bodies also recognise the need for a solid educational base for those working the field of concrete technology or projects that have a strong concrete theme. For example in the UK, the Institute of Concrete Technology (ICT) has accredited a number of Certificate and Diploma level qualifications. Certificate qualifications cover important subjects such as Concrete Practice, General Principles and Practical Applications whilst the Advanced

Concrete Technology (ACT) as now a globally accepted qualification in concrete technology and covers materials, concrete properties, testing, QA, repair and maintenance.

The Role of Concrete Technology Research in Education

Research also continues to play a vital role in ensuring that advances in education are transferred to those who will use it most. Whilst numerical modelling remains important, physical modelling of concrete is a vital research area which is under pressure across many research institutions and education establishments due to laboratory space constraints however, it is vital that students are exposed to hands on experience of such vital basics as mixing, casting compacting and curing of concrete, as well as testing mechanical properties such as compressive and tensile strength, creep, E-value and shrinkage. Laboratory spaces are key for teaching as well as research and are important when dealing with more specialist areas of concrete technology such as durability testing, repair and maintenance and comparative structural performance of constituent materials. Research projects undertaken by undergraduate and postgraduate students are often where the seeds of future developments are sewn by researchers (e.g. photocatalytic concrete, marine concrete for wave energy convertors, additive manufactured high fibre content concrete) but also allows students to explore their limits of material knowledge within a physical and/or numerical modelling environment.

CONCRETE IN THE DIGITAL ERA

Advancements in digitisation in the construction industry are manifold and can be seen primarily through developments in design techniques (eg advanced finite element modelling) or robotic construction (eg 3D printing of concrete structures). However, important developments in design and management software along with the creation of vast amounts of data is an area of importance for concrete technology.

Concrete and Building Information Modelling: 3D and beyond

Concrete technology education must continue to draw upon both academic research as well as industry experience to ensure that next generation of material scientists and engineers continue to develop concrete as a cost effective, durable, sustainable construction material. Advancements in design software now focus on building information modelling (BIM) to provide an integrated approach to construction projects. BIM has the potential to allow full collaboration on projects from the client right through to the supply chain and enable designers to work closely with contractors and suppliers to ensure the client’s needs are fully met. Figure 1 shows the various dimensions being considered by BIM software and the construction industry.

At this stage, BIM 4D is reasonable commonly used in many construction projects across Europe however, beyond 4D, the confidence in utilising software to provide reliable management of economics, facilities management and lifecycle analysis is still low.

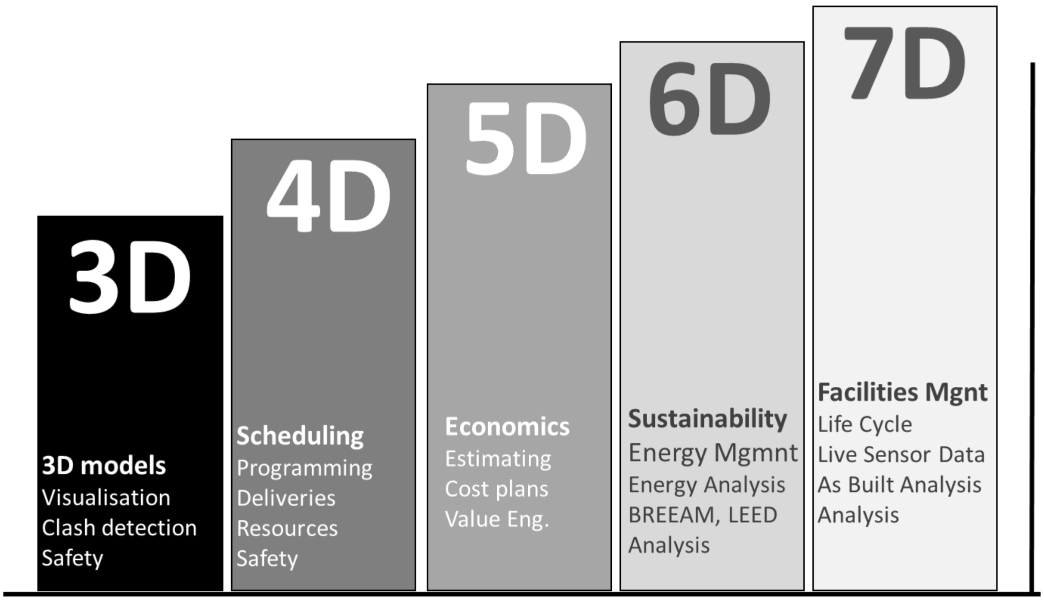

Figure 1 Current dimensions of BIM

The correct utilisation of BIM software is particularly important in terms of meeting the design brief (and associated requirements such as constituent materials specified, meeting standards and specifications, economics) but is now developing rapidly to encompass the performance of buildings and structures (6D BIM) and the life cycle assessment (7D BIM) 6D and 7D BIM have huge implications for concrete as a construction material given its excellent potential for encompassing a range of recycled materials and contributing to other performance requirements such as energy usage through exploiting thermal mass.

The link between physical and numerical modelling of concrete now becomes critical as this can allow the development of durability performance models as well as reliable input parameters to create and validate such models. The importance of BIM in construction is highlighted by the recent withdrawal of PAS 1192-2 [11] and publication of two ISO standards to replace this:

- ISO 19650-1 Organization of information about construction works - Information management using building information modelling. Part 1: Concepts and principles [12]

- ISO 19650-2 Organization of information about construction works - Information management using building information modelling. Part 2: Delivery phase of assets [13]

Whilst these documents are primarily to help industry align with BIM principles, the documents are a sign that digital models now embedded within the industry however there is much work to do on further BIM dimensions (4D and beyond) in which concrete will have a vital role to play.

Utilising Big Data in Concrete Construction

As the construction industry strives to streamline its processes and become more productive and efficient, it is now looking towards the use of big data as a means to achieve this. As data produced by the construction industry is expected to increase exponentially in the coming years, making sense and capitalising on the data is a huge task. Within the niche of the concrete construction industry, big data could be used by both concrete producers, designers and contractors. Whilst the benefits of analysing an using big data is likely to be focussed on key areas such as predicting risk and solving problems, within the concrete construction industry it may be used for the following:

- Resource demand
- Generative design
- Clash detection and resolution
- Durability performance modelling
- Energy and sustainability performance modelling
- Design for smart concrete

Work is ongoing to utilise big data for resource demand in concrete construction. For example, Shanks et al [14] focussed on cement demand data for applications within concrete construction to determine whether the industry is using cement in an efficient way within typical construction products. Figure 2 shows that there is potential for minimising resource demand in certain types of construction element, based on big data analysis from existing structures.

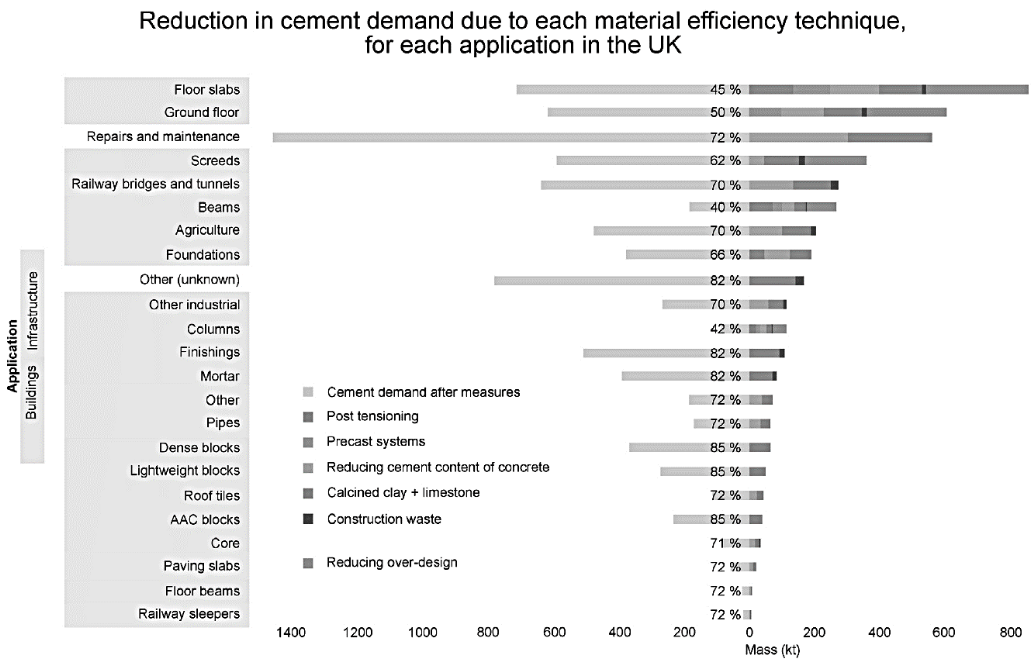

Figure 2 Results of the material efficiency analysis

Figure 2 Results of the material efficiency analysis ranked by the absolute demand reduction possible (grey bars and percentages on the left show absolute and proportional cement demand remaining, the shaded bars on the right represent demand reduction due to each of these techniques. The total length of the bars represents the current demand for demand for cement from each application.

Artificial Intelligence

Artificial intelligence is often closely linked with the utilisation of big data and is often seen as the output from the processing of big data sets. There are a few early-stage examples construction firms can evaluate:

- Project schedule optimizers can consider millions of alternatives for project delivery and continuously enhance overall project planning.
- Image recognition and classification can assess video data collected on work sites to identify unsafe worker behaviour and aggregate this data to inform future training and education priorities.
- Enhanced analytics platforms can collect and analyze data from sensors to understand signals and patterns to deploy real-time solutions, cut costs, prioritize preventative maintenance, and prevent unplanned downtime

However, the construction industry (and interestingly education) is still some way behind in adopting AI as shown in Figure 3 compared to other industries which are investing heavily in AI (eg the financial sector and telecoms).

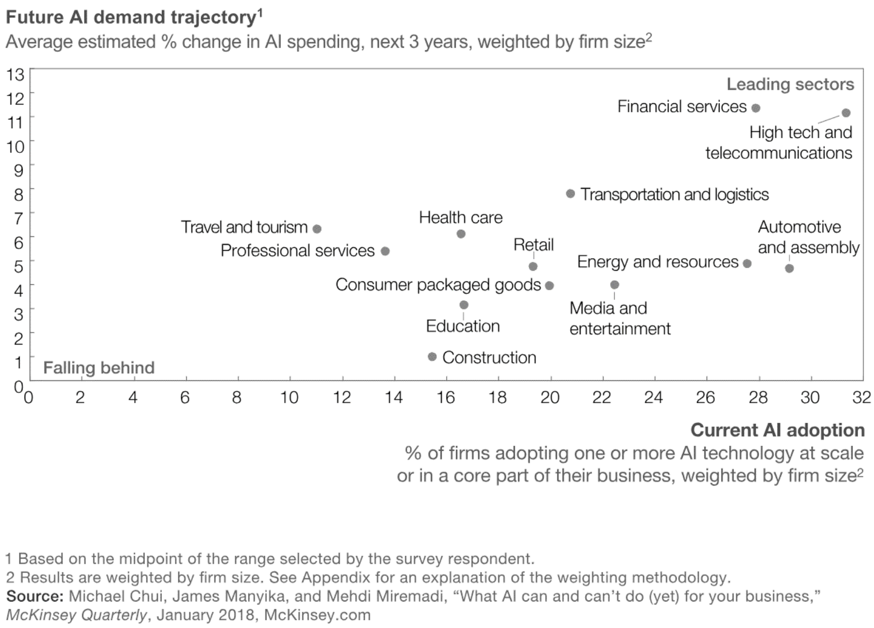

Figure 3 Comparison of estimated spend on AI across various industry sectors [15]

The research does however highlight industries using AI which could transfer techniques across to the concrete construction industry including:

- **Transportation** route optimization algorithms for project planning optimization;
- **Pharmaceutical** outcomes prediction for constructability issues;
- **Retail** supply chain optimization for materials and inventory management;
- **Robotics** for modular or prefabrication construction and 3-D printing;
- **Healthcare** image recognition for risk and safety management.

INDUSTRY INTERACTION: THE VITAL LINK

A strong relationship with the construction industry is vital for any educational programme to ensure that concrete technology topics remain relevant within degree programmes and graduates are industry-ready in terms of their knowledge and skills. Many of the topics mentioned in this paper are being delivered across University programmes but in conjunction with industry experts including designers, contractors and standards writers. In addition, degree programmes are now incorporating work-based learning into programmes which allow those in employment to undertake educational programmes part time and utilise their work experience in the classroom. These links with industry at the undergraduate and postgraduate level are becoming invaluable as it provides feedback into the degree programme regarding the level of concrete technology being delivered whilst helping to steer the direction in which it is heading.

Perhaps the most significant input and opportunity for interaction with industry is through Master's and PhD research projects. Students benefit from industry colleagues identifying contemporary issues affecting practice. Such projects have ranged from durability, recycling of by-products and demolition arising through to designing offshore wave energy convertors. The input of practicing engineers greatly enhances the development of these projects and the provision of data and advice that not in the public domain bring a rich depth to the work. In the UK, one good example of brokering this kind of arrangement is evident through the Construction Scotland Innovation Centre (http://www.cs-ic.org/) which works with the construction industry to identify real life problems which may be suitable for Masters and PhD students to examine.

THE FUTURE: CONCRETE IN THE DIGITAL LOW CARBON ERA

The continued drive towards more ambitious uses of construction materials means that concrete has to evolve rapidly. Advances in digital modelling and design, 3D additive manufacturing techniques and the use of smart materials has meant that traditional design and construction processes using concrete continue to be challenged and the material is under increasing pressure from other materials such as composites, lightweight steels and timber. Whilst an understanding of the fundamentals of the material continues to be important, "Futurecrete" will play a vital role in the education base of concrete designers, specifiers and producers alike. Whilst it is heartening to see a variety of concrete training courses available across the globe, there is still more to do to ensure concrete continues to be a vital core subject in the education of civil/structural engineers and material scientists and ensure that graduates are "workplace ready" for the multi-skilled 21st century construction industry.

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