John Orr

Developing new tools to help structural engineers make more efficient use of materials – and persuading them why they must do so – are key themes for Cambridge academic **Dr John Orr**. He talks to Helena Russell about his research and plans for the future.

WITH HIS CLEAR FOCUS ON practical outcomes, Dr John Orr is proof that a high-flying career in academia no longer breeds a lofty attitude towards the realities of frontline construction.

The range and extent of Orr's achievements in just 13 years since graduating is impressive; co-author of two books with practical guidance on embodied carbon, leader of a series of research projects focusing on automation of construction processes to optimise concrete use, and an active figure in the carbon reduction agenda.

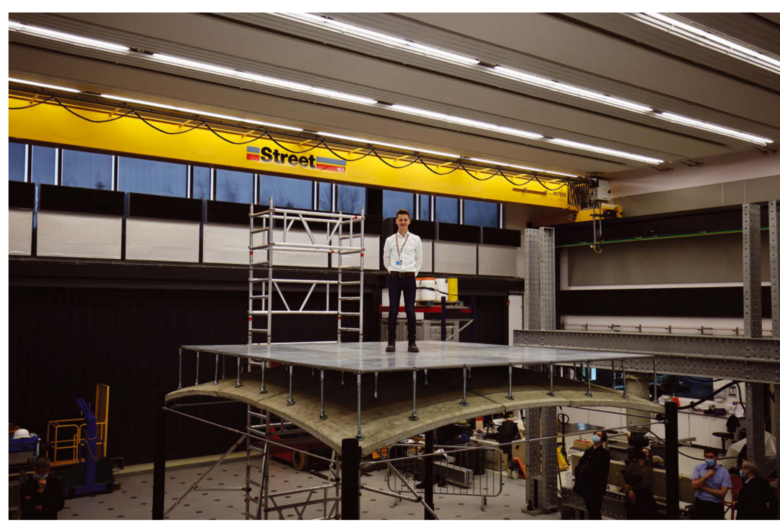
Blurring the lines

Orr's route into civil engineering was relatively conventional; he cites the classic childhood pursuit of playing with Lego, though recalls that he also played with dolls as a result of having two older sisters. Studying design technology cemented his pleasure in the process of designing and making, and gave him the arts fix that he craved to balance the maths that he admits was never his great passion. This blend of art and science has remained a thread through his life ever since, Orr notes.

Although he can't recall what first prompted him to consider engineering, he knew that he'd found his fit at the University of Bath, where civil engineering and architecture are taught in a combined degree. 'It really spoke to me in a way that maybe a pure engineering degree wouldn't have,' he says.

Orr explains that the distinction between the two disciplines is deliberately blurred at Bath, an approach he strongly supports, shunning the architect/engineer label in favour of 'designer'. 'If you are going to be a great architect, you need to understand the engineering, and the construction process,' he says, 'just as to be a great engineer, you need to understand how people use a space, and how spaces work together. For me, the people historically who built great structures would be the likes of Pier Luigi Nervi and Eladio Dieste; they were the contractor, the engineer and the architect and built fantastic structures.'

↑FIGURE 1: Underside view of ACORN segmented thin-shell concrete floor prototype



↑FIGURE 2: John Orr atop ACORN prototype structure

Flexible working

After graduating, Orr was awarded PhD funding to work with Professor Tim Ibell at Bath to investigate the concept of flexible formwork and its potential for optimising concrete use – allowing design to move away from regular beam and column elements to highly optimised structural shapes. The subject piqued his interest so much that he turned down a job offer at Arup in order to pursue it. 'I had already worked on

↑FIGURE 3: Robotic cell for fabricating concrete components on adjustable mould

placements at WhitbyBird, Ramboll, Taylor Woodrow and others; I felt that I had gained a certain amount of design and site experience, so I decided to do the research instead.'

A job opening came up for an assistant professor in the Civil Engineering and Architecture department at Bath in 2013, soon after Orr finished his PhD, and for the next four years he taught and led research at his alma mater. In 2017, he was appointed Assistant Professor in Concrete Structures at the University of Cambridge, and moved his research team to Cambridge to continue work in optimisation.

One of Orr's first research grants at Bath was to investigate whether granulated plastic could be used as a replacement for a proportion of the sand in concrete. The work sought to establish whether such concrete had the same structural properties. 'There was a black market in illegally dredged sand in India due to the huge demand for it,' Orr recalls. 'But while this solution would divert waste plastic temporarily, you would still have the same problem once the concrete reached the end of its life. The initial aim to use less sand led onto looking at using less concrete. This idea about reducing material is a key point of my research,' he says.

Concrete plans

In 2015, Orr was awarded an early career fellowship in structural engineering by the Engineering and Physical Sciences Research Council (EPSRC). This scheme provides five years of funding to a young academic, to enable them to establish a team of researchers and pursue a particular line of enquiry, taking it with them if they move jobs. It was a huge boost, he recalls; his theme was computational modelling of concrete, and how it could be developed and exploited in the optimisation of structural elements.

His first major grant was for research linked to his PhD, which had developed highly-optimised concrete shapes; the challenge he now took on was to find a way to automate creation of reinforcement to suit these curved elements.

Orr developed a machine that could wind carbon or glass-fibre strands around an arrangement of carbon-fibre bars, to suit the shape of the concrete element. This led him to think about whether the concrete casting process might be automated too – a train of thought he subsequently pursued at Cambridge, working with the Universities of Bath and Dundee on the Automating Concrete Construction (ACORN) project, which finished in March 2022 **(Figures 1 and 2)**.

This work focused on developing a shell structure to replace the material-intensive slab design that is traditionally used for floor construction, combining Orr's fascination for shell structures with his desire to have a serious impact on concrete use. 'Shell structures were more popular when materials were in short supply; now we need to go back to them as a way of dramatically

CAREER MILESTONES

2009	MEng (Hons) in Civil Engineering (First Class), University of Bath
2010	IStructE Henry Adams Award 2010 for research on concrete design
2011	IStructE Henry Adams Award 2011 for innovation in construction
2012	PhD in Civil Engineering, University of Bath. Flexible formwork for concrete structures. Sponsored by Atkins
2013–2015	Consultant to Atkins
2013–2017	Assistant Professor and Director of Research, University of Bath
2015	Awarded ESPRC Early Career Fellowship in Structural Engineering
2015–2017	Consultant to OPS Structures
2017	University Assistant professor in Concrete Structures, University of Cambridge
2018	Official Fellow, Magdalene College Cambridge
2018	Elsevier Atlas Award for Impactful Research on Sustainable Uses for Excess Plastic Waste
2019	IStructE Oscar Faber Award for Best Presentation of the Year for Research in Robotically Formed Carbon Fibre
2020	Elected to the IStructE Council for a three-year term
2022	Professor of Structural Engineering, University of Cambridge

←FIGURE 4: Optimised flexibly formed beam cast in fabric mould – reducing concrete use

reducing the amount of concrete, and more specifically Portland cement, that we use,' Orr suggests.

The project explored how shells for a typical 8m² grid could be created from nine elements, each cast separately using a robotic concrete-spraying machine over a bed that was adjusted to the appropriate shape using actuators beneath it **(Figure 3)**.

Moving on post-Covid

Unfortunately, the plan to build a large-scale, two-bay prototype at BRE had to be ditched when the Covid-19 pandemic hit, closing access to the lab for nine months and delaying deliveries of equipment. 'We ended up building a scaled-down prototype in the lab in Cambridge instead,' Orr says. 'It had a 4.5m span between columns, 20m² enclosed space and floor structure on top for testing. But we showed that it was feasible to build it, we did the carbon calculations and worked out the savings, and more importantly we tested it. Validating our models was very important,' he adds.

Some of the knowledge and achievements from ACORN will feed into Orr's next research project which starts in September, funded by EPSRC under the theme of sustainable manufacturing. This three-year project, in collaboration with materials experts from the University of Exeter, will examine the potential of auxetic materials for use in concrete construction.

Auxetic refers to materials woven in such a way that they have a negative Poisson's ratio – when stretched they get wider rather than narrower. 'We are going to trial the material as both formwork and reinforcement,' Orr says; the aim being to simplify material use and also create a more durable concrete by having porous fabric as formwork. The work will start with simple hollow elements, combined with lower-carbon concrete mixes; if successful, attention will turn to slabs or 3D elements **(Figure 4)**.

Cutting embodied carbon

In some cases, the results of Orr's research continue to generate interest, as with the two-year Minimising Energy in Construction (MEICON) project, an extensive survey of structural engineers and how their behaviour matched up with carbon-reduction aspirations.

Most of those surveyed said that they wanted to do the right thing in terms of cutting embodied carbon, but the pressures of commercial life – the time and money available, worries about how well buildings would be constructed, the risk of something going wrong on site and so on – result in buildings that are structurally inefficient. 'It's not a technical problem, it's a cultural one,' Orr says.

'We put forward suggestions for simple things people could do; immediate changes in behaviour can make a lot of difference even if they are small,' he adds. 'For example, if you don't have the stomach to go up to a 100% utilisation of capacity, try 90% instead – it will still make a difference.'

This research fed into *Design for zero* which Orr co-authored with Margaret Cooke, Tim Ibell, Claire Smith and Natasha Watson and which was published last year by IStructE. The book challenges overdesign, explaining why it is prevalent, and the impact it has on material consumption and CO_2 emissions. 'It states you should make 'form follows availability' your mantra,' explains Orr. 'Ideally, you should look at what materials are available from deconstructed buildings and work out how you can use those elements to build what you want.' Importantly, the publication includes real-life case studies that demonstrate successful reduction of carbon, highlighting scenarios that designers are likely to encounter.

Orr also co-authored the IStructE's *How to calculate embodied carbon* guide with Orlando Gibbons, the second edition of which was published in March this year. 'Before we put this together, we didn't have an agreed methodology for counting embodied carbon in structural engineering, which makes it hard to compare designs,' he says. The book provides a standard method that everyone can follow. Another crucial aspect of this initiative is the Built Environment Carbon Database, which Orr is advising on. When it launches, everyone will be able to report carbon counts for specific projects, the intention being that lessons can be drawn from those projects with notably high or low carbon counts, to identify how we can improve and do things more efficiently. It will be an anonymous, easy to use tool, Orr says. 'It's very important that practitioners work together on this as a collaborative effort.'

Breaking out

September marks the start of a two-term sabbatical for Orr, during which he will be relieved from teaching to concentrate on research and his own projects. With his interests still in demand reduction and automation of production, he hopes to visit industrial and academic centres in the cement sector on a fact-finding mission to see what preparations they are making for changes in the market.

Another exciting development that will finally come to fruition in two years' time is the launch of the University of Cambridge's new four-year undergraduate degree course in Design. Orr has been working with Professor Michael Ramage and others to develop this from scratch over the last five years.

'It integrates architecture, engineering and material science to create a truly interdisciplinary degree that will equip students with skills in creative design thinking, so that they know what questions to ask, not just how to answer questions,' Orr says. Structured around hands-on, problem-based learning projects with studio work and practical skills, it will lead to a Master of Design qualification, offering the blend of arts and science education that Orr believes is the key to tackling global societal and environmental challenges.

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