CONCRETE QUARTERLY

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P30→

Elaine Toogood
Director, architecture and sustainable design, The Concrete Centre

Repeat with variation

It always makes me smile when I see adverts for really expensive bars of soap as the height of sustainability and a new solution to plastic packaging – no need for a bottle! I can just imagine my grandma's unimpressed reaction.

There is undoubtedly value in looking backwards as well as forwards, especially in the context of a construction industry that is evolving in response to climate change. That's what comes to mind when I look through this issue of CQ. The gorgeous "naturbetong" casting process patented by Norwegian architect Erling Viksjø features not only in our From the Archive slot (page 12), but also as the star of the newly refurbished Health Council building in Oslo (page 30). A finish characteristic of 1960s Scandinavian modernism chimes with the current trend for embracing concrete's natural, of-the-earth appearance – we are once again receiving a growing number of enquiries from specifiers looking for ways of revealing the aggregate and celebrating the uniqueness of each pour.

The concrete industry is continually developing new products and ways to build with them – from the use of seashells in permeable surfaces on page 6 to the lower-carbon multicomponent cements now included in the BS 8500 standard (page 32) – but we can still find inspiration and some very useful ideas by looking at how concrete was used in the past, in eras with different priorities and constraints.

There are many old or forgotten techniques that have new relevance in the contexts of sustainability and material efficiency. Researchers are uncovering the secrets of Roman concrete's strength, and reviving the material-efficient thin-shell structures of mid-century projects. The methods used back then might be too labour-intensive to work today, but we can take advantage of new manufacturing technologies to make them viable again. Sometimes there are no technical barriers to a particular material or method – it's the wider industry context that makes something unworkable, whether that's standards or cost or availability or skill. But that can change: conditions shift again, recreating the situation where a solution can work. It's almost as if nothing's impossible, as long as there's a real desire to get there.

THERE ARE MANY OLD OR FORGOTTEN TECHNIQUES THAT HAVE NEW RELEVANCE IN THE CONTEXTS OF SUSTAINABILITY AND MATERIAL EFFICIENCY

This is what we can see happening right now across the built environment, with the impetus provided by the net-zero agenda – we have a clear target and we all have a role to play to achieve it, whether that's through technical innovation or market evolution, or just remaining abreast of all the new lower-carbon products that are coming through research and development and reaching the mainstream. It's deeply heartening to see what we can accomplish when everyone comes together, collaborating to seize opportunities and drive things forwards. But I'm happy too that, in pursuit of the best options, designers aren't afraid to go back and reclaim the past. ■

CONCRETE QUARTERLY

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On the cover: Salvation Army headquarters, south London, by TateHindle. Photo by Jack Hobhouse

Photos: Paul Burroughs

INNOVATION

CIRCLE PERMEABLE CONCRETE

CRUSHED WASTE SEASHELLS CAN BE USED AS AGGREGATE TO CREATE PERMEABLE CONCRETE SURFACES – AN INGENIOUS, LOCAL SOLUTION FOR FLOOD-PRONE COASTAL AREAS

ABOVE
Professor Karl Williams (left) and Dr Emmanuel Anike (right) hold the raw materials of their permeable concrete at the trial project in Blackpool

The seafood industry produces surprisingly large quantities of waste shells – some 30,000 tonnes of scallop, cockle and whelk shells in the UK alone every year. While the majority end up in landfill, some simply accumulate outside processing plants where they form mountainous shell "slag heaps". It is an under-appreciated problem, but one for which there may soon be a solution thanks to new concrete technology.

"We can use shells to replace up to 20% of the aggregate in concrete," explains Professor Karl Williams, director of the Centre for Waste and Resource Management at the University of Central Lancashire (UCLan). "Shells are basically calcium

LEFT
The mix produces a low-load surface, suitable for footpaths, cycle paths and car parks

WHEN CRUSHED AND PUT INTO A CONCRETE MIX, SHELLS BEHAVE MUCH LIKE LIMESTONE. THEY ARE INERT, BUT BIND WELL WITH CEMENT

carbonate and, when crushed and put into a concrete mix, they behave much like limestone. They are inert, but bind well with cement."

Better still, says Williams, the curved shape of shell fragments can create the small voids that make permeable concrete. UCLan has now laid a 50m^2 trial area of permeable shell-concrete in a community garden in Blackpool, working with local arts organisation LeftCoast.

"The technology was first investigated by French researchers at the BUILDERS École d'ingénieurs, and they originally looked at making permeable concrete paving slabs," says Williams. "The CIRCLE project developed a ready-mix concrete material based on formulations developed at UCLan, and we continue to work closely with them. Our Blackpool trial has made use of local shells from Fleetwood and has been laid in-situ."

The mix has been designed to produce a low-load surface, suitable for footpaths, cycle paths and car parks – applications where its permeable nature can reduce the risk of puddles and flooding without expensive drainage systems. To help form the voids that allow water to drain through, there is no sand in the mix, and 20% of the aggregate has been replaced by whelk and scallop shells that have been crushed and sieved to produce 2-4mm

fragments. "In laboratory tests it has performed well above the current drainage levels required for permeable concrete and better than many similar existing products," says Williams. "At Blackpool, we have laid a 150mm layer above a 150mm sub base. It will be exciting to see how it works in practice and how, for example, it copes with seedlings and encroaching vegetation."

More work needs to be done, however: "We want to optimise the crushing to reduce waste, and also to continue looking at how different shell combinations perform. For example, we cannot use mussel shells because they have a laminate structure that tends to splinter and form shapes that don't work well in a mix. Seasonal supply is also an issue. Some shells are only available when there isn't an 'R' in the month!"

Replacing aggregate with shells brings a number of benefits. "Most obviously it finds a permanent place for this material, reduces waste to landfill and the need for virgin aggregate," says Williams. "But there are carbon savings too, resulting from reduced aggregate extraction

ABOVE
Williams and Anike at the community garden with members of local arts company LeftCoast: Helen Jones (left), Abigail Gillibrand (centre) and Catherine Peters (second from right)

LEFT
Scallop (left) and whelk (right) shells have been crushed and sieved to produce 2-4mm fragments

IT WILL BE EXCITING TO SEE HOW IT WORKS IN PRACTICE AND HOW, FOR EXAMPLE, IT COPES WITH SEEDLINGS AND ENCROACHING VEGETATION

and potentially also reduced transport to landfill."

There is further scope to cut carbon, adds Dr Emmanuel Anike, senior product developer and concrete materials specialist at UCLan. "For example, we are investigating lower-intensity cements to reduce the footprint of the concrete even more," he says.

If the shell-aggregate is transported more than 80km from where it arises, much of the carbon benefit is lost. But, says Williams, waste shells tend to arise near the coast. "These are usually lowland areas, often prone to flooding. Permeable concrete can help with that – so we see shells in concrete very much as a local solution to a local problem. In any case, as we reduce waste and optimise our shell mixes, that 80km figure should extend quite a bit."

A total of six organisations have come together to help develop the shell-based concrete. Known as the Circle Project, it comprises BUILDERS École d'ingénieurs, EQIOM Bétons, the Communauté d'Agglomération des 2 Baies en Montreuillois (CA2BM), UCLan, the University of East Anglia, and the Golfe du Morbihan – Vannes agglomération (GMVA). It is funded through the EU's Interreg VA France (Channel) England programme. ■

Interview by Tony Whitehead

LASTING IMPRESSION

ADRIAN JAMES

THREE SIDES OF CONCRETE FROM THREE CORNERS OF THE WORLD – BRUTALLY HONEST IN INDIA, PROVOCATIVELY ARTIFICIAL IN TEXAS, AND POLITELY REFINED IN OXFORD

I was lucky enough to get to Chandigarh in the mid-1980s before it was cut off to visitors amid the Punjab insurgency. It was an obvious place of pilgrimage for a young architect. Universities didn't place a huge emphasis on materials at that time, so to see this monumental urban set-piece of raw concrete left a real impact on me. Le Corbusier's Capitol Complex is as brutish as you can get – just really rough, expressive concrete cast against standard sheet metal. It's like a kind of inhabited ruin. The masterplan originally conceived a city of 500,000 people but the housing is not so successful. You feel like the city will come into its own in 500 years when you can just see the bones of the Corbusier buildings – like an Italian town where the inhabitants have built between the remains of an amphitheatre.

In the 1990s, I got to see concrete from a completely different perspective, when I worked for John Outram on at Rice University in Texas. For John, concrete was more a medium for conveying a message,

Photo: Nathan Willock-VIEW / Alamy Stock Photo

ABOVE
Capitol Complex, Chandigarh, by Le Corbusier, 1951-57

a blank canvas to be manipulated. He exploited the material's plasticity, introduced pigments and created the terrazzo-like Blitzcrete. It was the perfect material to express the iconography of his wildly imaginative world – all these things he wanted to say about the history of architecture. I know many people find his buildings too much, but they have a real presence and a lot of that stems from the concrete. Whereas a lot of postmodern architecture feels paper-thin, like a stage set, these are incredibly massive and powerful buildings.

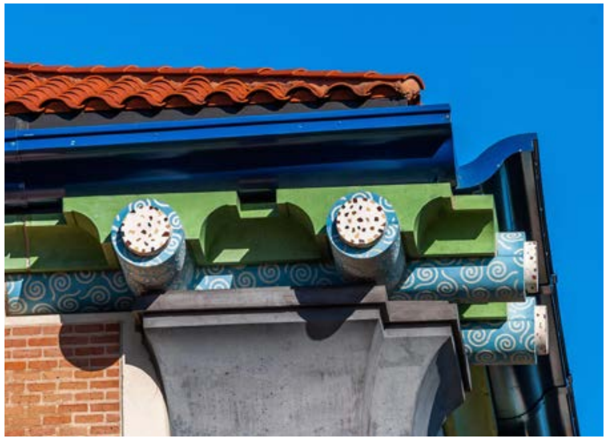
I live and work in Oxford, which is a brilliant place if you're a concrete afficionado. Powell and Moya's work in the 1960s offers some wonderful combinations of exposed concrete and Portland stone, and Arne Jacobsen's St Catherine's College similarly fuses concrete and brick to great effect. More recently, Níall McLaughlin's Master's Field buildings for Balliol College has these extraordinarily intricate precast panels, like a woven lattice.

One of my favourite buildings is Richard MacCormac's Garden Quad at St John's College. In some ways, it bridges the gap between raw, brutalist concrete and the way that postmodernists like Outram used the material. It harnesses a number of historic allusions, but in a way that makes functional sense. The domed interiors of the conference hall and lecture rooms, which emerge into the quad as oculus windows, are a reference to Sir John Soane's Bank of England, beautifully reinterpreted in precast concrete. ■

Adrian James is managing director of Adrian James Architects

BELOW
Anne and Charles Duncan Hall at Rice University, designed by John Outram, 1997

BOTTOM
Garden Quad, St John's College, Oxford, by MacCormac Jamieson Prichard, 1994



Photos: Serhii Chrucky; Archimage / Alamy Stock Photo

From the archive: Spring 1960
SCRATCHING THE SURFACE

Naturbetong, the casting process patented by Norwegian architect Erling Viksjø (see page 30), first came to the attention of CQ in 1960. With Corbusian fervour sweeping the architectural fraternity, the magazine thought Viksjo's more uniform and decorative method might offer a more acceptable form of modernism for those who found brutalism "a trifle too *brut* for their liking".

The key was the enticing combination of raw, honest structural material and sandblasting, which could cut through the Naturbetong's soft outer layer of mortar to create abstract patterns. "The sandblasting instrument, in the hands of the right person, has as many possibilities as the pencil or graver in the hands of the artist and is a great deal more than a mere builder's tool," wrote CQ. "In fact, this method should at last provide a common ground on which artist and architect can meet."

By way of example, the magazine highlighted Viksjøs Bakkehaugen church in Oslo. In form, the simple triangular building was little more than a steeply pitched, sharply folded roof slab. But inside, the effect was both mysterious and primitive. The decorative scheme, noted CQ, relied solely on the concrete surfaces for its effect. "A narrow ribbed pattern covers much of the soffit, emphasizing the triangular shape of the building. The four apostles appear on the surfaces flanking the altar – two on each side – and are represented as striking simplified figures extending from the floor to the apex of the triangle, where they are crowned by halos and two points of natural light."

The altar, font and lectern were all simple Naturbetong forms that relied on their richly textured surfaces for interest. A cross, similarly treated, projects from the wall behind the altar, "attention focused on to it by sweeping draped curves etched into the wall". And at the back of the church, a Madonna is portrayed tending a manger made up of large coloured aggregate, "polished to the richness of precious stones".

ORIGIN STORY

ELEMENTA, BASEL

PARABASE'S PIONEERING CIRCULAR SOCIAL HOUSING SCHEME BEGAN WITH A CATALOGUE OF COMPONENTS FROM A SOON-TO-BE-DEMOLISHED CAR PARK. BY NICK JONES

In pursuit of a circular economy, designers are increasingly looking for ways to reuse the structural elements of a building. But how do you design something when its constituent parts are still part of another building on a different site?

It starts with a catalogue. At least, this was the experience of Swiss architect Parabase when it entered the international open competition run by the city of Basel for 120 affordable homes and an integration centre for migrants. "With the brief, the city provided a catalogue of demolition components that we could reuse," says Pablo Garrido Arnaiz, partner at Parabase, which is now preparing to build its winning entry. "Everyone had the same information, but I think we were somehow the ones who made most use of the different pieces."

Most of the elements will be taken from the nearby Lysbüchel car park, earmarked for demolition in 2024. Circular planning consultant and "component hunter" Zirkular made an inventory of more than 60 building parts, categorized into structure, surfaces and fixtures, and covering everything from ribbed slabs to urinals. Each entry included an extensive factsheet, showing dimensions, weight, number of available pieces, and links to plans, sections, photographs, original reinforcement drawings and any other data. For structural elements, test sections were removed for analysis and testing at the EPFL technical university in Lausanne, enabling strength characteristics to be included in the catalogue.

Photo and CGIs: Parabase

Zirkular also calculated an embodied carbon saving for each component, which allowed the designers to quickly assess the reduced footprint of their proposals. Parabase's scheme, known as Elementa, will reuse 2,680 components from the car park and other catalogued sites, saving the equivalent of 1,088,082kg/CO_2.

Parabase came up with two housing types, using different catalogued items from the car park as loadbearing structure. A four-storey block repurposes columns and beams as an external frame, integrated with new concrete elements to make a grid and floor height suitable for housing. Recycled corrugated metal becomes the outer layer of the facade. The other three-storey housing type uses ribbed floor slabs as a loadbearing external wall, stacked vertically then horizontally like a brutalist Stonehenge.

As architecture, it's about establishing a set of constraints and prioritising these above aesthetics, says Arnaiz, citing Jean Nouvel's Nemausus social housing in Nimes (1987) as a precedent. There, fixtures such as metal stairs and outsized garage doors were specified from industrial catalogues to minimise costs, while greater attention was paid to space and layout.

At Elementa, an important element of the design will be the connection between old and new – details such as brackets and beam edges. "It's not like a unified system where everything fits perfectly. These elements have different dimensions, use different materials, behave

TOP
Columns from the car park will be repurposed as part of the external frame of one of Parabase's housing types

ABOVE
The columns will connect to new-build elements to make the frame a suitable height for housing (CGI)

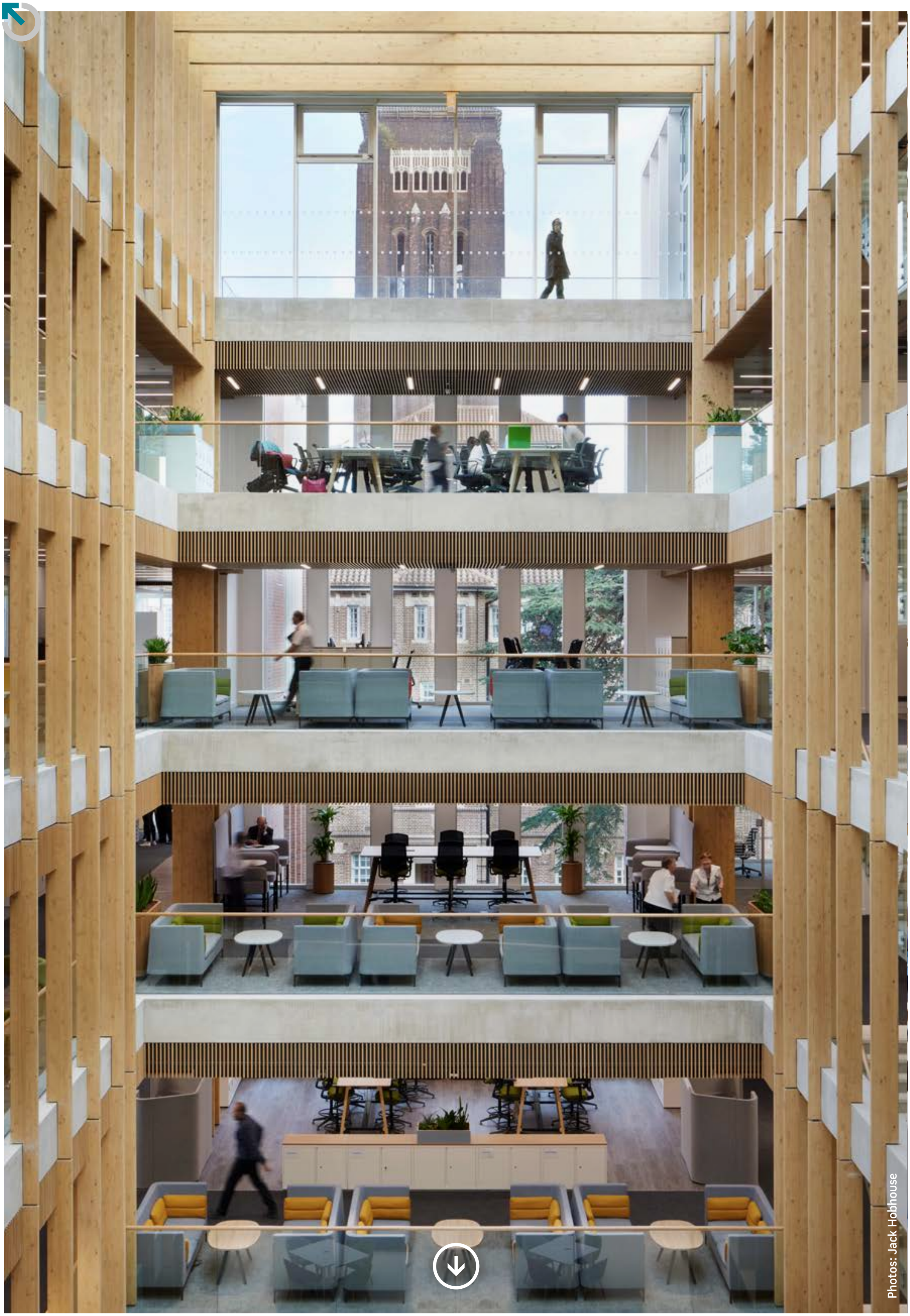
differently." Internally, the homes will have to adhere to strict design codes, but he expects them to bear traces of their unconventional heritage.

There is a lot of work to do before the project reaches that stage, and Parabase's role extends far beyond a traditional architectural brief. "We also have to coordinate how the car park is going to be dismantled," Arnaiz says. "We have to store the pieces on our plot, which is a huge logistical challenge. Already, at the start of the process, you have to know how you are going to build your building." Each element has been given a QR code to help with tracking, but the journey to their final destination in the new building has to be plotted with precision. "Some of these pieces are five or six tonnes, so if you need one that you've stored at the bottom of a pile, that's not going to work. We already know the position where they'll be stored, and even where the cranes are going to be located."

The architects are also working closely with other consultants on a legal framework to ensure a 40-year design life for the buildings. "There is no template or established way of proceeding. Everything is new." Arnaiz points out that, even armed with Zirkular's factsheets, they are introducing unknowns by changing the use of precast elements – from slab to wall, for example. "For some of the concrete, the reinforcement bars were allowed to be close to the surface. So that is then an issue that we need to solve."

Disassembly of the car park will begin in April and the development is slated for completion in 2028. ■

ABOVE
The other three-storey housing type uses ribbed floor slabs as a loadbearing external wall (CGI)



Photos: Jack Hobhouse

NEW MODEL ARMY

High levels of GGBS and a lean ribbed-slab structure have helped to reduced embodied carbon by 30% at Tatehindle's admirably restrained HQ for the Salvation Army, writes Tony Whitehead

The Salvation Army has always maintained a firm focus on frontline charity, holding fast to the "Soup, Soap and Salvation" mantra of its founder, William Booth. So when the organisation decided that a new headquarters was essential, it did so almost reluctantly, and with a keen appreciation that its supporters do not drop coins into collecting boxes in the expectation of funding a grand new building or vanity project.

ABOVE
The new HQ has been built next to Giles Gilbert Scott's existing William Booth College, built in 1929

THE CLIENT WANTED THE FRAME TO HAVE A 120-YEAR DESIGN LIFE AND WE FOUND THAT WAS MORE EASILY ACHIEVABLE WITH CONCRETE

BELOW
The facade comprises 200mm-thick brick-faced precast panels and cream-coloured glass-reinforced concrete

"The client was very clear from the start," says Jonathan Pinfield, associate with architect TateHindle. "They wanted a quality building that would last, but absolutely they wanted cost efficiency."

The result is the SA's new 5,100m^2 HQ in Denmark Hill, south London. Rated BREEAM Excellent, it has been constructed next to the existing William Booth College, built in 1929 and designed by Giles Gilbert Scott. The new building comprises six floors of mainly open-plan office accommodation, wrapped around a central atrium.

"The massing and proportions were determined partly by the fairly constrained site, but are also designed to pick up on those of the existing college," explains Pinfield. "One of our key challenges was to make those dimensions work

ABOVE
Concrete staircases rise from floor to floor, zig-zagging their way to the upper storeys (see box)

in a way that delivered the right user experience, but at a price that would be acceptable. The choice of frame was central to this."

The building has longish, 9m spans all round – the natural distance from the exterior facades to the central atrium which runs like a nave along the length of the building. "We could have shortened these with extra supports perhaps, but we didn't want a forest of columns obstructing the natural light from the external glazing and the atrium. We looked in some detail into how we could achieve those spans while bearing in mind the SA's concerns about cost."

They examined both concrete and steel solutions, he adds. "But the client wanted the frame to have a 120-year design life and we found that was more easily achievable with concrete. The steel option had issues with finishes and headroom and, having checked with our QS, concrete also came out cheaper. This was partly because leaving concrete soffits and columns largely exposed saved money on materials like plasterboard that would be needed to encase a steel frame."

Having chosen concrete, the challenge for the team was to come up with a design for the spans that was both sustainable and thrifty.

"It helped that we were working with the owner-occupier from day one," says Jess Davies, associate at structural engineer Davies Maguire. "The SA were operating from a number of different premises in London which were coming to the end of their usefulness, but when exactly they left them was up to them. It meant the programme was not particularly tight."

That gave Davies some leeway with the slab: "We came up with the final ribbed design after considering steel and precast concrete solutions," she says. "It was a little slower, because constructing the ribs with reinforced concrete poured in situ takes time compared with slotting in steel or constructing thicker, simpler slabs. But it's worth it because the design delivers a number of important benefits."

To span 9m, a flat slab would have been unusually deep and heavy: "The self-weight of the slab starts to get a bit much – you end up designing to support the slab, rather than any other loads. Using ribs releases the weight, uses less concrete, lowers the embodied carbon involved, but keeps the span."

The design is repeated throughout the building, so while the ground-floor slab is 350mm deep, those above are just 100mm, supported by ribs 150mm wide but 350mm deep, and typically spaced 530mm apart. Ribs and slab are poured as one element, with the gaps between ribs created using removable polystyrene forms.

This comparatively lightweight design reduced the loadings for the whole building and this, in turn, means

ABOVE
Timber slatting part-covers the slab edges where they meet the atrium space

ABOVE
The 50% GGBS mix lightens the tone of the concrete, complementing the spruce finishes

that the foundations are not as extensive as they might have been. As it is, these involve a contiguous piled concrete retaining wall (to cope with the Denmark Hill site's 5m drop) and 137 bearing piles up to 600mm in diameter. "But a heavier frame would have needed longer piles, adding to the total concrete used," says Davies.

The mix itself was also chosen with the carbon cost of the building in mind. "It's fairly common to use 20-30% cement substitute such as GGBS," says Davies. "But here the concrete in the columns and upper floor slabs had 50% of the cement replaced with GGBS. Again, it helped that the programme was not too tight, as the more GGBS, the longer the strike times."

Despite the generous programme, the longer curing times did prompt contractor McLaren to split each floor into six pours rather than the planned four, to help maintain progress on site. The efforts to minimise embodied carbon have paid off, however: "We compared our solution with that of an equivalent steel frame with composite concrete and metal deck slabs, and found we were achieving a 30% saving on CO_2 per square metre of floor space," says Davies. "The ribbed design accounted for most of that saving."

Davies Maguire also looked in detail at the impact of using GGBS as cement replacement: "Our final figure for the building was 297kg of embodied CO_2 per m^2 – which is 70kg less than if we had built the final ribbed design with a standard CEM I mix – that is, with no GGBS," says Davies. The engineers worked out the CEM I values using their own in-house carbon calculator, based on the IStructE carbon calculator and ICE v3.0 Module A1-A3 data. The values for the GGBS mix, meanwhile, were from the actual project data during construction. "We included the full mix design values for the stated concrete mixes provided by the piling subcontractor, waterproofing subcontractor, and concrete frame sub-contractor – calculations which also included distances to plants."

Davies adds: "The savings might have been even more, but some of the foundation works contained less GGBS. The ground-floor slab, for example, included a waterproofing admixture, and so the mix was to a specialist's design."

The slabs are supported by 40 reinforced-concrete columns constructed using ply forms. "Most of

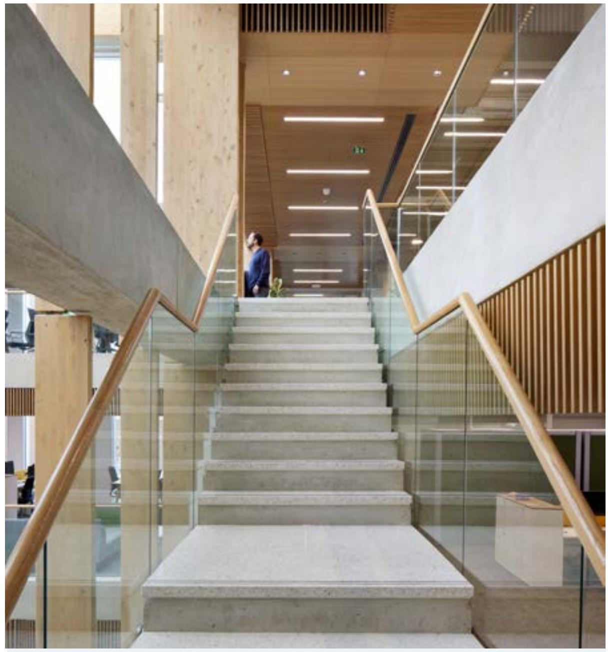
BELOW
The ribbed slabs help to conceal lighting and some services, while leaving the soffit exposed

these are 500 x 500mm," says Davies. "But there are some 250mm x 1m rectangular columns where the architecture requires it – for example, where the perimeter steps in a little around the entrance."

The rectangular columns have also been deployed where the upper floors step back from the street – a feature designed to echo the style of the existing college buildings. "Moving columns is always interesting," says Davies, explaining that the upper columns land a meter or so back from the front facade columns of the first four storeys. "The ribbed slabs have a 1m-wide concrete band beam running the whole way around every bay, so where the columns step back on the fifth floor, they land on the beam. There is added reinforcement in the beam at those points."

Despite the dominance of exposed concrete in the design, the interior does not feel in any way industrial, partly due to the colour of the concrete. "The high GGBS content gives the concrete a pale grey colour," says Pinfield. "It helps maximise the natural light. At the top of the atrium we have deep glulam [timber laminate] beams which provide some solar shading, but in daylight they also have a warm glow about them which is taken up by the light-coloured concrete."

There is a great deal of timber used throughout the building. It part-panels some interior columns and, on each floor, timber slatting part-covers the concrete ribbed



Designing the staircases

Standing in the central atrium of The Salvation Army's new headquarters, there is much to admire: its cathedral-like proportions, the stylish timber bulwarks and the glulam top beams. But one of the most striking and important features are the elegant concrete staircases that rise from floor to floor, zig-zagging their way to the upper storeys.

They are meant to stand out, and to foster connectivity by enticing building occupants to explore other floors and other departments. Constructing them, however, was not straightforward.

"The original plan was to have them precast," says Jess Davies, associate at structural engineer Davies Maguire. "They are very visible features, and precast would have guaranteed a good finish. But at more than 7m, we realised they were too long for most precasters' facilities, and would not have fitted on a lorry because of the length and angle."

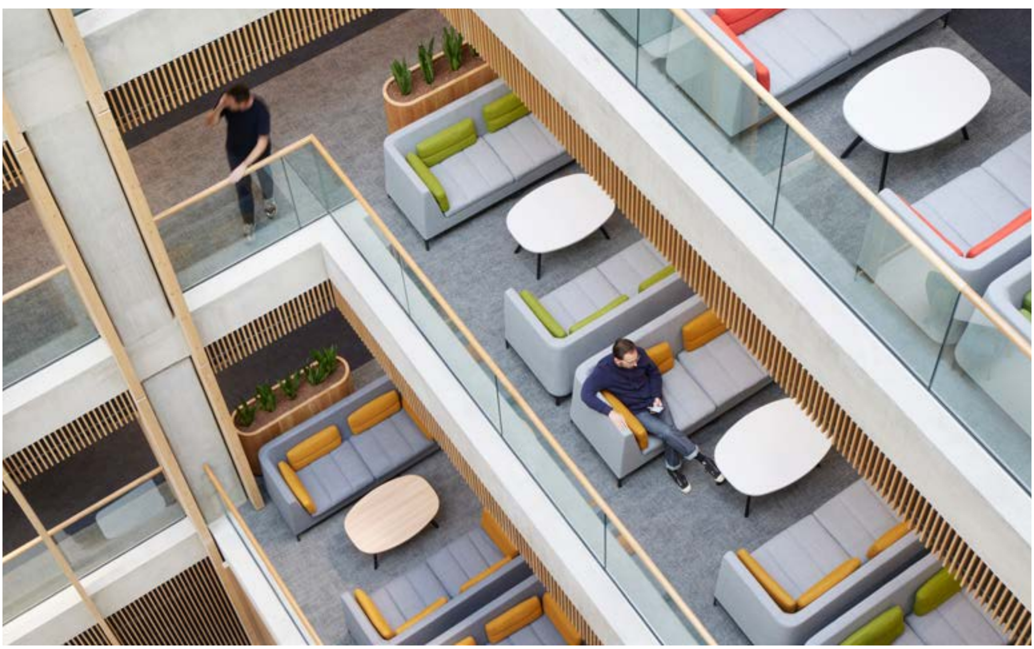
slab soffits where they meet the atrium space. "The timber works hard acoustically," says Pinfield. "The atrium is completely open to help provide connectivity between different departments, and people can easily see colleagues on different floors (see box). But the risk is noise transmission, so the ribbed slabs are useful here as they help disrupt sound reflections."

In addition, the timber slats have acoustic backing, and the spaces between the ribs also contain acoustic panels. The effect is

She then looked at constructing the 1.2m-wide staircases from two precast sections, roughly 3.5m-long, but this solution was also rejected: "The stairs are unsupported by any columns, and to construct in two pieces would have involved having a moment connection cast in to the half-landing, which would have been quite complicated," she says. "The stairs also have quite a slim, 275mm, waist (the minimum thickness from soffit to step) so there was not much room for complex connections."

In the end, the stairs were cast in-situ. "This was quite a challenge for the contractor, as they had to start with the most visible staircase on the ground floor, so they had no time to practise the finish." Each one was constructed in two pours using traditional ply formwork supported on scaffolding. "Mitchellsons worked hard to get a smooth, clean finish, and hide the joints between the pours," says Davies. The steps are topped with terrazzo tiling to match the ground floor atrium.

BELOW
Timber slatting part-covers the slab edges where they meet the atrium space



remarkable: despite the hundreds of occupants and open-plan scheme, the whole building enjoys a library-like calm.

"The ribs also help to conceal lighting and some services," adds Pinfield. "The client didn't want the full, exposed services look – so the ribs are a way of largely concealing these while still leaving the soffit exposed. And because there is no false ceiling, the building can benefit from the thermal mass of the concrete."

By absorbing excess heat during the day, the exposed concrete frame reduces the need for air conditioning in summer. Alternatively, by not venting the building overnight in winter, the stored heat can be used to reduce heating requirements. The thermal mass effect works in conjunction with air-source heat pumps to heat and cool the building, which is part-powered by 90 photovoltaic panels on the roof.

BELOW
The roof terrace takes advantage of the views from the site's prominent location on top of Denmark Hill

Despite appearances, the stylish brickwork facades of the building feature yet more concrete: the brickwork is constructed using 150mm-thick precast panels set with 50mm-thick brick slips. Pinfield explains that the precast option suited the design, which features deep reveals and brick piers. "It means that when you look at the facade from an angle, you read it as a heavy brick building – in tune with the original college buildings. But from the front you see there is plenty of glazing to provide the interior with lots of natural light."

The precast brick-faced panels offered a number of advantages over traditional brickwork: "You have the quality control of off-site manufacture, and its quick to build on site with less scaffolding and fewer people," says Pinfield. "But, in any case, we would have struggled to create some of the tall slim piers – just one brick wide – traditionally. They would not have been stable. The precast panels, however, are structurally self supporting. They sit on a ground beam and this has the added benefit of not adding any loading to the upper frame."

In all, 296 precast panels were used, the largest weighing seven tonnes and measuring 7.7m x 2.7m.

The facade brickwork has been combined with creamy coloured glass-reinforced concrete to echo the brick and Portland Stone pallet of the original college. The overall effect is an elegant blend of modern and traditional, with the new HQ respecting the old buildings, while asserting its own identity. William Booth would surely approve. ■

ABOVE
The double-height reception space and adjacent cafe provide a public "shopfront" for the charity

PROJECT TEAM
Architect TateHindle
Structural engineer Davies Maguire
Contractor McLaren
Concrete contractor Mitchellson
Precast supplier Thorp Precast

LEARNING CURVE

Stanton Williams has reworked the grade II*-listed headquarters of the Rhodes Trust educational charity in Oxford, improving its environmental performance and doubling the usable area largely by reimagining previously vacated spaces beneath the existing structure. Basements and archives have been transformed into light-filled foyers, offices and a 300-seat conference hall beneath a concrete vault.

Photos: Hufton + Crow; Neil Keynon

The vault offers a number of advantages. It introduces an arcing window along the top of the back wall, which brings daylight into the basement and gives views out to the landscaped garden. It is also extremely material-efficient. Spanning the 9m x 12m central section of the hall, the vault is 200mm thick – far slimmer than a flat slab.

A coffer is introduced in the hall's side wings, based on a 1.5m x 1.5m grid of 600mm-deep beams with a 150mm-thick slab in between. Overall, the vaulted and coffered structure means that the volume of concrete is reduced by 50% compared to a more standard structural design.

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FORCE OF NATURE

Mad arkitekter has completed the refurbishment and retrofit of Oslo's 1960s Health Council building – one of the finest examples of Erling Viksjø's naturbetong architecture (see page 12). Known as the Trekantblokka, or triangle block, the building has been modernised and extended by a storey to house new office space, while public functions have been introduced at street level.

Mad's refurbishment has uncovered abstract stem-like patterns of smooth mortar on the naturbetong walls. The team found that the concrete was still in good condition both inside and out – for the most part, it simply needed cleaning with water, with only small repairs to the more exposed surfaces.

Photos: Kyrre Sundal

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EXTERIOR MOTIFS

Architect Bureau de Change has married traditional brickwork with exposed in-situ concrete and precast elements to offer a modern interpretation of the 1930s suburban houses of Clapham, south London. Bay windows and other traditional motifs have been incorporated into the cast concrete while intricate details, such as framed lintels, were precast on site.

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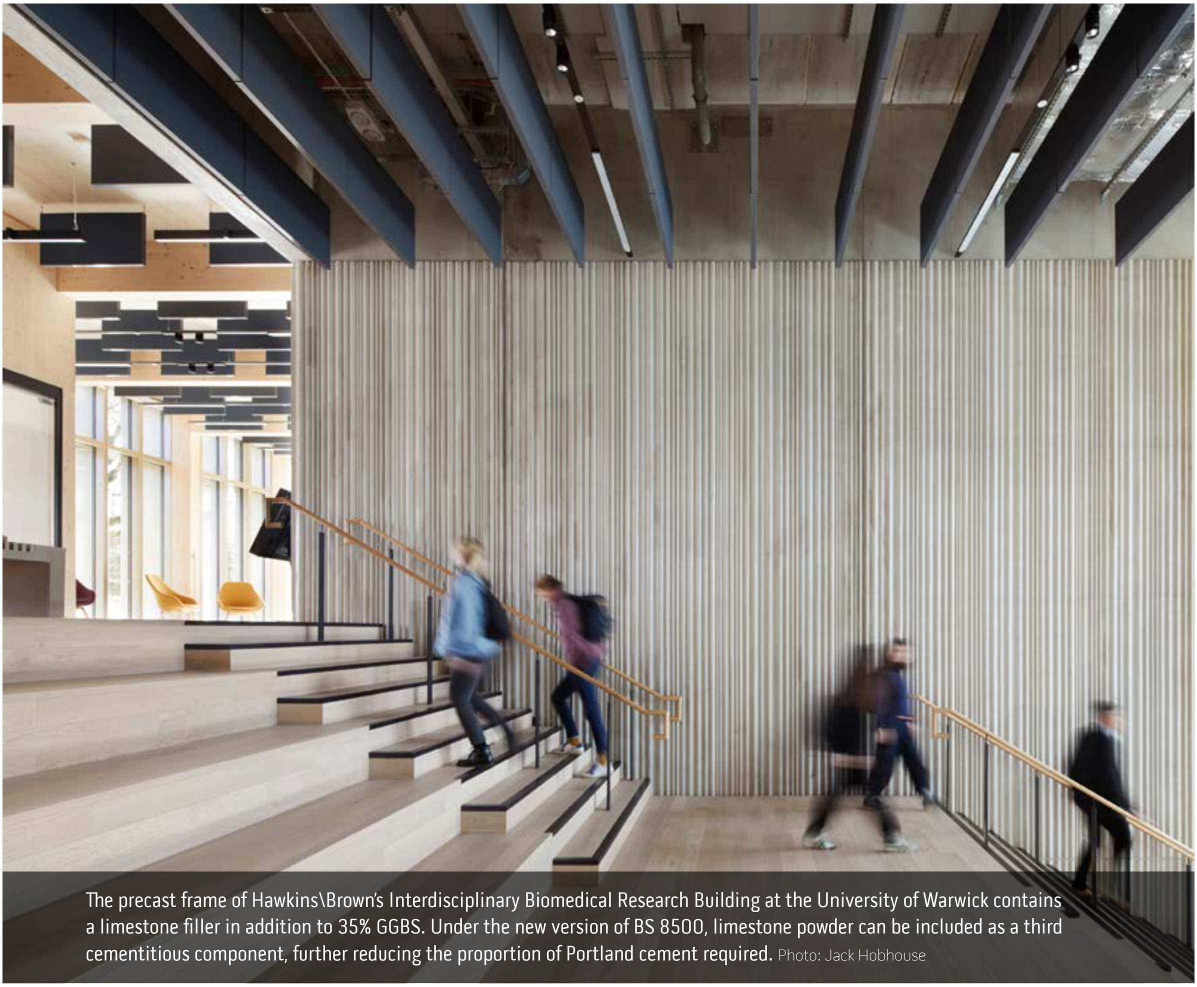
Photos: Gilbert McCarragher



The precast frame of Hawkins\Brown's Interdisciplinary Biomedical Research Building at the University of Warwick contains a limestone filler in addition to 35% GGBS. Under the new version of BS 8500, limestone powder can be included as a third cementitious component, further reducing the proportion of Portland cement required. Photo: Jack Hobhouse

Specifying lower-carbon concrete using BS 8500

The updated standard now includes a much wider range of lower-carbon mixes, potentially reducing the UK's annual carbon footprint by 1 million tonnes. Gareth Wake explains how specifiers can use it

The key UK standard for the specification of concrete is BS 8500, which complements the overarching European standard BS EN 206 and providing UK-specific guidance. On 30 November 2023, a revised edition was published, substantially increasing the range of lower-carbon concretes available to specifiers. In particular, it now includes a wider range of multicomponent cements that combine Portland cement with two additions or supplementary cementitious materials (SCMs).

Since the 1980s, SCMs such as fly ash and ground granulated blast-furnace slag (GGBS) have been included in concrete, both for the specific properties they bring and to lower its embodied carbon. Cement production accounts for around 90% of concrete's CO_2 emissions, because the raw materials must be heated to high temperatures, and because of the chemical reaction involved in the process. Replacing a proportion of the Portland cement with another cementitious material is therefore currently a key strategy for reducing embodied carbon. The UK concrete and cement industry has set out a roadmap to fully decarbonise by 2050 – for example by phasing out fossil fuels and introducing carbon capture and storage at cement manufacturing plants. But specifiers can make an important contribution, now and in the future, by always choosing the lowest-carbon mix that can meet their project's requirements. With the 2023 update to BS 8500, the options have increased considerably.

How multicomponent blends reduce embodied carbon

In 2021, the cement standard BS EN 197-5 was updated to include products in which up to 65% of the Portland cement (CEM I) content was replaced by two SCMs – adding multicomponent equivalents to the binary combinations that are already well-established in the UK. These new "ternary" combinations consist of a range of proportions of CEM I and limestone fines with either GGBS or fly ash, or a range of proportions of CEM I with GGBS and fly ash.

ABOVE
The first CEM VI cement to be certified in France is being used for the construction of the Grand Angle apartment building in Villefranche-sur-Saone. The ternary blend contains limestone and GGBS and is produced by Lafarge, which says it has 40% lower embodied carbon than CEM I

Extensive testing was carried out, leading to the update to BS 8500:2023 that will enable the specification of multicomponent blends as part of the available lower-carbon concretes. Now, up to 20% of the binary combination can be replaced with limestone powder, an SCM that can be sourced locally across the UK. For every 5% of limestone powder used, there is a corresponding carbon reduction of approximately 5% per tonne of cement. If the new concretes were used across all mainstream applications, this would add up to an annual carbon saving of about 1 million tonnes.

Research commissioned by the Mineral Products Association found that limestone fines could be used as a material-efficient replacement for both Portland cement and GGBS in a CEM I/ GGBS concrete, resulting in an equivalent performance but with a lower carbon footprint, while reducing consumption of GGBS.

Standard methods for concrete specification

BS 8500 is published in two parts. While Part 2 is intended for use by producers of concrete, it is Part 1 to which the specifier should refer. This provides detailed guidance on compiling specifications, and on exposure classes, aggregate classes, intended working life, and properties of the fresh concrete such as consistence.

BS 8500:2023-1 offers five approaches to the specification of concrete:

- **Designated concretes** are a range of predetermined mixes for common applications, split into five categories: GEN concretes for unreinforced applications, RC concretes for reinforced applications, PAV concretes for external paving, FND concrete for foundations in aggressive ground conditions, and

CB cement bound concretes for highway reinstatement. For example, FND2 is a concrete suitable for ground assessed as DC-2; RC28/35 is a concrete in the strength class C28/35 suitable for use in an internal suspended floor. Designated concretes can only be supplied by ready-mixed producers with third-party conformity certification. They are not suitable where there is a risk of chloride corrosion, where a designed concrete should be specified instead.

■ **Designed concretes** are for the informed specifier, where the designer considers all the requirements for the hardened concrete to derive the necessary strength class and other properties such as cement type, minimum cement content and maximum water/cement ratio. Normally the designer will assess the exposure conditions and consider the recommendations set out in BS 8500-1 to determine the concrete properties and minimum cover to the reinforcement. The flexibility of designed concretes makes them suitable for specifying the most sustainable concrete, using lower-carbon cements alongside other considerations such as the use of recycled or secondary aggregates. Once the designer has completed their sections of the specification, it is passed onto the contractor to add requirements for the fresh concrete, such as consistence. The producer is then responsible for meeting the requirements of the specification through provision of the mix design.

■ **Prescribed concretes** allow the more informed designer to specify concrete by prescribing the composition. This method is rarely used but is useful where a particular ratio of constituents is required. The specifier is responsible for the strength and other performance characteristics of the concrete.

BELOW
Tarmac used a Portland Limestone Ternary cement C VI at the Hexham Flood Alleviation Scheme in Northumberland. This concrete has three cementitious components – cement clinker, GGBS and up to 20% of limestone filler to replace some of the GGBS. Compared to a standard CEM I it offers a 64% reduction in embodied carbon to 119kg/m^3 CO_2e

■ **Standardised prescribed concretes** are intended for small building sites where concrete is either mixed by hand or in a small mixer less than 150 litres. They are denoted ST, and have no requirement for strength demonstration, but BS 8500-1 provides some indicative values for the strength class that may be assumed for structural design. To ensure ST concrete is safe for the indeterminate range of materials and site supervision, the cement content is very high, resulting in much higher embodied carbon compared to designated concretes. Their use should therefore be avoided where a ready-mixed concrete, either designated or designed, can be used instead.

■ **Proprietary concretes** are developed by the producer and marketed based on their enhanced fresh or hardened properties. The producer will normally guarantee the performance of these products and provide test certificates. They may be covered by third-party product conformity certification. The range of proprietary concretes include lower-carbon concretes and concretes for high-performance applications, where a lower-carbon solution can be produced by a reduction in the total volume of material.

Specification simplified

BS 8500:2023 aims to increase the use of lower-carbon mixes by removing unnecessary barriers. Using the methodology of the previous edition

Understanding cement classification

Cements that are produced in a cement works are denoted CEM. Portland cement (CEM I) consists of at least 95% Portland cement clinker. Other common cements are designated using CEM II, CEM III, CEM IV, CEM V or CEM VI, with further qualifying letters to indicate the proportions and types of constituents.

The first letter indicates the proportion of the clinker that has been replaced, as shown in Table 1. For example, a Portland-composite cement designated CEM II/A contains between 6-20% clinker replacement, whereas a Blast furnace cement designated CEM III/C contains between 81% and 95%.

Table 1: Allowable proportions of cement replacement by different designations

Cement designation	/A	/B	/C
CEM II	6-20%	21-35%	36-50%
CEM III	36-65%	66-80%	81-95%
CEM IV	11-35%	36-55%	n/a
CEM V	36-60%	62-80%	n/a

CEM VI only has one range of Portland cement replacement proportions (51-65%) so does not have a designation letter. A further letter indicates the type of addition(s) in the cement combination:

S	GGBS
V	Fly ash
L	Limestone fines
D	Silica fume
M (A1 – A2)	Multicomponent (addition 1 – addition 2)

For example, CEM II/A-V is a Portland-fly ash cement with 6-20% fly ash, while CEM II/B-M (S-L) is a multicomponent cement where GGBS and limestone fines replace between 21% and 35% of the Portland cement clinker. Where more than one addition is listed, the first has the higher proportion. Cements that meet the requirements for sulfate resistance have the additional notation "+SR", as in CEM III/A +SR.

for specifying the increased number of cements and combinations would have been impractical, so this edition simplifies specification by introducing the "combined performance category", which covers resistance to sulfates and chloride. Cements and combinations of cements are categorised according to their relative resistance to chlorides (graded from 1-4) and sulfate attack (graded from A-G). This is based on Concrete Society Technical Report 61: TR61 Enhancing reinforced concrete durability, and BRE Special Digest 1, Concrete in Aggressive Ground.

In exposure classes XD and XS where reinforcement is at risk of corrosion due to chloride ingress, the update has removed the minimum recommended characteristic strength. It has gone further with regard to corrosion due to carbonation, removing limiting values of minimum cement content and maximum water/cement ratio, to leave just a minimum recommended characteristic strength for each nominal cover to the reinforcement. ■

Gareth Wake is director of the British Ready-Mixed Concrete Association, part of the MPA

For more details of combined performance categories, as well as minimum concrete strengths and depth of cover to reinforcement, refer to The Concrete Centre document "How to design concrete structures using Eurocode 2: BS 8500 for building and civil structures"

CEM designations refer only to products made in the cement factory. Equivalent combinations to these cements are produced at the concrete batching plant from a cement and one or more additions in the mixer that conform to the requirements of BS EN 197. These are denoted slightly differently, with C instead of CEM. So, CEM III/A would be CIIIA, and CEM II/C-M (S-L) becomes CIIC-SL.

Table 2: Indicative embodied carbon (modules A1-A3) for different cements and combinations

Cement types			
Cement factory	Combined at concrete plant	Supplementary cementitious material (%)	Embodied carbon ($kgCO_2/t$)
CEM I / Portland cement	n/a	n/a	840
CEM II/A-L Portland limestone cement	CIIA-L	6-20	791-673
CEM II/A-M (S-L) Portland composite cement	CIIA-SL		
CEM II/A-V Portland fly ash cement	CIIA-V		
CEM II/B-V Portland fly ash cement	CIIB-V	21-35	693-553
CEM II/B-S Portland slag cement	CIIB-S		
CEM II/B-M (S-L) Portland composite cement	CIIB-SL		
CEM II/C-M (S-L) Portland composite cement *	CIIC-SL	36-50	569-452
CEM III/A Blast-furnace cement	CIIIA	36-65	575-362
CEM III/B Blast-furnace cement	CIIIB	66-80	355-252
CEM IV/B-V Siliceous fly ash cement	CIVB-V	36-55	545-390
CEM VI (S-L) Composite cement *	CVI-SL	51-65	459-342

* New cements

House Made by Many Hands

Case study Cairn Architects and Structure Workshop have trialled a limestone calcined-clay cement on a low-carbon extension in east London

Designed by Cairn Architects, House Made by Many Hands in east London is the first building structure in the UK to specify concrete containing limestone calcined-clay cement (LC3), a multicomponent blend made from 50% clinker, 30% calcined clay and 15% limestone, with 5% gypsum for workability.

LC3 was developed at the EPFL research university in Switzerland, with academic partners in Cuba and India, and has been calculated to generate 30-40% less CO_2 in production than CEM I. Calcined clay is processed at a much lower temperature than Portland cement – 800°C rather than 1,400-1,500°C – and limestone does not need to be processed at all.

Like limestone, clay is abundant in the UK, but there is also much that could be diverted from other industrial waste streams. An MPA innovation project is nearing completion on tests of secondary sources from brick manufacturing and reclaimed resources from mineral extraction sites, with the aim of enabling much wider use of calcined clay as a supplementary cementitious material.

At House Made by Many Hands, LC3 has been used for the floor slab and to underpin the existing brick footings of a Victorian house extension. The low-carbon approach extends to the rest of the project, which has been completed in natural materials such as hempcrete, cork and lime plaster.

Structural engineer Structure Workshop took on the risk of pioneering the LC3 technology, carrying out cube tests to verify its C25/30 strength. "Because of the small scale of this project, hopefully it can be a test case and a piece of evidence that allows these things to be used at a much bigger scale," says Kieran Hawkins of Cairn.

The concrete was mixed and poured in the same way as standard concrete, requiring no additional site training. "If we hadn't told the contractor it was different, they wouldn't have known," says Hawkins, adding that the cost was also comparable to a conventional mix.

Structure Workshop used its own carbon calculator, which applies industry carbon factors sourced from Bath University's ICE database. The embodied carbon of the LC3 slab was measured at 65% that of CEM I. Overall, the design team are reporting the project's embodied carbon at 40% lower than that of a typical Victorian extension.

The LC3 for the slab was imported from Denmark, where it has already been used on several projects, including the Bjarke Ingels Group HQ in Copenhagen. ■

IF WE HADN'T TOLD THE CONTRACTOR IT WAS A DIFFERENT CONCRETE, THEY WOULDN'T HAVE KNOWN

FINAL FRAME: CHARLES NÈGRE LIBRARY, GRASSE

Designed by Ivry Serres and Beaudouin Architectes, this cultural centre on the French Riviera is one of 40 buildings shortlisted for the EU 2024 Mies van der Rohe Award. Located in a seismic zone, the design is based on a structure of in-situ concrete vaults which lend lateral stability to the cantilevering form. The glazed envelope is wrapped in fluted white columns, made of nearly 14,000 seperate precast-concrete elements.

Photo: Fernando Guerra