CONCRETE QUARTERLY

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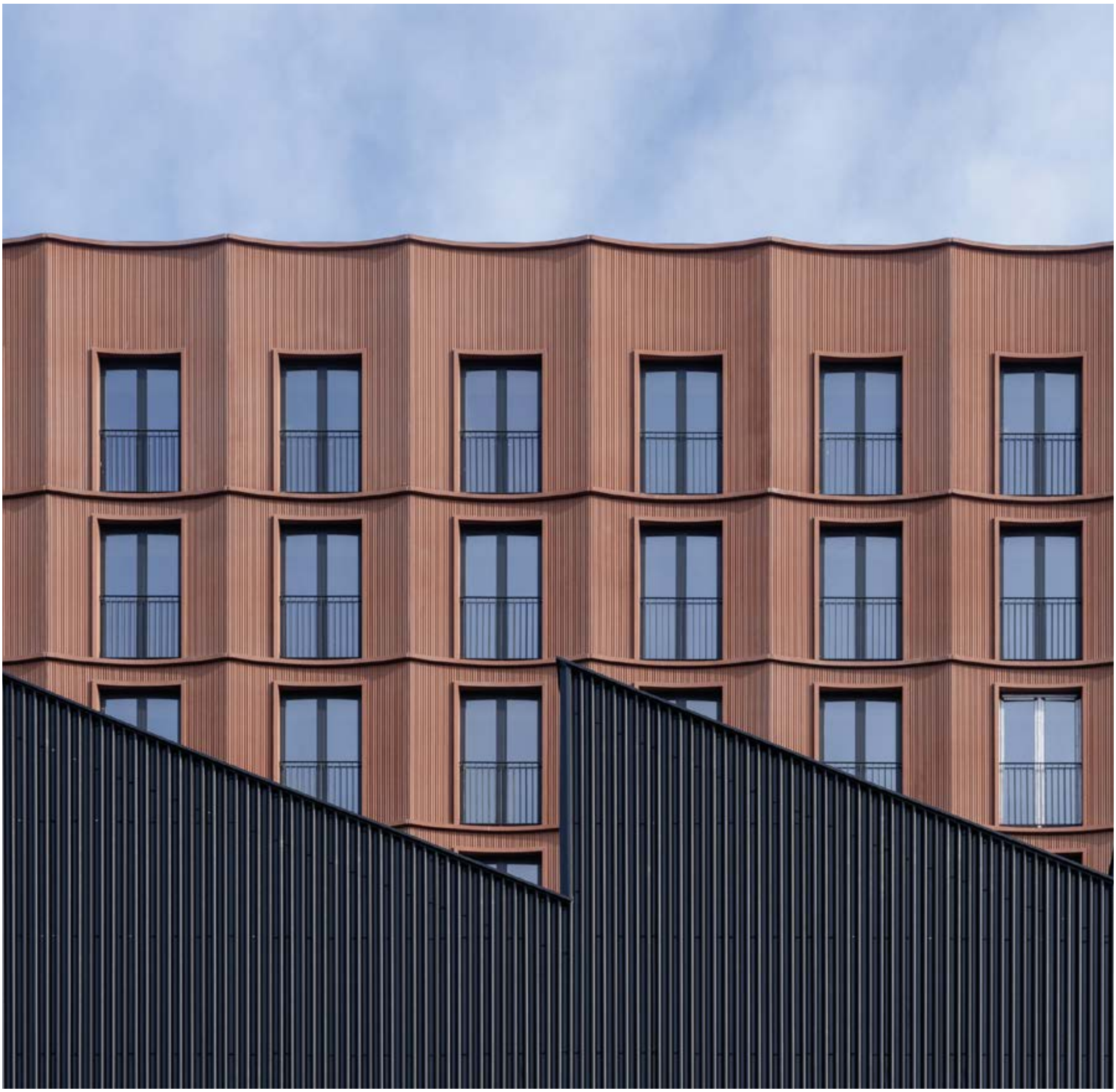

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HS2 crosses the Colne Valley in style on the UK's longest rail bridge

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Elaine Toogood
Senior director, MPA Concrete
& The Concrete Centre

Ways of seeing

Scale is something of a theme within this issue, in a thought-provoking if unintentional way. I found it fascinating to read about how the design teams of both Goods Yard in Stoke (page 14) and Colne Valley Viaduct (page 18) considered their projects from different perspectives and evolved beautiful shapes, textures and details for viewers near and far, fast and slow.

That was of course made possible by the sculptural, amorphous nature of concrete itself, and its ability to be almost anything to anyone. This is not only true of its form, but of its carbon content. Rather than a single material, concrete could perhaps be thought of as a loosely worded traditional recipe, which may vary enormously from one cook to another. It can be made from different ingredients for different uses, with significant variations in embodied carbon.

This can make it difficult to find the most appropriate carbon data, which is an ongoing strand of our work at The Concrete Centre and the wider Mineral Products Association. Much of our activity is about helping project teams to locate the data they need, and helping the industry to produce it, which is likely to be a never-ending process, as the understanding of measurement deepens and key documents need to be updated and refreshed. For example, MPA Cement has just released a revised version of Fact Sheet 18 on the embodied carbon of UK cements, to incorporate the wider range of multicomponent cements now available for specification under BS 8500. Our new Concrete in Practice webinar series will share essential learning from projects that are still under construction – the first features engineers at

Ramboll discussing the innovative processes they've adopted on the UK's first high-rise laboratory at One North Quay in Canary Wharf, to reduce the embodied carbon of its concrete frame.

ANY INNOVATION ALSO RELIES ON SPECIFIERS AND SUPPLIERS TO UNDERSTAND HOW TO APPLY IT AT A BUILDING LEVEL

Somebody much cleverer than me once said the more they looked for carbon, the more they found. It resonated because that's the case with so many things, just as you discover more of interest about a building the closer you look, or the way in which the coastline of Britain becomes infinitely longer as its crags and coves come into sharper focus.

I have always found shifting perspective – pulling back, zooming in – a fascinating exercise, and an invaluable tool for the design process and for tackling problems of any kind. When it comes to decarbonising concrete, the big picture and the detail are both important. Our regular Innovation feature shines the spotlight on the scientists hard at work in laboratories around the UK and further afield, who are concerned with its molecular structure and chemistry. But any innovation also relies on specifiers and suppliers to understand how to apply it at a building level, and ultimately on big-picture industrial strategy and policy to reach widespread implementation. We need all these perspectives because different views offer different insights – and because carbon is a problem we have to solve at every scale. ■

CONCRETE QUARTERLY

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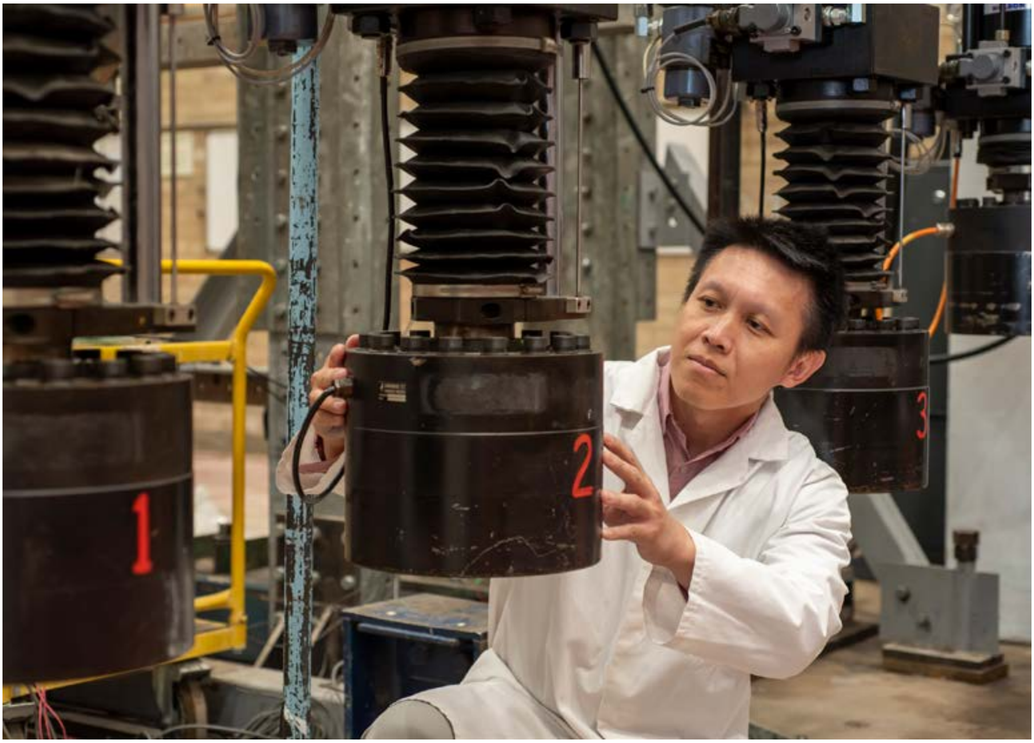


Photos: Paul Burroughs

INNOVATION

RECYCLED STEEL FIBRE CONCRETE

BY REUSING STEEL WIRE FROM WASTE TYRES, RESEARCHERS AT BIRMINGHAM UNIVERSITY ARE CREATING HIGH-STRENGTH CONCRETE WITH AROUND ONE QUARTER LESS COST AND CARBON

ABOVE
Sakdirat Kaewunruen and his colleagues carried out full-scale tests with composite concrete beams to study how recycled steel fibres can improve structural performance

Structural engineer Sakdirat Kaewunruen is a reader at the University of Birmingham and an expert in railway construction – so the reason for his interest in tyre recycling is not immediately obvious.

"It is to do with how to make concrete resist shear forces more efficiently," he explains. "Shear forces happen when one part of a concrete structure tries to move relative to another, when sunlight heats a road pavement, for example, and the surface concrete expands relative to that underneath. Or when a train passes over a bridge, or an aircraft lands on a runway. In these circumstances you have to guard against significant shear forces

THERE'S AROUND 50M OF STEEL WIRE IN AN AVERAGE CAR TYRE. WHEN THE TYRE IS BURNT FOR ELECTRICITY, THIS ENDS UP AS TROUBLESOME RESIDUE

causing delamination and cracking. The traditional solution is to use more reinforcement, and thicker, higher-strength concrete."

This comes at a cost, however. Extra steel, cement and concrete increases expenditure on materials, and also the carbon footprint of the structure concerned. "But if you reinforce the concrete with steel fibres, it becomes much more resistant to shear forces," says Kaewunruen. "Then the amounts of concrete and traditional reinforcement can be minimised."

Kaewunruen and his former PhD researcher Xia Qin are working with the Concrete Society to update its TR63 guidance on steel fibres, to allow their use more widely and in higher-strength applications.

This solution is not perfect, however, as industrial steel fibre (ISF) comes with its own financial

BELOW
Recycled steel fibres from tyres (right) are a lower-carbon alternative to fibres made from new materials (left). The recycled fibres shown here had short bends added, but the team tested straight fibres too

and environmental costs. This is where the tyres come in: "Europe alone produces nearly four million tonnes of waste tyres every year. Many end up in landfill, though they can be burnt to produce electricity, or in cement production." One problem with this is the steel wire used to reinforce the tyres: "There's around 50m, or just over 1kg, in an average car tyre. When the tyre is burnt for electricity, this ends up as troublesome residue."

Even if the wire is stripped out, it is usually recycled in power-hungry electric arc furnaces. "It would be better to reuse it. As it happens, the wire is usually around 1mm in diameter – a similar specification to the wire used to make steel fibre composite concrete."

Kaewunruen and Qin have just completed new research into how well recycled steel fibre (RSF) would work in concrete. It is not entirely straightforward: even when the wire is removed from the tyre, it has to be cleaned, as rubber residue can affect hydration rates in concrete. "Fortunately the machinery to efficiently strip out the steel already exists, and the wire can then be vacuumed to remove rubber dust."

Another issue is the shape of the individual wires or fibres. Those currently used in ISF composite concrete are specially manufactured with short bends, or ankles, at the end of each wire to increase the grip of the wires within the set concrete. "It's not practical to add these features to recycled wire," he explains. "So we had to check what effect using simple straight wires would have."

Kaewunruen and his team tested a full range of mixes across all strength classes of concrete with different concentrations of RSF. "The good news is that our mixes proved highly effective at improving the shear resistance of the concrete. Our 0.8% mix, for example, is almost as effective as purpose-made steel fibre. It proved less effective at increasing tensile strength, probably due to the shape and surface characteristics of the fibre."

The team also found that it was best to mix the fibres with the aggregate first before adding cement and water: "It improves their distribution and helps to maintain good flow by preventing them from balling and clogging."

FLOW OF ISF CONCRETE BECOMES DIFFICULT MUCH ABOVE 1%. WITH RSF, IT IS POSSIBLE TO GO TO 2% WITHOUT SIGNIFICANTLY IMPACTING FLOW

ABOVE
Kaewunruen and his team tested a full range of mixes across all concrete strength classes with different concentrations of RSF

In fact, RSF improved fluidity: "You can have higher concentrations of straight fibres. Flow of ISF concrete becomes difficult much above 1%. With RSF, it is possible to go to 2% without significantly impacting flow."

Clearly these particular characteristics of RSF composite concrete would have to be taken into account when specifying it – but the potential cost and carbon savings seem considerable. "RSF is cheap, and does not need to be manufactured in a blast furnace," says Kaewunruen. "We calculated that a 0.8% mix delivers a 25% carbon saving and a 28% cost saving compared with ISF."

A number of full-scale tests with composite concrete beams have been conducted at the university to study RSF's capacity to improve structural performance. The team has also built an AI tool to help designers optimise RSF use for a particular concrete strength.

Kaewunruen hopes that RSF composite concrete can also be included in any update to TR63, which will boost many more engineering applications: "So we solve two problems with one solution, and hopefully make the world a better place." ■

Interview by Tony Whitehead

LASTING IMPRESSION

PIERS GOUGH

CELEBRATING THE MID-CENTURY ENGINEERS WHO MADE CONCRETE CURVE AND FLOAT, AND THE VISIONARY ARCHITECT WHO FORGED A RIVER THROUGH A SÃO PAULO FACTORY

Thin shells give me a kind of surreal thrill. Between the wars, when this type of construction was at its height, ultra-thinness became an engineering obsession. Architecturally, thicker shells would, no doubt, have been fine enough. But these engineers were pushing structural concrete to its exquisite limit.

BELOW
The Zarzuela Hippodrome in Madrid, designed by architects Carlos Arniches and Martín Domínguez with engineer Eduardo Torroja. Work began on the project in 1935; it was completed in 1941 after the Spanish Civil War

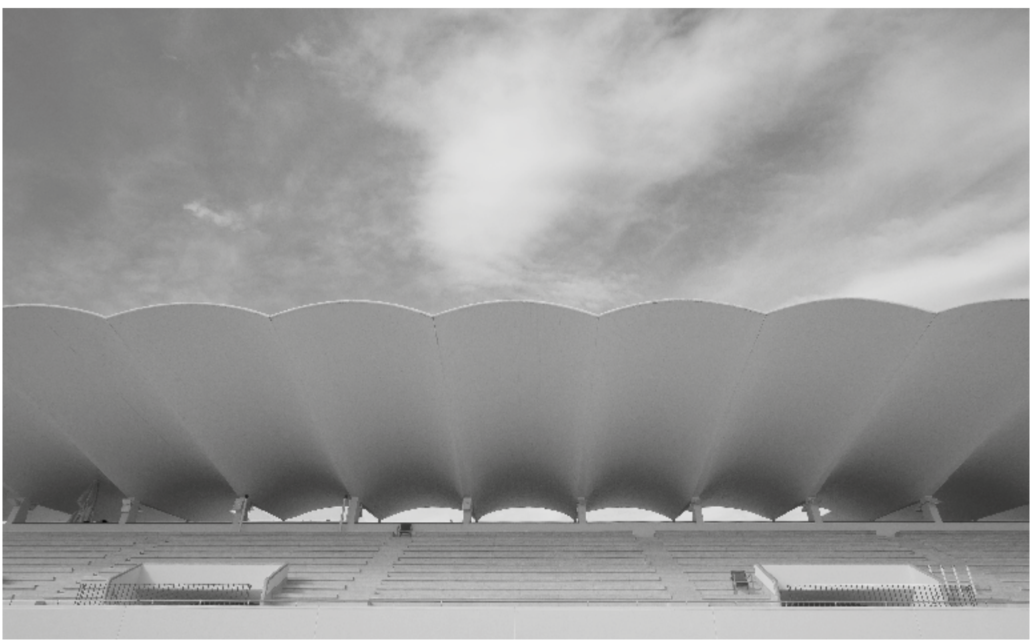


Photo: Ana Amado

The Zarzuela Hippodrome in Madrid has always inspired me. The engineer, Eduardo Torroja, pushed the feasibility of the shell to the limit, using an asymmetrical section to balance out the weight. It's unbelievably thin and delicate – the roof edge is just 60mm. It looks like it's fluttering in the wind.

The Spanish-Mexican architect and engineer Felix Candela was perhaps the master of the thin shell. The Oceanografic aquarium and restaurant in Valencia, which was his final work, is almost ethereal – a delicious ruffle of paper-thin concrete. The opposite of brutalism. Quite often, these shells are slightly spoiled when the facade is filled in, by the weight of the glazing bars. But here, the glazing is very slight, so a sense of lightness pervades the building.

Photos: Ana Amado; Carlos Dominique / Alamy Stock Photo

ABOVE
After years of neglect, the Zarzuela Hippodrome was revived in 2005 in a project led by architect Jerónimo Junquera

LEFT
The Oceanografic aquarium in Valencia, designed by Félix Candela and structural engineers Alberto Domingo and Carlos Lázaro, and completed in 2003

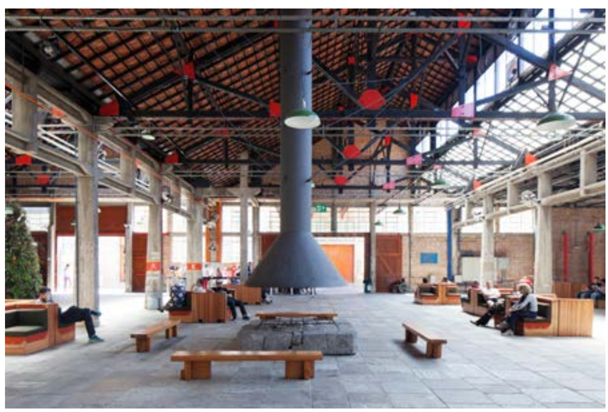
My final choice is a fabulous use of concrete in its rawest state: Lina Bo Bardi's SESC Pompéia, a sort of leisure centre for the São Paulo shop workers' union. The scheme is dominated by two very industrial-looking concrete towers with windows that look like they've been punched out by a fist. One contains a pool and gym spaces, all on top of each other, and the other houses changing rooms.

The reason for the vertical stacking is interesting. When Bo Bardi got the job, she found that people were already occupying the old industrial buildings on the site, making things and generally having a great social time. So she decided to keep and refurbish them – leaving less space for the new buildings.

The existing structures, which date from the 1920s, show a different use of concrete again. Where the towers are awe-inspiringly raw, the factories are sharp and precise. They use the Hennebique system – the first system-built reinforced concrete frame, which was actually imported from Britain. Rather than having separate columns and beams, the portal frame acts as a monolithic structure, which saves on material. It's also quite elaborate, with almost decorative openings like a Vierendeel truss.

Bo Bardi was very imaginative with this space, cutting a wavy pool that runs like a river through the concrete paving. There's also a sort of seaside boardwalk, where people just hang out and sunbathe. It's a wonderful reinvention. ■

Piers Gough is a director of CZWG Architects



TOP
SESC Pompéia by Lina Bo Bardi (1977-86), with the boardwalk in the foreground

ABOVE
The existing buildings have a precast portal frame and now host various activities

From the archive: Autumn 1974

SUN, SEA AND FERRO-CEMENT

Concrete Quarterly doesn't often feature yachts. But back in 1974, we were celebrating the maiden voyage of the largest ocean-racing schooner to be built in Britain since the Second World War. The reason for this brief excursion into nautical matters was that the yacht in question, *New Freedom*, had another claim to fame: at 84ft long, it was the largest ferro-cement vessel ever launched in this country.

The twin-masted boat was the result of a "massive do-it-yourself project" by amateur boatbuilder Captain Tony Fincham. His plan was to sail it in the 1975 Round the World race, docking in Antigua where it would be available for charter bookings. Ferro-cement was chosen for its combination of strength, minimal maintenance requirements ("essential in the tropics") and ease of repair.

Construction was carried out by a team of nearly 80 people, including a number of volunteers from a local sailing club. The thickness of the hull was just 1 and 1/16 inches, "including reinforcement of welded rods and six layers of tight-packed welded galvanized mesh", and it was finished with a smooth layer of mortar.

The launch itself was "most unusual", *CQ* observed. The challenge was to find a way of moving 40 tons of ferro-cement across 70 yards of mud flats to a creek on the Thames estuary on the north side of Canvey Island. This was finally achieved by a local engineering company, "who winched the yacht on a cradle to a ramp sloping into the creek and, using two giant telescopic jib cranes to restrain the weight, allowed her to drop slowly into the water".

New Freedom didn't make the Round the World Race, but Captain Fincham and his crew of seven did make it to Antigua. There, his ferro-cement creation led a glamorous life as a luxury charter yacht, playing host to the likes of Mick Jagger and Princess Margaret, before eventually falling into disrepair. Last year, the Antigua and Barbuda National Parks Authority sank the hull close to the shore, where it will become an extension to a natural reef and a unique attraction for scuba divers.

Browse through nearly 80 years of *Concrete Quarterly* at concretecentre.com/archive

'NEW FREEDOM'

Britain's largest ferro-cement yacht

The most unusual boat-launching took place on 16 September 1974 when Captain Tony Fincham, an amateur boatbuilder, launched *New Freedom* – the largest ferro-cement yacht ever built in this country, at Benfleet. His boat is the result of a massive do-it-yourself exercise and is a highly sophisticated twin-

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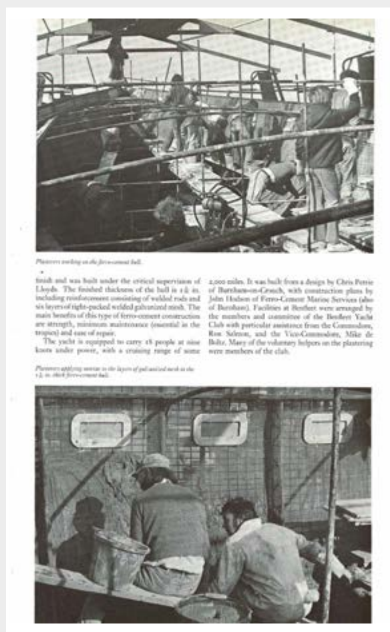


Plasterers working on the ferro-cement hull.

finish and was built under the critical supervision of Lloyds. The finished thickness of the hull is 1 1/16 in. including reinforcement consisting of welded rods and six layers of tight-packed welded galvanized mesh. The main benefits of this type of ferro-cement construction are strength, minimum maintenance (essential in the tropics) and ease of repair.

The yacht is equipped to carry 18 people at nine knots under power, with a cruising range of some 2,000 miles. It was built from a design by Chris Petrie of Burnham-on-Crouch, with construction plans by John Hodson of Ferro-Cement Marine Services (also of Burnham). Facilities at Benfleet were arranged by the members and committee of the Benfleet Yacht Club with particular assistance from the Commodore, Ron Selmon, and the Vice-Commodore, Mike de Boltz. Many of the voluntary helpers on the plastering were members of the club.

Plasterers applying mortar to the layers of galvanized mesh in the 1 1/16 in. thick ferro-cement hull.

Photos: Greg Holmes

ORIGIN STORY

STOKE GOODS YARD

FRASER GODFREY EXPLAINS HOW HOWELLS HARNESSED THE REPLICABLE AND SCULPTURAL QUALITIES OF PRECAST CONCRETE TO EVOKE THE POTTERIES' INDUSTRIAL HEYDAY

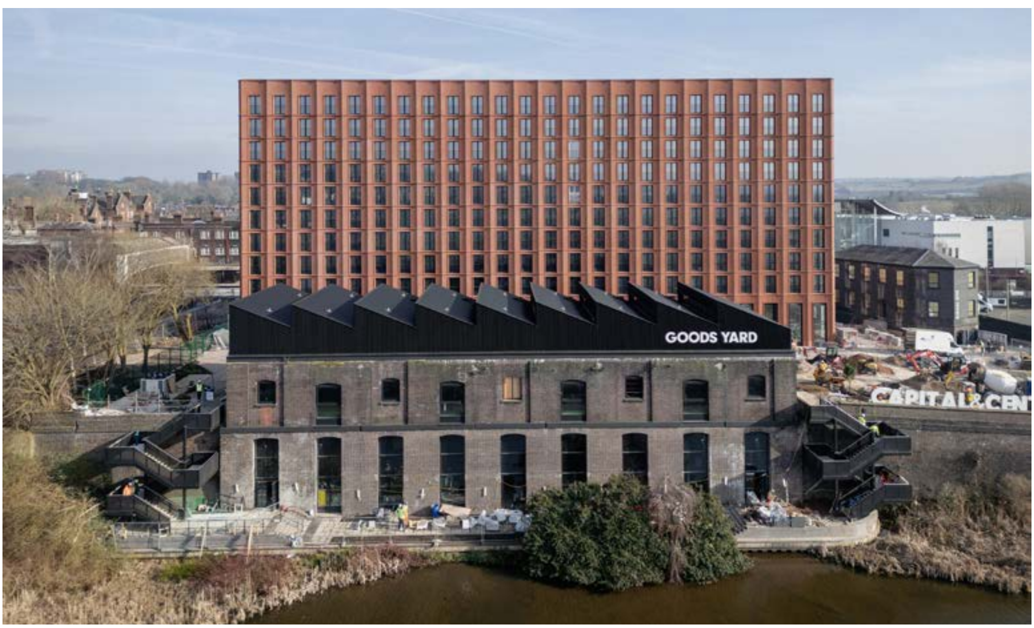
I grew up in Wolverhampton, where you can still see the immense industrial wealth that used to flow through the town in the richly ornamented Victorian buildings. Many of these are now derelict, or underused. It's ironic because, as an architect, I know that no client would pay us to design buildings like those now. The time, labour and craftsmanship involved would just be too expensive. But I believe that even on a budget there are things we can do, by using modern methods of construction, to put some detail and interest back into buildings. We had an opportunity to do that when we were asked to design Goods Yard in Stoke-on-Trent.

As in many of these post-industrial towns, young people tend to move away from Stoke to where there are better opportunities. There isn't the kind of exciting, new-build rental market that has developed in the trendier areas of bigger cities like Manchester and Birmingham. So when Stoke secured some levelling-up funding to redevelop the area around the station, part of the aim was to create homes for rent that would be attractive to young people – encouraging them to stay by providing affordable but high-quality places to live, from where they could easily commute to neighbouring cities.

Goods Yard is a mixed-use scheme located close to Stoke station, and right next to the Trent and Mersey Canal and the A500. The site used to be a busy interchange of materials and manufactured goods and the development repurposes a number of Victorian structures. Dominating the scheme, though, is a new, ten-storey block of 174 apartments for rent. At 76m long and 20m wide, its size and form are reminiscent of the mills and warehouses of the Victorian era.

The development had to work economically – rents here are not high – and we had to extract the utmost from our budget. Our approach was to keep the form very simple, with lots of repetition throughout the apartments and the core designs.

BELOW
The project also included the retrofit of a brick-vaulted warehouse as a food and drink venue



We started with an in-situ concrete frame, arranged on a 6m grid. This kept spans short and allowed us to save material (and carbon) by keeping the slabs slim. The concrete frame is also a very cost-effective way of dealing with fire protection and acoustics – vital considerations in a residential building.

That left enough budget to do something interesting with the facade. It is built from 360 terracotta-coloured precast concrete panels, the vast majority of which are made from just three mould shapes, corresponding to the lower floor, middle floors and top floor. The only exceptions were the corners, which have a special edge piece cast onto the regular panel. Each panel weighs approximately 7 tonnes.

I felt that the building would mainly be viewed from two perspectives: by people passing it at an average of 50mph in a car or a train, but also by pedestrians who would have a closer, slower experience. For the former, we created the scalloped shape of the facade panels. These are 6m x 3m, so even from a distance, or when passing quickly, the repeated shape provides shadows and interest. Then, for the pedestrians, we introduced the vertical fluting in

BELOW
Exposed soffits maximise ceiling heights and remove the embodied carbon associated with additional finishes

each panel, and this detail also responds to the light, creating shadows and texture.

Of course, this costs more than using plain, flat panels, but by keeping to a limited number of shapes we made it very efficient – the building was delivered for just £220 per ft^2. The panels were fabricated by Techrete, which made the curved scallop shapes from reuseable timber formwork, and then lined it with off-the-shelf ribbed rubber mouldings to create the vertical grooves. Each panel arrived on site with windows, Juliet balconies and interior insulation fitted, cutting the trades required and site time significantly.

The concrete facade is coloured terracotta by the addition of iron oxide – so the colour is reminiscent both of local brick buildings and also the clay that made Stoke a historic centre of ceramics. But there is more going on here than just the colour. We've used the concrete something like the way that Josiah Wedgwood used clay to create high-quality ceramic pottery – complex, subtle shapes, designed to be reproduced in volume very efficiently. I think Wedgwood would understand what we've done here, and I hope he would approve. ■

Interview by Tony Whitehead

ABOVE
Shared gardens and permeable public realm have been threaded between existing structures and the new buildings


Photo: Grimshaw

BEAM OF LIGHT

Colne Valley Viaduct is a new icon of UK rail travel, 3.4km of high-speed track soaring gracefully over lakes and protected woodland. Nick Jones explores the design and delivery of the UK's longest rail bridge

HS2 trains will only spend a minute or so above ground between the tunnels that take them out of London and through the Chiltern Hills – but a lot happens in that minute. They will soar past a tapestry of ancient woods and wetlands, skimming across four lakes and the River Colne. They will traverse roads, new cycle routes and footpaths. And they will race over the Grand Union Canal – the future of British transport briefly exchanging glances with its industrial past.

ABOVE
The viaduct crosses a landscape of lakes and reservoirs, as well as the River Colne and the Grand Union Canal

↓

This whole scene will unfold on the longest rail bridge in the UK – a title that had been held by the Tay Bridge in Scotland for the past 140 years. The Colne Valley Viaduct, now structurally complete, is an epic piece of engineering. Following a gently curving 3.4km route through the Colne Valley, it is made of 56 reinforced concrete piers, spaced up to 80m apart. Above these sits a box-girder bridge deck, ranging in height from 3m to 6.7m and built from 1,000 unique concrete segments – an assembly that required its own on-site precast factory and a launching gantry so big that onlookers assumed it was the bridge itself (see box, page 26).

Despite its colossal scale, the viaduct had to tread lightly on this protected slice of greenbelt, and enhance rather than overshadow the landscape. The project team – a joint venture of Bouygues Travaux Publics, VolkerFitzpatrick and Sir Robert McAlpine known as Align JV, and its design consultants Jacobs, Ingerop-Rendel, Grimshaw and LDA Design – had to minimise the carbon impacts too, in line with HS2's commitment to cutting construction emissions by 50% by 2030, against a 2016 baseline. This presented a challenge, but also an opportunity: a structure that can withstand trains hurtling at 200mph will inevitably need a lot of materials, but across 3.4km any design efficiencies quickly add up to huge savings.

For architect Grimshaw, one of the biggest questions was how to make cohesive architecture from a form measured in kilometres rather than metres. "It's a really complex site, and probably has every constraint you can imagine in terms of building a viaduct – the regional park, lakes, roads, reservoirs, the Grand Union Canal," says Chris Patience, principal at Grimshaw. "There was a real risk that it would look different at various points along the route, with multiple engineering solutions all dealing with different issues."

Their answer was a common design language, with a strict grammar that would apply across all structural elements. Gradually, a lexicon emerged

IT'S A REALLY COMPLEX SITE, AND PROBABLY HAS EVERY SINGLE CONSTRAINT YOU CAN IMAGINE IN TERMS OF BUILDING A VIADUCT

based on folded planes of fair-faced concrete, with triangular geometries and defined edges. This seemed to resolve a number of problems, not least how to make massive structural objects appear lighter.

"We probably tested about 50 different ways of expressing form," says Patience. "We found that facets were the most efficient way of breaking up visual mass because of the way they emphasise the contrast between light and dark. That allowed us to play with the silhouette and highlight particular geometries." While more muscular elements retreat into shadow, the eye is drawn towards the free-flowing lines of the underside of the deck – the only curves in the entire structure.

The folded forms were also the most efficient way of supporting the load: "We initially looked at including more curved elements, but you end up adding concrete. The facets are optimised for structural performance."

This language was developed into a family of four structural components. The two main elements are a wide V-shaped pier, which carries the 80m spans over water, and a straighter, more upright form to support shorter 60m spans through the woodland. "We wanted the structure to be responsive to the different contexts," says Patience. "Over water, you want to maximise the views through the landscape by creating really wide spans. But in the dense woodland, the straighter piers push the structure up above the canopy, maximising clearance below." Foot and cycle paths weave in and out of the piers – in all, 3.5km

ABOVE
The family of four pier types share the same language of folds and facets. From top: the expansion portal, the fixed buttress, the woodland pier and the wetland pier

of new routes have been created as part of the viaduct project.

The other two elements are an expansion portal, a type of double pier that supports movement joints in the deck at 900m intervals, and a fixed buttress, which disperses the braking load from the trains into the ground. As with the main piers, these components are used in response to specific site features, says Patience. One of the most prominent locations is the Grand Union Canal, where the buttresses form a gateway on either side of the tow path. "It's quite an amazing moment – the converging of entirely different speeds of travel. You've got canal boats, barges, and now high-speed rail."

Each pier stands on four to six rotary bored piles, embedded up to 55m into the underlying chalk bed. They were cast using steel formwork – standardised to enable reuse.

All of the in-situ concrete, which contains 70% GGBS, has been left as struck. Partly, this was because of the requirement for a 120-year design life, so there are no additional finishes to compromise durability or increase maintenance needs. But it is also another way of bringing cohesion. The architects introduced a single variation: a bush-hammered effect created using a flexible formliner, selectively applied where the structure meets the ground or water. These rougher surfaces are recessed by 25-50mm, with a chamfered edge helping to navigate the turn into the adjacent face.

This use of texture helps to mediate between the vastly different scales at which the viaduct

Photo: Grimshaw

ABOVE
The rougher surfaces are recessed by 25-50mm, accentuating the play of light and shadow on the faceted forms

Photo: Grimshaw

ABOVE
The V-shaped piers are designed to allow expansive views across the water

is experienced. In the woodland sections, the rougher surface offers a finer level of interest to passing walkers and cyclists, and subtle horizontal definition to the hammered finish conceals day joints from the eagle-eyed. At the other end of the scale, where the viaduct is seen from across the water, the texture adds another layer of contrast, helping some planes to retreat into shadow as the structure melds into the water.

At the top of the piers, mechanical bearings take the full load of the deck and allow for thermal expansion and contraction. They also introduce visual separation between the main structural elements, conveying a sense of lightness. This is not disingenuous – the designers worked hard to minimise the load. The box girder locates most of the structure directly below the track, improving efficiency, while the deck width was chipped away until it stood at 13.4m, 1m narrower than in the outline design presented to Parliament in the High Speed Rail Bill.

"We probably spent about a year reducing the cross-section of the deck as far as we possibly could," says Patience. "Across 3.4km, even saving 10mm makes a huge difference." There are also knock-on effects – the piles, for example, are 10-15m shorter than in the outline design. "The more weight we put on the deck, the bigger

PROJECT TEAM

Architect Grimshaw
Structural and civil engineers Rendel-Ingerop, Jacobs
Contractor Align JV (Bouygues Travaux Publics, VolkerFitzpatrick, Sir Robert McAlpine)
Specimen design team Knight Architects, EDP (Atkins Jacobs Sener)

Photo: Grimshaw

ABOVE
The bush-hammer style finish helps the lower surfaces of the piers to merge with the water below

the piers, the bigger the foundations, the more carbon – and the bigger the structure is visually."

A continuous parapet wall envelopes the deck in a clean, uninterrupted horizontal band of fair-faced concrete. This reprises the language of faceted forms, with a fold line breaking up the scale of the outer face and providing a slender band of shadow along the top edge. These elements were precast in 3m-long panels and fixed into the deck reinforcement on site. To further reduce the weight of the deck, the wall sections were made from ultra-high performance fibre-reinforced concrete (UHPFRC), enabling thicknesses of just 55mm. UHPFRC also has low levels of porosity, which will slow the effects of weathering over the viaduct's lifetime.

The project's embodied carbon is 28% – or 63,300 tonnes – lower than the outline design. Often, it is hard to visualise what numbers like this really mean. But here, the absence of carbon is perceptible: there is simply less viaduct. A monumental piece of infrastructure has been broken into light and shadow, the dynamic forces of high-speed rail distilled into pure form. The HS2 project has often been depicted as something like the construction equivalent of Sisyphus pushing a boulder uphill for eternity. At Colne Valley, it skims like a stone over water.

Photo: HS2 Ltd

ABOVE
The 160m-long launching gantry crosses the Grand Union Canal. The tressle-like fixed buttresses on either side of the canal take the braking load from the trains into the ground

A bridge to build a bridge

How do you build a 3.4km-long viaduct in a regional park without turning sensitive natural environments into delivery roads, pumping several years of transport emissions into the atmosphere and destroying protected habitats? One answer is to build it 500m up the road.

This was the approach taken by HS2 on the Colne Valley Viaduct. Beyond the north-west end of the site, next to a slip road to the M25, the Align joint-venture construction team erected a 5,000m^2 factory, in which it has built the box-girder bridge deck in precisely 1,000 precast-concrete segments. HS2 estimates that this has diverted the equivalent of about 4,000 lorries from local roads.

This is precasting on a phenomenal scale. The V-shaped sections weighed between 60 and 140 tonnes, and were up to 6.7m tall and 13.4m wide. Because of the curving route and varying spans of the viaduct, each was unique: in total, the pier design required more than 5,000 separate drawings, which was refined to 111 typical geometries. The precasters were able to import the drawings directly from the BIM model, speeding up the casting process – at its peak, the factory was able to produce 18 per week.

Fabrication took place in a vast casting cell made from reusable steel formwork. Despite the differences between segments, there was a high level of repetition: variations could largely be dealt with using an adjustable table to alter the height and angle of the deck.

The pieces were cast in sequence, enabling the use of a process known as "match-casting". This involved casting a ridged pattern into the connecting face, and then using this as a mould for the corresponding face of the next segment. In order to accommodate curves in the deck, the casting cell could be rotated slightly to meet the negative mould at a precisely defined angle. "It was

ABOVE
The precast segments were up to 6.7m high and fabricated in a casting cell in a purpose-built 5,000m² on-site factory

BELOW
Each segment was "match-cast" against its neighbour, ensuring that the ridged patterns interlocked precisely

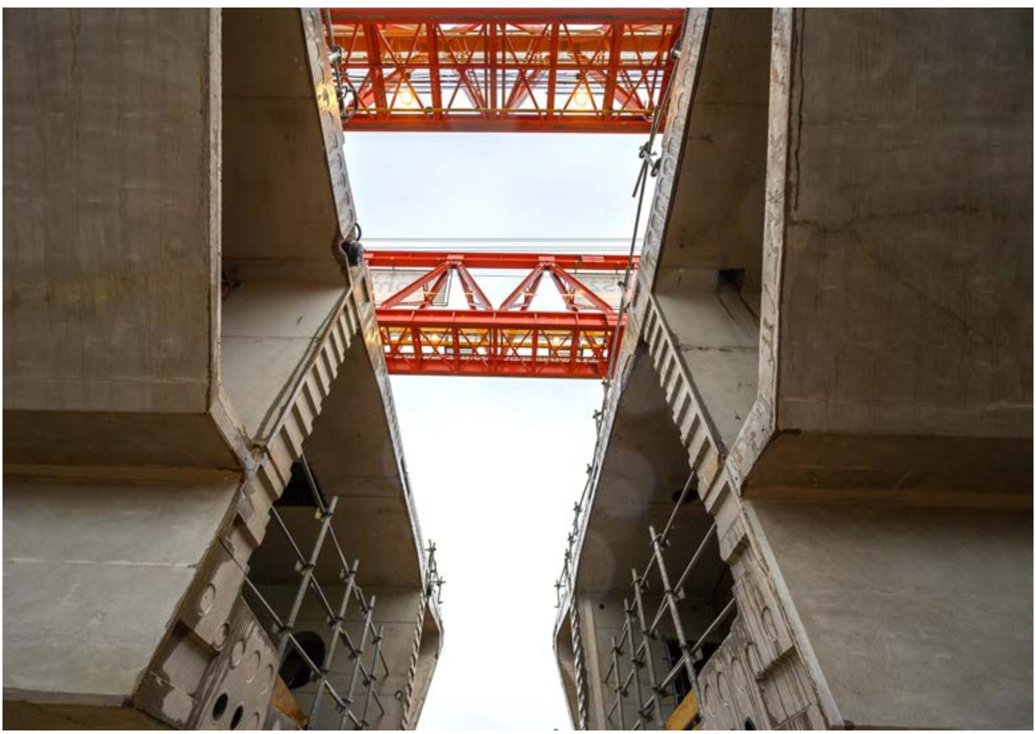


Photo: HS2 Ltd

Photo: HS2 Ltd

ABOVE
The segments were lifted into position before being tied together, initially with temporary post-tensioned bars

a really good way to make sure the sections interlocked precisely," says Grimshaw's Chris Patience. "Any imperfection would become the mould for the next piece anyway." To ensure that they remained in sequence, each segment was given an identifying catalogue number and a QR code.

To install these gargantuan concrete sections, a launching gantry was brought in from Hong Kong. This was basically a huge steel girder, 160m long and 700 tonnes, which could stand astride two consecutive piers on a support framework built out from the pile caps. The gantry was so big that, when it arrived on site, the parts took more than three months to assemble. "A few people who came to site thought it was actually the bridge," says Patience.

Installation began when the first 900m of piers had been completed, after which the in-situ work and deck fabrication continued in parallel. Each precast segment was delivered to site on the back of a trailer and placed beneath the gantry. A system of steel winches and chains then lifted and rotated it through 90 degrees, moving it slowly into place at a rate of 8m a minute. A small ground team of 10 to 15 operatives manoeuvred it into its final position.

The deck was built out from the piers in both directions. The first two segments were placed on either side and fixed to the pier with vertical post-tensioned (PT) cables to form an anchor. The following sections were then installed alternately, balancing each other out in a cantilever.

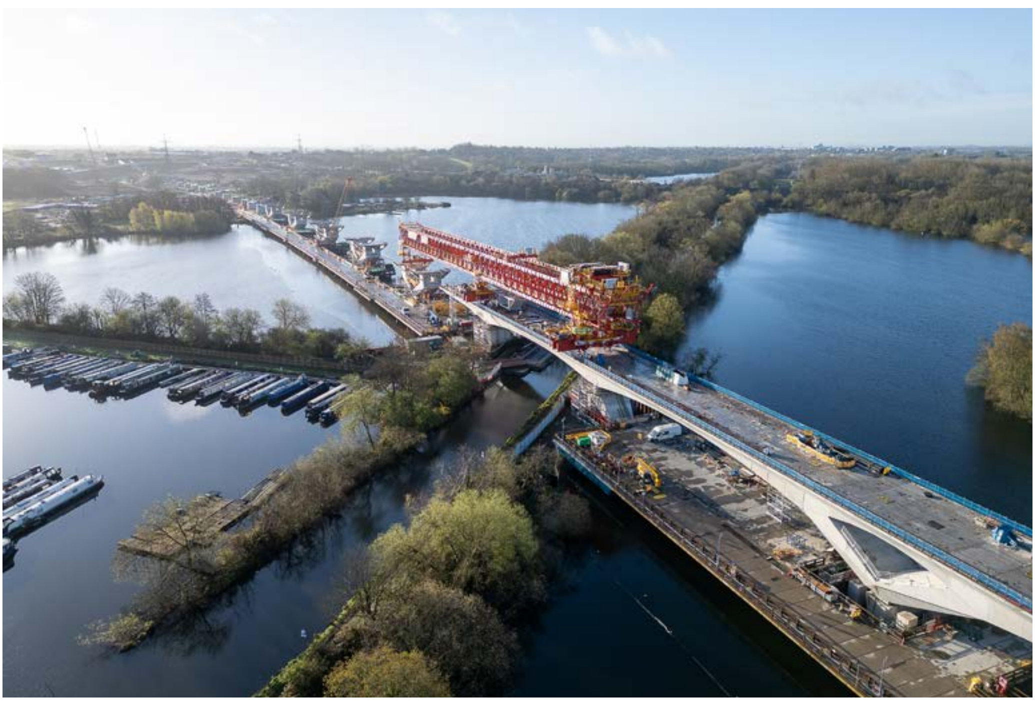
A strong epoxy provided the initial bond between segments, which were temporarily held together with 40mm-diameter PT bars. As the segments progressed, the box girders were permanently connected with internal PT cables, encapsulated and bonded within the concrete.

The gantry was able to install half a span – typically 10 to 12 segments – in both directions from a single base. Its legs were then lifted and "walked" to the next pier. Where the cantilevers meet in the middle of a span, they are joined with a 250mm "stitch" of in-situ concrete, which is reinforced with more internal post-tensioning.

The structure also integrates external PT, where sheathed, greased cables run within the box segment, only touching the structure at certain points. These are replaceable should the need arise, helping to ensure that the viaduct remains fit for a 120-year service life. ■

ABOVE
Inside a viaduct arch. The segments were reinforced using both internal and external post-tensioning

BELOW
The gantry was supported on consecutive piers, with the segments cantilevering out in both directions



Photos: HS2 Ltd

LAYER CAKE

Deep in the Swiss Alps, a team of designers from ETH Zurich have constructed the first 3D-printed structure to be made from loadbearing elements, using a novel method of integrating reinforcement within the automated process. The 30m-tall Tor Alva is also notable for its richly textured design – inspired by the region's baroque architecture and its equally baroque cakes.

Photos: Birdviewpicture Hansmeyer/Dillenburger

Photos: CheWei Lin; Girts Apskains

The four-storey tower is a cultural venue and viewing platform, nestled in the alpine village of Mulegns. By hosting events in this spectacular eyrie, the aim is to bring new life to the village, which has dwindled to just 11 full-time residents.

The structure is based around 32 unique white concrete columns, cast at ETH's robotic fabrication lab. They are essentially hollow tubes, with concrete applied only where it is needed. A crenelated inner lining creates voids for the vertical rebar.

While one robot applied the concrete in layers, a second placed a ring of reinforcement every 20cm. Because the concrete layers are just 15-20mm deep, non-corrosive stainless steel was specified.

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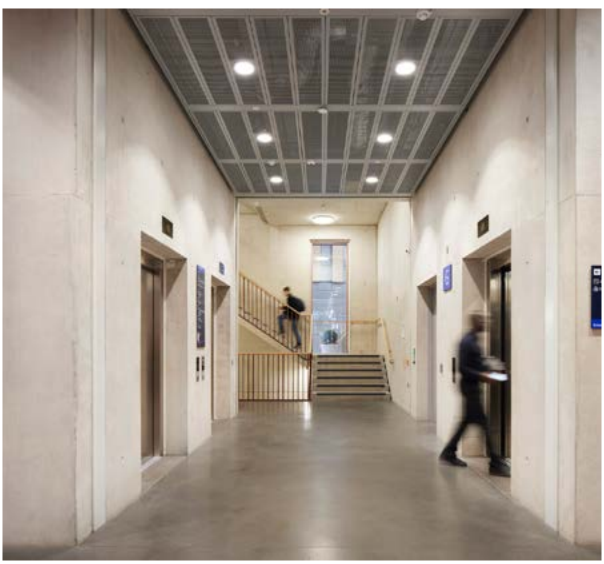
A CERTAIN RATIO

Designed by Allies and Morrison, the School of Public Health at Imperial College London's new White City Campus in west London is a ten-storey building that radiates calm and order, while packing in a huge amount of reconfigurable teaching and research space.

Even though it is next to a 30-storey tower, height was restricted, says Laurie Hallows, director at Allies and Morrison. "We had to navigate the height from the neighbourhood Victorian terraces and step up to the higher scale."



Photos: Jack Hobhouse

To fit in Imperial's expanding programme, the team rationalised the structure. A 10.5m x 7.8m grid became 7.8m in both directions. The shorter spans helped to reduce the slab thickness, cutting the floor-to-floor height from 4m to 3.8m, while maintaining ceiling heights of 2.7m. "This meant we were able to lower the overall height of the building while still squeezing in the floors we needed," says Hallows.

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BETON BLANC

In Paris' 15th arondissement, a 1970s office block has been reborn as "Pong", the largest co-living development in France.

Architect Calq has preserved the distinctive rhythmic facades of profiled windows. High-performance aluminium joinery has increased the glazed area by 120mm in height and 200mm in width, drawing in more natural light and expanding views out. In all, 800 new window units have been installed.

Nearly 90% of the in-situ concrete frame was retained. A key intervention has been the addition of double-height loggias, which open out from the communal living area.

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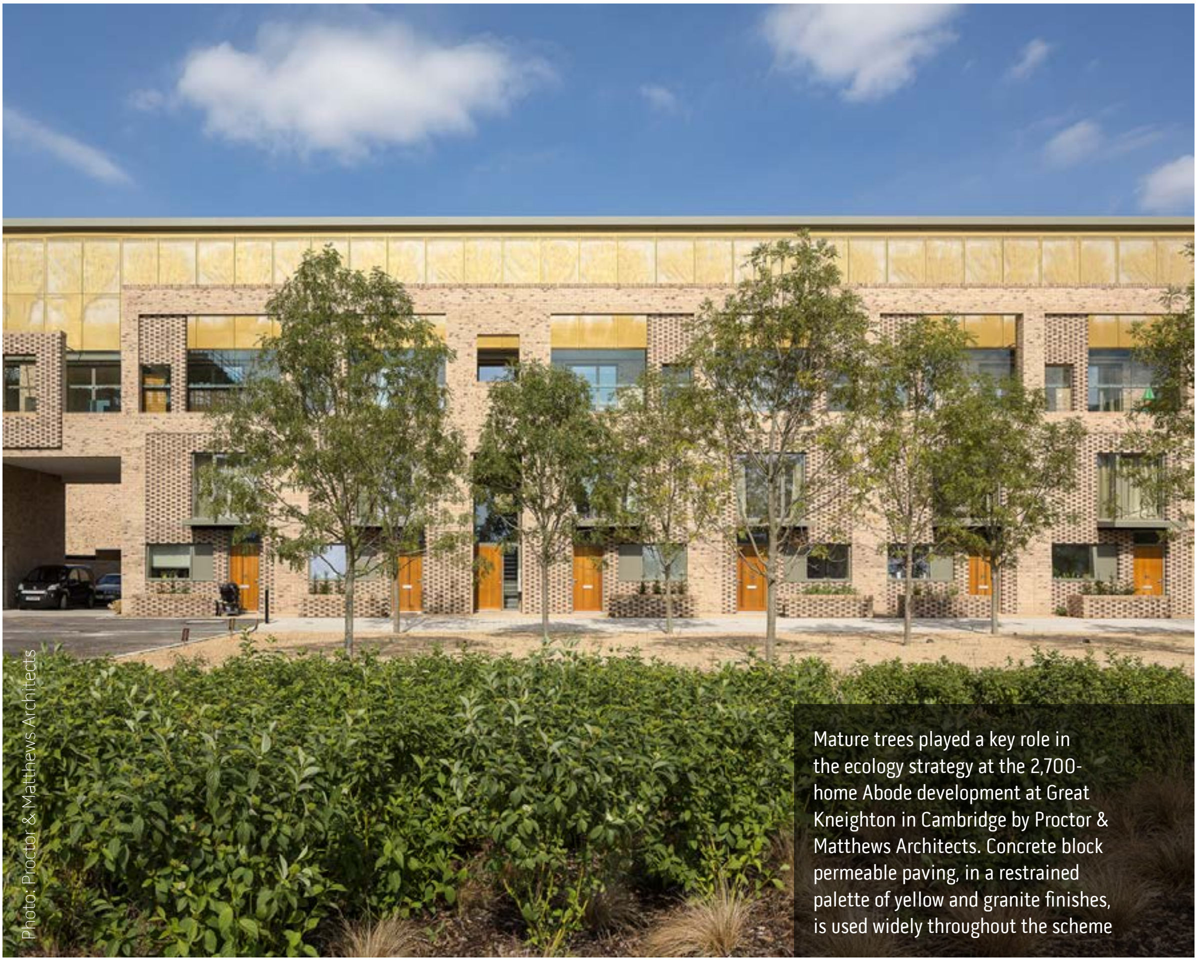
Photos: 11h45



Mature trees played a key role in the ecology strategy at the 2,700-home Abode development at Great Kneighton in Cambridge by Proctor & Matthews Architects. Concrete block permeable paving, in a restrained palette of yellow and granite finishes, is used widely throughout the scheme

Designing hard landscaping to support trees

Trees are essential for making our towns and cities liveable, but we have to meet their needs too. Chris Hodson explains how concrete block permeable paving can be used to create durable urban landscapes that support healthy growth

↓

For centuries, trees have contributed to the character of our towns and cities, providing shade from the sun and shelter from rain. Their wider benefits include carbon sequestration and reducing flood risk, as well as mitigating the urban heat island effect with cooling from shading and evapotranspiration. Urban trees support biodiversity and human wellbeing, and research has linked their presence to everything from reducing noise, air and stormwater pollution, to preventing crime, increasing business activity and property values.

The importance of urban trees is recognised in the new National Planning Policy Framework (NPPF) for England, published in December 2024. This sets the standards and guidance that local councils must follow when writing Local Plans and deciding on planning applications. The NPPF states that: "Planning policies and decisions should ensure that new streets are tree-lined and that opportunities are taken to incorporate trees elsewhere in developments."

What trees need

It's not enough to simply include trees in developments. Measures also need to be put in place to nurture and allow them to mature, generally over decades. The NPPF recognises this, requiring that "appropriate measures are in place to secure the long-term maintenance of newly planted trees, and that existing trees are retained wherever possible".

Trees require access to water, nutrients and oxygen through their roots. They also need to be planted in an environment that allows carbon dioxide to escape. Equally important is soil, or a similarly permeable medium, that allows for deep and expansive root growth to ensure stability.

As our urban areas have effectively been sealed up with impermeable materials, this has created problems for street trees, as well as increasing the risk of surface water flooding. Installing permeable surfaces, such as concrete block permeable paving (CBPP), is a straightforward solution that can help to meet long-term tree maintenance requirements, as well as provide the hardstanding required in urban environments.

Photo: Robert Bray Associates

ABOVE
A community rainpark at Bridget Joyce Square in west London, designed by Robert Bray Associates. Concrete block permeable paving was laid over the existing concrete slab of an adopted street and adjacent parking areas. Rainwater is cleaned, attenuated and conveyed to tree-planted basins as part of a sustainable drainage system

Permeable surfaces are also an important element of sustainable drainage systems (SuDS), which reduce flood risk, remove pollution, support biodiversity and provide amenity. The NPPF requires developments that could have drainage impacts to include SuDS, and the government is considering making them mandatory on all developments.

How CBPP works

Concrete block paving generally combines interlocking high-strength blocks with granular material to form a flexible pavement with minimal movement between blocks. Conventional block paving uses sand for joints and laying courses, and is therefore not permeable. CBPP, however, uses angular aggregate of 2-6.3mm to fill enlarged joints, usually generated by spacer nibs, and as a permeable laying course. This allows rainwater runoff to be collected, attenuated and treated, removing pollutants for a gradual supply of clean water.

CBPP can be applied on top of various permeable structural layers, but typically coarse-graded 4-20mm aggregate is used. This forms voids, making up around 30% of the layer's volume, enabling water attenuation and storage.

The blocks have consistent performance characteristics, making them slip-resistant, safe, strong, durable and reusable. CBPP therefore provides a trafficable surface, while mimicking the dispersed run-off pattern of natural vegetation. It enables water, nutrients and air to reach tree and shrub roots, and CO_2

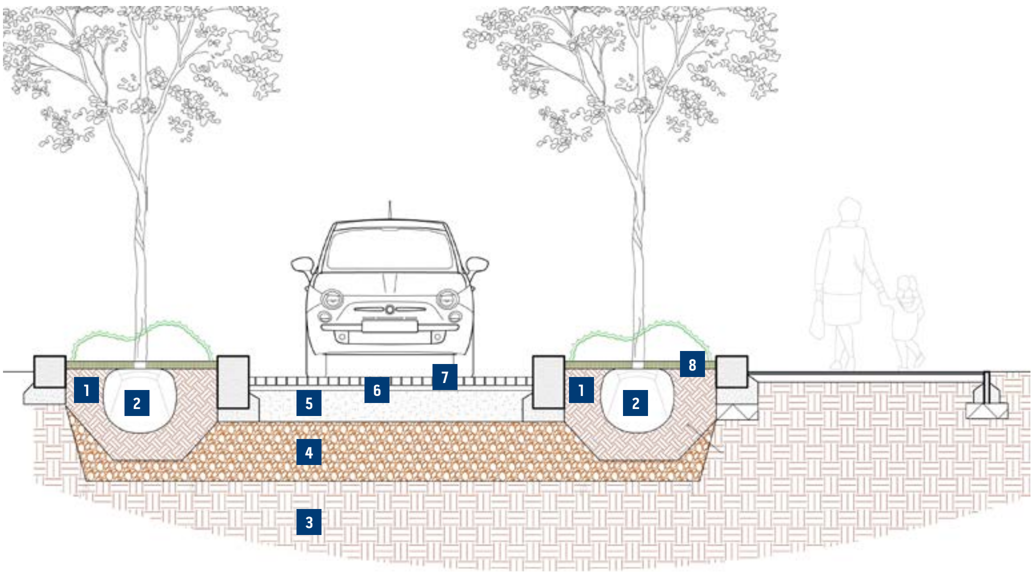


Image: Robert Bray Associates

to escape. Rainfall can be captured over a much wider area for gradual, lateral conveyance to root systems – particularly useful for irrigation in drier summers.

By creating a favourable environment for roots, permeable paving helps to prevent surface damage from upward growth, and facilitates natural expansion into lower levels for stability and longevity.

Alternative profiles and techniques to support urban trees

In addition to the coarse-graded aggregate sub-base described above, alternative structural layers can be included to support trees and green infrastructure, while also providing additional water storage, space for utilities or multifunctional needs.

The ability of CBPP to remove silt is particularly important for protecting many of these alternative systems from clogging.

Tree pits CBPP can be used over and around standard tree pits, enabling irrigation and simple gas exchange, without the need for additional reservoirs or pipes. This also avoids root disruption common with other paving used close to trees, by providing space for tree roots.

Geocellular systems Proprietary permeable sub-base replacement systems can be used instead of the coarse-graded aggregate sub-base. These usually consist of plastic units that form a cellular raft, designed to support anticipated traffic

ABOVE
A tree planting trench with structural soil at Robert Bray Associates' scheme on White Hart Lane, north London (see next page)

1 900mm-deep tree pit backfilled with topsoil

2 Tree root ball

3 Subsoil, ripped (broken up) to depth of 200mm

4 600mm-deep structural soil composed of graded crushed rock and planting soil

5 300mm layer of hydraulically bound coarse-graded aggregate

6 50mm layer of 2-6mm grit

7 Concrete block permeable paving

8 75mm layer of compost mulch

Photo: Robert Bray Associates

loadings. With over 90% void space, geocellular systems can provide water storage and space for soils. They can also improve load distribution beneath paved surfaces, potentially allowing for reduced pavement thickness, and are useful for forming inlets and outlets from the permeable constructions.

Structural soils This system, used widely and successfully in Stockholm, has a load-bearing base of compacted crushed stone or recycled concrete. Selected soils – some incorporating biochar – are then introduced into voids to enable root growth. CBPP, usually laid over a coarse-graded aggregate layer for aeration, provides irrigation and gas exchange, making aeration wells, gulleys and other devices unnecessary.

Retrofit solutions

Mature trees can be protected and their lives extended by replacing impermeable materials around them with permeable surfaces that facilitate hydration and gas exchange.

Hybrid retrofit One approach for introducing SuDS and trees in existing streets is the partial replacement of existing impermeable paving with CBPP to one or both sides, which

ABOVE
Robert Bray Associates' regeneration of White Hart Lane, north London, incorporating a new pocket park with small-element flag concrete block permeable paving. As well as SuDS, it includes new trees with integrated sustenance and protects previously "suffocated" mature trees

avoids utilities and can help to demarcate on-street parking areas. Here, the existing road profile directs water from the impermeable carriageway and also footways onto the CBPP. Correctly specified, CBPP has the capacity to capture all of the rainwater falling directly on it, as well as runoff from surrounding impermeable surfaces, up to twice its own area. Water storage for SuDS and/or sustenance for trees and green infrastructure is achieved with modular geocellular systems or structural soil profiles below the CBPP, and/or rain gardens.

Permeable paving overlays The permeable surface zone can simply be applied as an overlay to impermeable constructions to collect, clean and convey water laterally to raingardens, trees, SuDS features or sewers. This is a low-intervention, low-cost approach to SuDS that reuses existing impermeable road-bases and locks in their embodied carbon.

Specifying CBPP

CBPP can withstand heavy loadings, and is suitable for urban areas where speeds are lower, typically below 30-40mph.

The relevant British standard for the design of permeable paving is BS 7533-13:2009. However, an updated standard, BS 7533-103, is under development and expected to be published for public consultation in June 2025. For guidance on designing SuDS, refer to The SuDS Manual (C753) from CIRIA.

Correct design, detailing and construction of CBPP is key to its long-term performance. This includes:

- preventing soil and mud from entering the base and surface both during and after construction
- ensuring that joints are completely filled and topped-up at construction completion, and avoiding soil and mulch being washed from landscaping onto the CBPP.

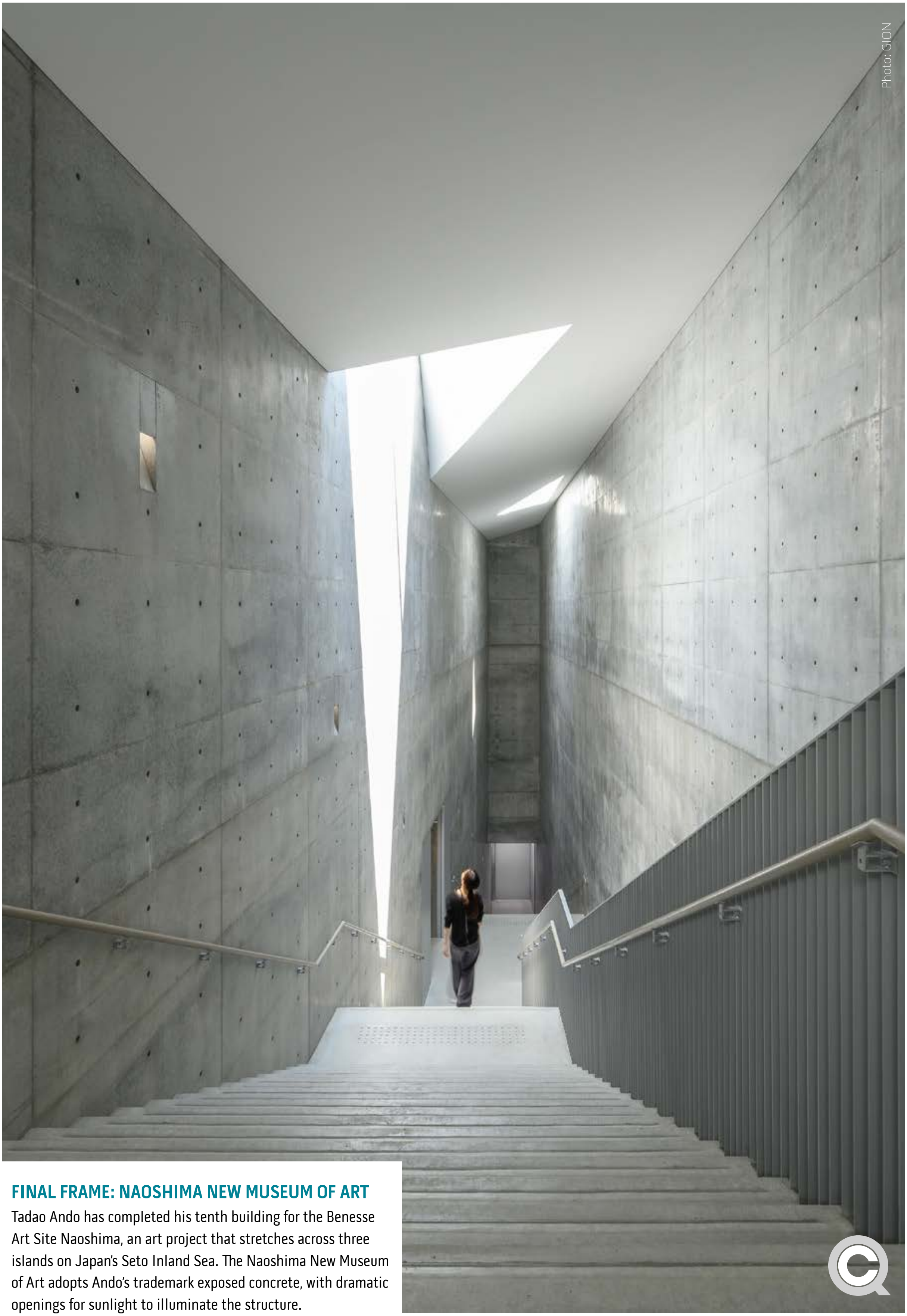
Current maintenance regimes for other paving can generally be applied to CBPP, although aggressive mechanical brushing which might dislodge jointing material should be avoided.

Any localised problems will generally be apparent on visual inspection: ponding on the surface indicates that the joints may be blocked, which can be resolved by suction brushing and replacement of jointing material. Damaged or displaced paving units indicate structural issues. In the absence of these indications, no remedial action is necessary.

Chris Hodson is a consultant to MPA Precast and author of its guidance document, *Understanding Permeable Paving*. For case studies and guidance on all aspects of permeable paving and SuDS, go to mpaprecast.org/paving

Photo: Chris Hodson

ABOVE
Hybrid retrofit street enhancements by Robert Bray Associates at White City, London. Concrete block permeable paving has been installed to demarcate on-street parking, providing sustainable drainage and a puddle-free surface. Litter, silt and pollutants are retained on the surface for removal with straightforward cleaning



FINAL FRAME: NAOSHIMA NEW MUSEUM OF ART

Tadao Ando has completed his tenth building for the Benesse Art Site Naoshima, an art project that stretches across three islands on Japan's Seto Inland Sea. The Naoshima New Museum of Art adopts Ando's trademark exposed concrete, with dramatic openings for sunlight to illuminate the structure.