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CONCRETE QUARTERLY

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CASTING OFF

INSPIRATION

APPLICATION

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

The beauty of doing less

To start with a generalisation, there are two reasons why an architect might need to stick their nose into how concrete is made: because they care about its appearance, or because they want to reduce its embodied carbon.

Much of my time is spent answering designers' technical queries on each of these – and while they might seem like separate conversations, I've found that it's very hard to discuss one without talking about the other. This is because it's the cement content of concrete that is largely responsible for both its colour and its embodied carbon emissions. So when advising architects on visual finishes, I have always indirectly ended up talking about sustainability – in terms of cement replacements such as GGBS and fly ash. When the topic is sustainability, visual concrete often comes up too – not only because the composition of a mix affects its appearance, but because leaving concrete surfaces exposed is increasingly common as part of a holistic low-carbon approach. By allowing the concrete to act as both structure and finish, and often fulfilling a range of acoustic and safety functions too, this reduces the overall amount of materials required, and the need for maintenance over the long term. And it can lower operational carbon emissions too, by tapping into concrete's thermal mass to reduce demand for heating and cooling.

The challenge here is that exposed concrete is not everyone's cup of tea. It is traditionally associated with an industrial aesthetic, beloved in warehouse conversions, creative offices and funky retrofits, even though a quick flick through these pages, let alone CQ's extensive archive, reveals myriad other ways to display it. This is a familiar conundrum that recurs in every other aspect of

life, where halting climate change requires us to change our habits, preferences or tastes: it won't work as well if it is perceived as a hair-shirt option.

Fortunately, there are as many ways to refine concrete's appearance as there are to lower its carbon – which is to say a lot. The composition of this material and the way it is made is multifaceted and undeniably complex. As architects, we've never really needed to get into this level of detail, and it's generally not been part of our training . But the pressing need to reduce carbon, and to ensure materials are responsibly sourced, means that we can no longer afford not to: the industry is steadily reducing the embodied carbon of UK concrete, but some of the biggest, unexplored opportunities for carbon savings using concrete are in the hands of specifiers – if they know how to seize them. Architectural education needs to be updated to reflect this too.

We can't lose sight of the bigger picture: we are building not for its own sake but to meet a social need – for shelter, for education, for community or civic life – and if people don't enjoy being in the spaces we're creating, all our efforts (and a lot of materials) will be wasted. So if we are specifying exposed concrete as part of a sustainability strategy, we need to talk about how to make it beautiful too. ■

IF PEOPLE DON'T ENJOY BEING IN THE SPACES WE'RE CREATING, ALL OUR EFFORTS (AND A LOT OF MATERIALS) WILL BE WASTED

CONCRETE QUARTERLY

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On the cover:
West Hub, University of Cambridge, by Jestico + Whiles. Photo by Ståle Eriksen

Photos: CREST

INNOVATION

CHARCOAL CONCRETE

A RESEARCH PROJECT IN NORTHERN IRELAND IS EXPLORING HOW ADDING RECYCLED CARBON – IN ITS PUREST FORM – COULD MAKE BETTER CONCRETE

ABOVE
Unprocessed biochar (left) and a concrete sample containing 2.5% biochar by weight as an aggregate replacement

Glance in any skip and you will probably see a large quantity of wood waste: everything from plywood and old window frames to chipboard and MDF. It is tricky stuff to recycle or reuse, but a research project in Northern Ireland is looking at how this motley collection of waste items could be put to use – in concrete.

"Construction and manufacturing produce a lot of wood waste, but much of it is contaminated with glue, paint or resin," says Seán McKenna, industrial development associate at the CREST Centre. "Our research was initially focused on how it could be made more reusable."

McKenna's team, based at Enniskillen's South West College, found that turning the waste into charcoal made it a purer, more consistent product. "Charcoal is created by pyrolysis: heating the waste in the absence of oxygen. This drives off a lot of the volatile impurities and leaves us with mainly carbon." This process is already used in agriculture to make the soil improver, biochar. "Unfortunately, our waste wood charcoal is still not pure enough for agricultural purposes. But just as biochar's unique properties can enhance soil, we believe it could also be a useful additive to concrete."

McKenna is now investigating charcoal's use as a cement substitute, a hydration controller, and as a

JUST AS BIOCHAR'S UNIQUE PROPERTIES CAN ENHANCE SOIL, WE BELIEVE IT COULD ALSO BE A USEFUL ADDITIVE TO CONCRETE

volume replacement material. "Of course, using charcoal is a way of storing carbon for the long term and reducing concrete's carbon footprint. But we are not out simply to maximise carbon sequestration. We want to take an unbiased look at exactly how charcoal can affect concrete in both the curing process and the finished product. The more we know, the more applications will emerge."

Early research has involved grinding down the charcoal to a fine powder with particles about 50 microns across – a size comparable to cement powder. "As a cement substitute, we are probably looking at just 1-2%," says McKenna, "but the effects on hydration are interesting. Essentially the charcoal acts as a micro-sponge, initially absorbing moisture and tending to speed up the curing process. This has the potential to deliver buildability benefits on site, or speed up precast production."

Counterintuitively, charcoal's sponge-like properties could also reduce concrete shrinkage: "This usually happens because moisture escapes the concrete too quickly after pouring," says McKenna. "But we think the charcoal could help by buffering that process. Though charcoal does at first absorb moisture, it seems more water is available for the later stages of curing because it is stored within the charcoal's high surface area."

Finally, says McKenna, charcoal could make concrete more waterproof: "Carbon is an amazing element. It's the building block of life and has been called the Lego of the universe. In concrete, we find its shape tends to fill gaps within the microstructure, potentially improving impermeability." It is an impressive array of qualities for a material derived essentially from dirty wood, and McKenna, who is also an architect, is keen to develop the research further in conjunction with a producer or manufacturer. ■

Interview by Tony Whitehead

BELOW
CREST's Seán McKenna uses a ball mill to reduce the particle size of the biochar to about 50 microns

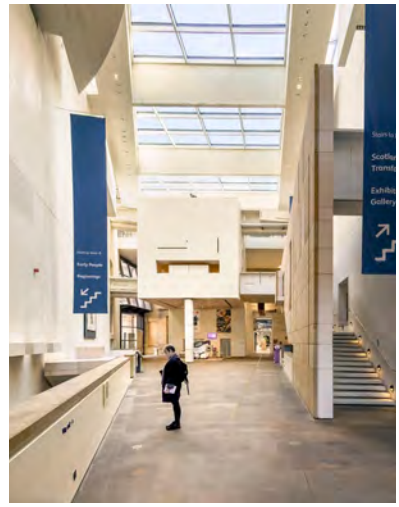
LASTING IMPRESSION

ANDREW McEWAN

FOUR BUILDINGS THAT INVITE YOU TO ROAM, FROM A CASTLE-LIKE MUSEUM AND AN EERY ISLAND GALLERY, TO A TEA HOUSE ON THE ROCKS AND A BANK WORTH BREAKING INTO ...

As a practice, we often talk about buildings as being "ultra-practical", drilling into but transcending practicality to get to a point where there's no other solution. We like buildings that have an exploratory, storytelling nature behind them. Benson and Forsyth's Museum of Scotland extension (1998) is a very ambitious, urbane building but it evokes the Scottish castle, as a series of really thick, inhabited walls. There's not a clear route, there's lots of nooks and crannies to hide in and move through. It feels like it was designed around the collection. The exposed concrete only reveals itself where it benefits the exhibition, and they've used its plasticity, cutting and making incisions to allow light and views through the structure.

Benesse House (1995) is a museum and hotel in one, designed by Tadao Ando, on Naoshima Island in Japan. It's a completely exposed concrete building, with single and double-height gallery spaces and a whole series of circulation ramps that take you on a journey. There are lots of glimpses out through rooflights and apertures into



LEFT
Museum of Scotland extension in Edinburgh, by Benson and Forsyth, 1998

BELOW
Benesse House, Naoshima Island, Japan, by Tadao Ando, 1995

Photos: Xia Zhi; woolver / Alamy Stock Photo

adjacent spaces and onto framed views of the Seto Inland Sea. The light is amazing, especially if you're staying in the hotel and you're there at dusk. It's a bit surreal – you go for dinner and then you have free rein to meander through the gallery when everyone else has gone.

Álvaro Siza's Boa Nova Tea House (1963) on the coast north of Porto is a different sort of journey. You approach it as a very modest white rendered building on the shore, and you go up a series of steps through the rocks. As you pass through the front door, everything slopes down – there's a sense that you've crossed a threshold to a point of compression. There's one slit window directly ahead that must be about 300mm high, and the sky meets the sea perfectly in the middle, like a razor blade. The concrete is juxtaposed with a rich timber ceiling and joinery pieces, and there's a real humanity to it. The full-height windows drop down into the ground so that, as you sit at your dining table, the sea is within touching distance.

Clorindo Testa's Bank of London and South America HQ (1959) in Buenos Aires is another amazing piece of architecture, with a concrete exoskeleton that kinks and bows and thrusts itself forward to match the adjacent cornice line. It's totally modern but incredibly contextual. As you enter the expanse of the banking hall, it's a structural masterclass, with four floors of offices hung from the exoskeleton and a sculptural concrete stair at the heart of it. It's a world that you just want to explore. ■

Andrew McEwan is an associate at ORMS

BELOW
Boa Nova Tea House near Porto, by Álvaro Siza, 1963

BOTTOM
Bank of London and South America HQ in Buenos Aires, by Clorindo Testa, 1959

Photos: Fernando Guerra/VIEW; Federico Cairoli

FROM THE ARCHIVE: AUTUMN 1950
'LEAN AND TAUT AS A GREYHOUND'

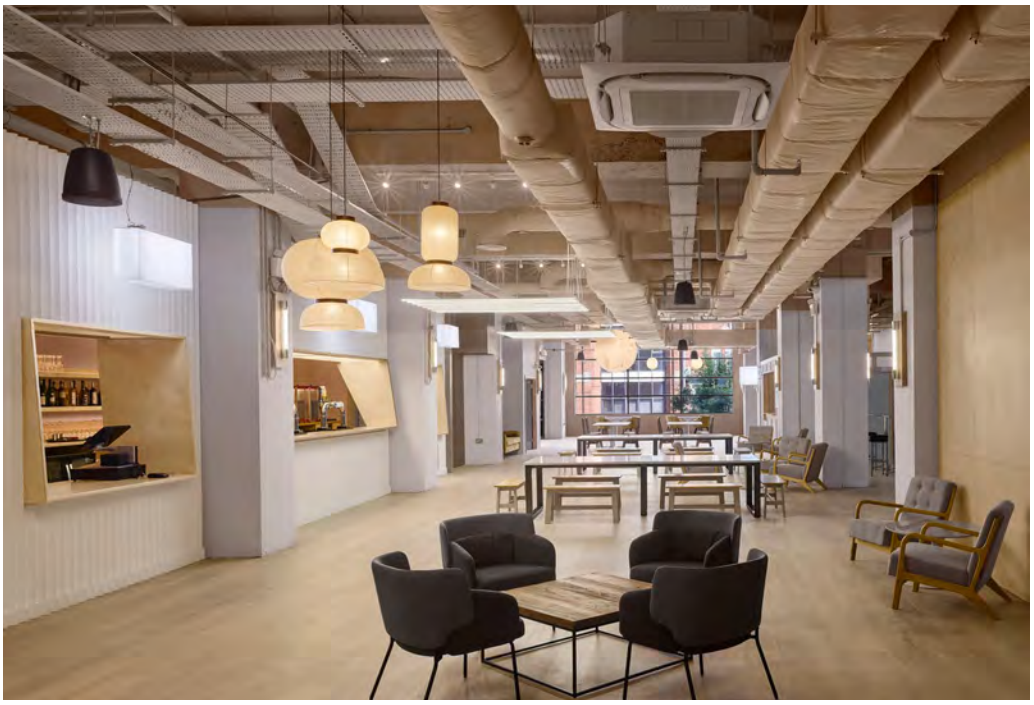
This year marks the 150th anniversary of the birth of Robert Maillart, the Swiss engineer who revolutionised the use of reinforced concrete, revealing it to be a material of not just strength but, as Concrete Quarterly put it, "spare beauty". Between the two world wars, Maillart designed over 40 bridges of slender lines and elemental simplicity, his hallmark a three-hinged box arch that united arch, roadway and spandrels as one structural unit. His 300ft-span bridge over the Salgina gorge, CQ wrote, sprang "lean and taut as a greyhound across the ravine".

Reflecting on Maillart's legacy in 1950, 10 years after his death, CQ was keen to stress that such "lovely leaping lines" were not only great engineering but great art. Maillart was "a modern designer in the truest sense – a man who could use an unfamiliar material in a way wholly appropriate to it and to no other and in so doing evolve a new structural style".

That said, it was neither engineering nor art that impressed his clients, so much as what he described as the "economic advantages" of his material-efficient designs. Indeed, CQ noted, Maillart's bridges horrified Swiss officials, who tended to commission them in remote Alpine gorges where few people would see them. "In some far away valley where a cheap bridge would do, a Maillart design might as well be used and money saved." Of course, this just elevated the drama, the mountains providing an awe-inspiring context for the delicate, arching structures.

Maillart saw beauty and economy as closely entwined, and perhaps in our energy-constrained times this is his most important legacy. "Let the engineer free himself from the forms dictated by tradition," he wrote, "to achieve in complete freedom and with his eyes fixed always on the whole, the most perfect and most economic use of his material. Perhaps in this way we may attain, as with aeroplanes and motorcars, a new style, attuned to the new material – in short, we may attain beauty." ■

Explore the CQ archive at concretecentre.com/cqarchive



ORIGIN STORY

BISCUIT FACTORY

WREN ARCHITECTURE'S CINEMA AND COMMUNITY SPACE HIGHLIGHTS THE LATENT POTENTIAL OF DISUSED SHOPPING PRECINCTS

"There are empty stores all over the country that people are trying to figure out what to do with. I don't think anyone's got a magic bullet," says Philip Wren, director of Wren Architecture.

He knows what he's talking about: his practice has worked with some of the most unprepossessing shops left behind by changing shopping and leisure patterns: a discount store in a 1970s Catford precinct, a stockroom in Reading, even a notorious nightclub in Ealing.

"There are all sorts of advantages to retaining the structure and finding a new purpose for it," Wren says. "Obviously, there's the carbon footprint, but also just in terms of the health of the local economy. If you tear something down, it could

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take anything up to 10 years to replace. In the meantime, there's a big black hole in the middle of the town."

The most recent example of this approach is the Biscuit Factory in Reading, a second cinema project for Really Local Group, a venue operator that specialises in regenerating high streets with cultural and community projects. The Biscuit Factory, like the previous project at Catford Mews, is not really a cinema in the traditional sense at all, admits Wren. "It's more like a rethink of a community centre – somewhere between a coffee shop, a cinema, a food hall and a venue."

It has certainly come a long way from its former life as a dingy first-floor stockroom for Argos. Facing onto Oxford Road, a prominent shopping street, the building is a reinforced-concrete structure that forms both the corner of the mall and a podium for a nine-storey office tower above. The redundant stockroom was essentially a black box – "perfect for a cinema, but not so good for anything else". The main question for the architects was how to draw people in past the ground-floor supermarket. "Because it has all these different functions, the issue was, how do you get them upstairs?"

Considering the dramatic change needed, the interventions have been surprisingly minimal. "We don't go in with a plan to rip out as much as possible," says Wren. "We want to be quite surgical about what we do."

A large picture window has been cut into the front, and a big slice taken out of the corner, above the main entrance, to create a balcony. "That external space forms a much

TOP
One corner has been carved open to create an external terrace

ABOVE
Exposed columns offer a "little clue" as to the building's past life

more positive connection with the street below – there's no physical barrier. It's a signifier that there is something happening up here."

Wren was fortunate that the landlord had all of the original building drawings, so the team knew where they could cut into the reinforced-concrete slab. A hole was made for a platform lift, and smaller incursions were threaded through the thick slab to the plant area above level one. The open cafe/communal area is dominated by a series of huge columns that hold up the office tower. "We kept them clear. The way they march down the space creates a nice sense of order."

There are further columns in the three screening rooms, but again the designers have worked around them, orienting the screens so they can act as separators between the seats and aisles. Similarly, a massive slab structure from the shopping centre car park has been avoided by raking the seating in the main auditorium.

The acoustic design has been aided by the fact that the screens are all fairly small – two have 60 seats and the third has 92. They are divided by lightweight plasterboard double walls, isolated using resilient pads and detailing, but otherwise there is no sound absorption. "You get a little bit of reverberation in the room, which actually is quite nice. It makes the sound slightly livelier."

There are plenty of reminders of the building's less glamorous past, not least the stripped-back columns of time-worn concrete that adorn the balcony. "It's like leaving a little clue," Wren says, "a scar or tattoo of what's been before. ■

ABOVE
The opened-up terrace creates a connection to the street below

RIGHT
Oversized columns in the main communal space support the office block above

Photos: Will Pryce, Richard Parkes

Photos: © Ståle Eriksen

HUB AND BESPOKE

The beating heart of Cambridge's new innovation quarter, Jestico + Whiles' West Hub is a unique academic and public building with a highly tailored structure, writes Tony Whitehead

As its name suggests, Cambridge University's West Hub is primarily a place for connections to happen. The £40m, three-storey facility houses a library, cafe, seminar rooms, offices and work space. So far, perhaps, not that unusual. But West Hub represents the start of a radical transformation of this research campus to create a new quarter in the city, dubbed the West Cambridge Innovation District.

ABOVE
The structure – including the 275mm slab edge and 550mm-high concrete upstands – is legible throughout the atrium

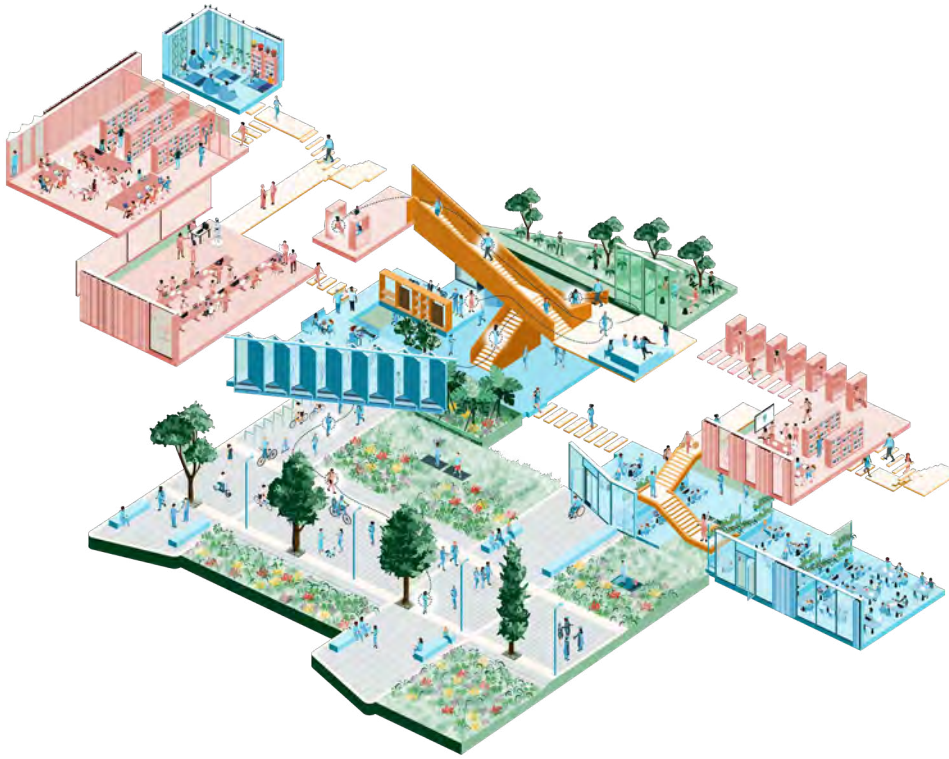
THIS IS A BUILDING WITH A VARIABLE AND UNPREDICTABLE OCCUPANCY – YOU MIGHT HAVE 200 STUDENTS COMING IN FOR A LECTURE AND THEN DISAPPEARING

The buildings here have to walk the talk in terms of inventiveness, sustainability and cutting-edge technology – so the 4,700m² West Hub is rated BREEAM Excellent, and features a ground-source heat pump, a blue (water-retaining) roof, and internal gardens to promote wellness via biophilia. And the whole and its parts are carefully organised to foster links between the university and the town, and between business and academia.

This desire for user-friendly openness informed the whole design, including the choice of concrete for the structure. "The building is open to the public," says architect James Tatham, a director with Jestico + Whiles. "You don't have to cross a security threshold to enter it, and in fact there is a pedestrian route through the building via its two main entrances, so we wanted it to be welcoming. We considered several options for the frame (see page 20), but we wanted this place to feel different to other university buildings: not too academic or polished, but more like shared workspace with a cafe feel. So the largely exposed concrete frame, with its slightly rougher, almost industrial aesthetic, really works well for us."

ABOVE
The building is clad in perforated aluminium, which will reflect the colours of the landscape as it develops

The exposed concrete is also integral to the heating and ventilation strategy: its thermal mass absorbs sudden influxes of excess heat and stores it to reduce heating demand later. "This is a building with a variable



and unpredictable occupancy – you might have 200 students coming in for a lecture and then disappearing," Tatham points out. "Compared with a more lightweight structure, the concrete helps to even out the fluctuations that can cause."

Finally, he says, standard reinforced-concrete flat slabs of variable depths provided robust flexibility to deal with a demanding range of loading requirements: "The shelves of books in the library area, together with some permanent bespoke furniture, results in some heavy loadings. The structure needs to be able to cope with that along with the potentially large live loads caused by groups of people – queuing to get into a lecture, for example."

The building sits on an 800mm-deep raft slab made from concrete containing a high proportion

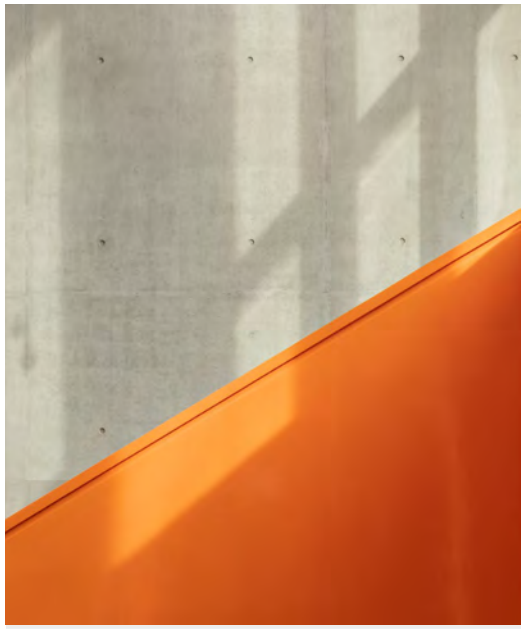
ABOVE
Axonometric drawing showing the different uses and loadings throughout the building. The slabs and spans vary to support the different functions

of GGBS cement replacement. "We specified at least 70% GGBS for this," says Oliver Neve, an associate at Ramboll, which undertook the structural design of the project to stage three. "The higher content slows the curing process and helps keep down the heat of hydration during the pour."

Generating less heat, which helps to maintain the integrity of the finished concrete, is also achieved by keeping slabs thin. So why did Ramboll choose the thick raft option? "We've done a lot of work in this location and find that a raft is usually the best solution in terms of cost and concrete volume," says Neve. "It sounds counterintuitive, but long piles and a slimmer suspended slab can actually use more concrete and are more time-consuming and expensive to construct."

The building was designed back in 2016, so there was no specific embodied carbon

BELOW
Each storey is a different height, creating different ambiances: an active and lively ground floor, a relaxed, calmer first floor, and a quieter upper floor for focused study



Tough choice: filtering the structural options

Standard reinforced in-situ concrete is seen as a safe and cost-effective structural option – but it would be wrong to assume designers simply pencil it in without giving thought to alternatives. At West Hub, the team undertook an exhaustive "filter" study to ensure that a fair hearing was given to a wide range of structural choices.

"For example," says Ramboll's Oliver Neve, "we looked at cross-laminated timber and glulam, but discounted them because we wanted to use the thermal mass of concrete to cope with temperature variations. The university likes to minimise active heating and cooling where possible, so that choice resulted very specifically from the client's assessment as there would be now, he adds. "But clearly the GGBS content of the raft helps reduce the carbon content. We specified 20% GGBS for the rest of the building."

West Hub's many different functions are reflected in a structure that is quite irregular, or "bespoke" as Neve puts it. "There's a lot going on. We have spaces here providing many different functions – from library to kitchen to auditorium – and this results in different loadings and different ceiling heights."

"The slabs vary to suit spans and loading types that vary within the floorplate," agrees Nicholas Clegg, a structural engineer at BDP, which took the design forward from stage four. "So we have slab depths of 275, 300, 350, and 375mm – putting the strength where it is needed. It's the same with the grid. Typically it is 7.2m between columns along the length of building. But across, it varies, being either 6.45m, 6.725m or 6.85m."

The main atrium provides visitors with an excellent view of the structure: a 275mm slab edge is clearly visible and rising from it is a 550mm-high concrete upstand. As well as forming part of the balustrade, these 400mm-thick upstands stiffen the slab edge around the atrium, effectively acting as slab edge beams.

This upstand beam arrangement is continued beyond the slab, part way along the glazed facade side of the atrium. This works both aesthetically and structurally: "The beam here is

long-term sustainability strategy. We also considered post-tensioned concrete slabs but, on this occasion, felt that the grid arrangement was not regular enough to realise efficiencies there."

The design didn't involve enough repetition to make precast concrete economically practical. Meanwhile, the long spans involved ruled out a steel-and-precast combination: "They would have led to some very heavy sections and the need to design-in downstands."

Finally, metal composite decking was discounted as "failing to meet the architect's aesthetic requirements", or simply: "Too ugly."

In the end, says Neve, "we felt a standard reinforced-concrete frame was the most cost-efficient way of achieving the design flexibility we needed throughout the building."

825mm deep to match the slab/upstand combination, and spans between columns at the facade in order to support the corner of the atrium slab that does not align with the column grid."

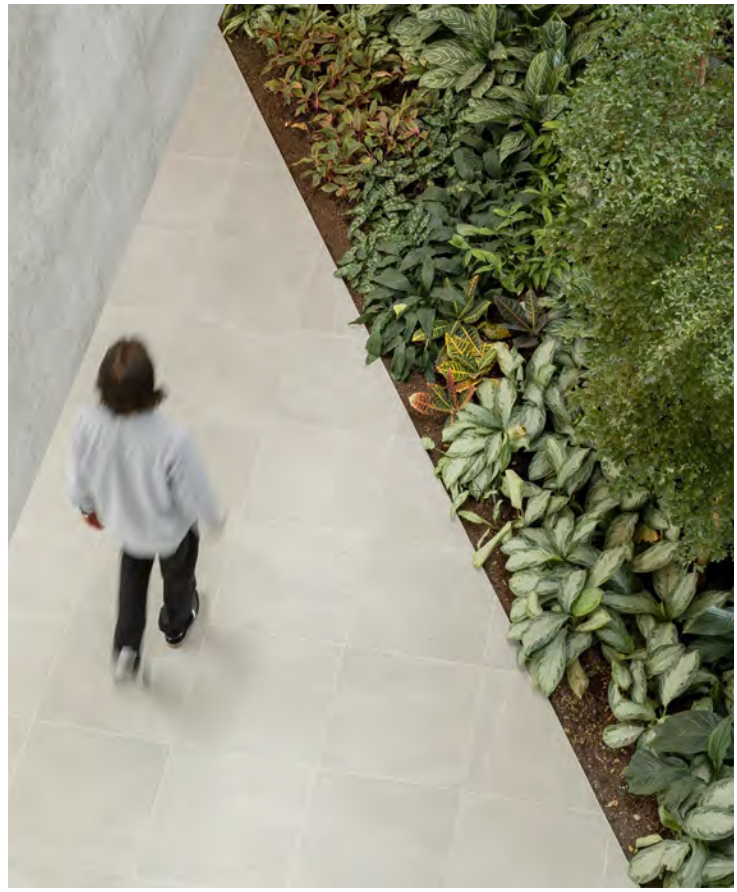
One corner of the building required unusually long spans: "This is the area with the bar on the ground floor and seminar rooms above it," says Clegg. "To keep these areas as column-free as possible, the slabs here span 10.8m from the building perimeter to support from a central column. To achieve the longer span, the slab is a thickish 350mm, but is also pre-cambered by about 10mm to accommodate the deflection."

BELOW
To keep the bar area as open as possible, the slab spans 10.8m from the building perimeter

The pre-cambering was created by pouring the slab over a thin, mound-shaped form. The effect is that of a very shallow arch to the underside, which disappears once formwork is removed and the concrete has settled. In accommodating the deflection, the weight of the slab also compresses its centre, helping to strengthen and stiffen the element. Most of the columns in the building are 400 x 400mm square, but here they are increased to 450mm sections to support the extra load of the longer spans.

The chamfer-edged, square-section columns are visually impressive. Around the atrium areas they rise up to two storeys and have a smooth, almost precast appearance, with little evidence of the pouring process. The smooth finish results partly from the use of metal forms: being more than one storey high, the weight of concrete could have distorted traditional timber shuttering.

"Much as you can try to specify a finish, it is ultimately quite subjective," says Tatham.



BELOW
Trees and planting are integrated into the fabric of the building, with two internal gardens in the light-filled atriums

ABOVE
Ground-floor seating areas – part of the public route through the building

"So early on we visited several existing buildings to benchmark and reach a consensus with the contractor on what was acceptable in terms of quality." A number of test panels were constructed before final approval – a luxury afforded to West Hub by virtue of the fact that it shares both designer and contractor with the new Cavendish Laboratory, now being constructed on the next-door site. "The investment in samples would have been difficult to justify for us alone," he explains. "But as the combined value of the projects is around £200m, we

could afford to try various approaches." In some places, he adds, post-finishing was carried out by GreyMatter, a firm that specialises in improving the appearance of in-situ concrete. "Its work is akin to art restoration – blending in any problem areas."

The clean, pale concrete is set off by bold orange accents from the permanent furniture, and the orange-clad steel truss staircases which are attached to fixings cast into the slab edges. Moving out on to the second-floor open terrace, building users will be able to look over the super-sustainable Innovation District – but may not be aware that they are actually standing on one of West Hub's green innovations. "Being a north-facing building we were keen to allow occupants the chance to get out into the sunshine," says Tatham. "Rainfall on the roof is drained through

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PROJECT TEAM
Architects Jestico + Whiles; BDP
Structural engineer Ramboll
Main contractor Bouyges UK
Concrete finishing GreyMatter

RIGHT
The second-floor terrace incorporates a blue roof that controls rainfall run-off from the building

ABOVE
Glazed facades and illuminated signage highlight the building's hybrid public-academic function

the terrace pavers into a 600mm-deep "blue" roof – effectively a wide, shallow, concrete attenuation tank that works to regularise run-off from the building and avoid putting any undue pressure on local drainage systems."

The terrace is typical of how this building works. It is undemonstrative, yet subtly working hard to achieve its owner's goals: a friendly, collaborative space, and one that treads lightly on the earth. ■

BARE FACED CHIC

Edinburgh Park began life in the 1990s as a business park but is being reimagined as a mixed-used urban quarter for the Scottish capital. Allford Hall Monaghan Morris' 1 New Park Square is one of its centrepiece buildings – an all-electric, concrete-framed office block, with events space, restaurants and public facilities. 'The brief was for a relatively simple building made of robust material that would stand the test of time," says AHMM associate Matthew Hart.

Photos: Timothy Soar

The decision to use concrete was supported by the findings of an early-stage sustainability review, which suggested that summer cooling loads would be reduced by 38% with exposed concrete as opposed to lightweight plasterboard. This drove a strategy that included both exposed thermal mass and openable windows, along with 3.15m floor-to-ceiling heights to improve daylighting and thermal comfort, and deep window reveals to provide some passive solar shading.

A 40% GGBS mix was used for the main structure of the BREEAM Excellent building.

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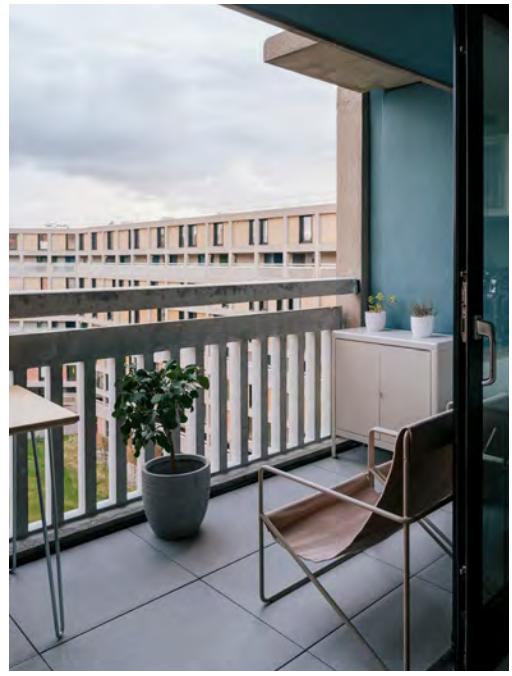

Photos: Tim Crocker

BRUTE, MUTED

Mikhail Riches has taken a light-touch approach to the latest phase of the mammoth Park Hill regeneration project in Sheffield, celebrating the original structure while reconfiguring the horseshoe-shaped block as 195 modern homes, alongside offices, shops and cafes.

One of the major challenges was the cold bridging inherent in the structure. The beams and slabs run through the apartments to the balconies and "streets in the sky", with only a layer of asphalt covering the concrete access decks. The streets also had low soffits, not only making them feel institutional, but giving the team very little space to work with. As much insulation as possible has been added while still maintaining a 2.2m floor-to-ceiling height. This has included linings to all of the decks, soffits and external beams and an upgraded 600mm floor zone inside the flats.

Colour – in 12 subdued tones – has been added to the balcony reveals rather than the main face of the building. "So when you look at it front on, you just see the brick. But as you turn the corner, the colour reveals itself," says Alim Saleh, senior architect at Mikhail Riches.

READ THE FULL STORY
concretecentre.com/cq

STACK EFFECT

A pair of residential towers in east Stratford, designed by Hawkins\Brown, has been delivered using a new approach to modular high-rise construction.

Portlands Place, which contains 524 private rental homes, was built by Mace using an innovative system based on the precision placing of precast-concrete floor modules. Perimeter floor units were delivered with the facade attached, fixed at the bottom and supported with temporary props. This meant that as soon as the units were lowered into place, the perimeter became a safe, enclosed working environment in which to complete the internal floor modules (see photo, bottom). These were fabricated complete with precast columns and included provision for other factory-assembled or hybrid elements, such as twin walls, lift shafts, vertical riser modules, and bathroom and kitchen pods. The entire process was carried out using just two cranes.

Mace says the use of the system led to 25% programme savings, a 40% reduction in site traffic, 75% less waste and 15% reduction in embodied carbon across the project.

READ THE FULL STORY
concretecentre.com/cq

Photos: Simon Kennedy, PCE Ltd

ABOVE The HiRes Concrete Slab at the Nest research building in Zurich, designed by DBT and Block Research Group. A binder-jetting process was used to 3D-print an optimised mould with highly complex contours and double-curving seams

On the surface: Formwork for visual concrete

Exposed concrete finishes can be both beautiful and sustainable. But their success relies on designers understanding the many different ways of creating formwork, writes Hannah Fothergill

When it comes to high-quality visual concrete, the type, control and accuracy of formwork is often the differentiating factor. There is an old industry adage that good quality concrete is the result of good quality joinery. While contemporary formwork systems are more likely to consist of a kit of parts with reusable layers and elements, bespoke, individually crafted timber moulds are also still possible. The solution chosen by a contractor will depend to a large extent upon the scale and form of the concrete being poured, but may also be dictated by aesthetic decisions such as tie bolt locations and joints. It is therefore useful for architects and engineers to understand the processes and the many different ways of creating formwork to align their design aspirations with achievable outcomes.

In the National Structural Concrete Specification (NSCS), the surface finish of concrete is divided into four categories: basic, ordinary, plain and special. Visual concrete tends to be plain – where visual quality is of some importance – or special, where visual quality is of high importance, and architectural formed finishes and worked finishes are required. Architects and structural engineers do not typically design or choose the formwork system – this is the responsibility of the specialist concrete contractor. However, for visual concrete, where there is a desire to control the sheen or texture of the concrete surface, type of tie bolt holes, joint lines and other details, it is useful to understand the available formwork options and their impact on the concrete. The desired visual concrete results should be clearly described in tender documents, using benchmarks, and design intent drawings, informed by advice from the contractor and supply chain. This is especially important for complex geometries or other unusual features. The contractor's detailed proposals should be reviewed and agreed before construction begins.

FORM-FACING MATERIALS

The form-facing material is a key area to consider, as this is the surface that is in direct contact with the concrete. The type of form-facing board may dictate the overall choice of formwork solution, and potential materials include plywood,

steel, polycarbonate, timber or special ply boards. Impervious materials such as steel and phenolic-faced ply create a more reflective surface sheen and can give a slightly mottled tonal appearance to the concrete, with more blow holes. Permeable materials, on the other hand, tend to provide a matt finish and fewer blow holes. Some standardised systems offer a choice of facing material, others are integral and more commonly used for basic and ordinary concrete finishes.

Where specific surface finishes or controlled joint lines are required, a form-liner can be added to the surface of the formwork system, providing more design freedom. Form-liners typically provide little support, but may add some useful stiffness and tolerance control to the formwork.

For curved forms or textured surfaces, the choice of form-facing material to enclose the concrete will also be dictated by the ability of the material to be bent or made into the design form.

Common types of formliner include:

- **Steel.** This creates a shiny finish, as it is non-absorbent. Concrete is prone to more blow holes and colour variation. Steel is extremely durable and can be reused many times on different projects.
- **Phenolic board / high-density overlay board (HDO).** This creates a shiny finish and leaves tiny pinholes as it is non-absorbent. HDO is very durable and can be re-used multiple times.
- **Paper-faced board / medium-density overlay board (MDO).** This creates a matt finish, with reduced colour variations. MDO has medium durability and can be reused, but not as many times as HDO.

Photos: Hufton + Crow, Peri Ltd

ABOVE
The elaborate curves of Kengo Kuma's V&A Dundee were constructed using bespoke pieces of hand-built timber formwork, supplied by Peri

▪ **High-quality birch-faced or other ply.** The timber grain is lightly expressed in the surface of the concrete, with a matt finish. Reuse is limited.
▪ **Timber.** Nowadays, if the visual aim is a classic boardmarked finish, similar to that seen in the National Theatre, this is typically achieved by adding timber boards as a form-liner.
▪ **Polyurethane elastomer.** Commonly referred to as flexible form-liners, these reusable form-liners are most commonly used for architectural precast but are also available for in-situ concrete, and can be a cost-effective way to create a textured appearance over a large area. Thousands of standardised patterns are available, and it is possible to create bespoke designs too.
▪ **Glass-reinforced plastic (GRP).** This is a good option for repetitive ribbed and coffered slabs with bespoke profiles and where the visual quality of the concrete is important. GRP gives a shiny finish which needs to be rubbed down with post-finishing if a matt concrete finish is desired. Alternatively, the mould maker can sometimes make the GRP face slightly textured, but this should be discussed early on in the design and procurement process.
▪ **Coated expanded polystyrene (EPS).** This is available as both off-the-shelf standardised units and bespoke machined shapes. It is usually coated in a durable material to allow reuse, although the number of reuses and as-struck concrete texture depends on the coating type. Commonly used coatings include ABS, correx, fibreglass and polyurea.
▪ **Be imaginative!** You can cast against pretty much anything as long as you can strike the formwork. Everything from fabric to dimpled drainage boards and corrugated metal have been used to create textural effects in concrete.

Typical formwork systems for columns include:
▪ **Cardboard column formers.** Prefabricated cardboard column formers

BELOW
At Hugh Broughton Architects' IStructE headquarters in north London, timber shuttering was specified with self-compacting concrete to create a precise and beautiful pattern. Douglas fir boards were sanded and brushed to bring out the grain, before being varnished and finished with a release agent. This caused the concrete to react differently to sapwood and harder areas, thereby creating a striking "zebra-like" colour contrast within the grain of the finished surface

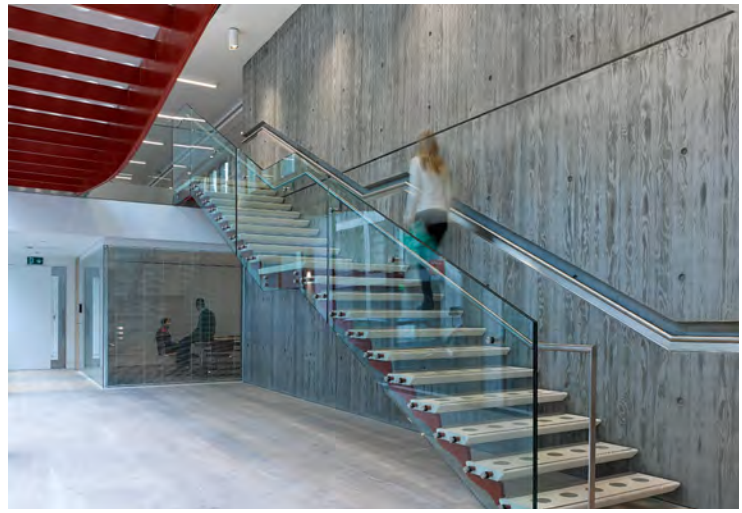

Photo: James Brittain

are typically used for rounded columns, either with a spiral or vertical seam. They tend to be single use and are lined internally with plastic, which results in a shiny as-struck finish.

▪ **Steel column formers.** Prefabricated steel formers are highly durable and can be reused multiple times on various projects. Commonly used on infrastructure projects, steel column formers give a shiny as struck concrete finish.

OTHER DESIGN CONSIDERATIONS

Important or tricky details should be trialled with full-scale mock-ups and requested in the tender documents. If this is not possible within budget, it is advisable to carry out tests in areas that are not so visually important, such as back-of-house plant rooms and basements.

Tie bolt holes

The layout of tie bolts is another factor that can affect the contractor's choice of formwork system. Tie bolts are an efficient, modern solution for connecting the two sides of vertical formwork together while holding them the correct distance apart. Without them, large temporary supports and props would be needed around the formwork, taking up space and material on site.

The final positioning of tie bolt holes will be subject to detailed design by the contractor, but if the layout and number is important, this should be made clear by the design team on their design intent drawings. Standard formwork panels are likely to space tie bolts in fixed locations, where they are needed structurally – for example, they are often

Photos: Hufton+Crow; Hollaway Studio

ABOVE
At the F51 Skatepark in Folkestone by Hollaway Studio, bespoke formwork units were needed to create the complex geometry of the skating bowls, which were suspended 5m above the ground floor. Sections of expanded polystyrene were cut to the exact dimensions and profile using a CNC 5-axis router linked to a 3D digital model. An epoxy resin seal coat was applied to the casting surface to aid striking

spaced more closely at wall ends or door openings. Designers can opt to add extra tie bolts for visual effect, but this needs to be understood and controlled through discussion with the contractor.

The finishing of tie bolt holes must also be considered. Usually an impression will be left in the concrete by the tie bolt cone. This needs to be filled or finished to cover the tie bolt sleeve, which is left in place. The finish can be expressed or blended in, either by filling on site or with precast cone heads. It is nearly impossible to make tie bolt holes disappear altogether, no matter what finishing method is used.

Joints

Joints between sheets of form-facing material or form-liner will also always be visible. Even with the tightest joints, there will be a small amount of water seepage between the boards and some variation in position is to be expected. For a "plain" concrete finish, a 3mm tolerance is permitted between formwork boards within the NSCS v4 specification. Tolerances can be made tighter for "special" concrete finishes, but the NSCS states that these must be achievable. The formwork

BELOW

Architect Jake Edgley's Pear Tree House in Dulwich, south London. A timber garden fence is cleverly juxtaposed with the concrete walls that its panels were used to cast

Photo: Edgley Design

Photo: Daniel Hopkinson

ABOVE
Two St Peter's Square, Manchester by SimpsonHaugh. The tracery screens, which reinterpret stone details found in the Town Hall opposite, were precast using digitally manufactured formwork. An acid-etched finish with fewer exposed aggregates was specified to give an understated effect

should be grout-tight and carefully jointed to eliminate grout loss and minimise the inevitable darkened line at the joint from water loss.

Board sizes, setting out and joint types are often refined during a trial process, but it is important to establish the design intent pre-tender. When setting out joints it is best to use standard board sizes, usually 1,200 x 2,440mm for flat panel applications. Ply boards of 18mm thickness will usually be sufficient, but this depends on the height of the pour and other site factors, so should be discussed with the contractor as part of its detail design process. The design team should decide whether they would prefer joints to be installed flush or expressed, and how the boards are to be fixed. Fixing from behind is preferable as this avoids damaging the board facing and does not show in the finished concrete. It is best to avoid using cut-edge boards as they are always more difficult to seal on site. If possible test details of joints with the contractor on a full-scale mock-up.

Edge details

Traditionally, corner details of concrete were nearly always chamfered. Contemporary formwork systems do enable sharper corners, but these can be prone to damage during the striking of the formwork and by follow-on trades, particularly if corner angles are acute / less than 90 degrees. Repairs are not impossible, but do require colour and texture matching and can add cost.

Coffered and ribbed slabs often have slightly rounded edges or angled sides, known as draft angles. These make it easier to place the concrete and strike the formwork, minimising damage to the concrete and allowing the formwork to be reused.

Release agents

Release agents are applied to the surface of the formwork to enable it to be removed easily and without damaging the concrete. They work by preventing a bond between the concrete and the form face. There are numerous types of release agent, and concrete contractors

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are likely to have their own preferences. At the tender stage, it is usually sufficient for the design team to simply state that the release agent should be selected to suit the concrete mix and formwork facing material, and applied correctly in accordance with the manufacturer's guidance. The intended release agent should be included in a trial panel to test that it is appropriate before use. If the release agent is incorrectly or unevenly applied, staining can occur on the finished concrete.

Unformed faces

It is important not to forget about unformed faces too. These are the surfaces of the concrete that are not poured against the form face or form-liner. Unformed faces are a common detail on stairs and handrails and can either be post-finished by hand or covered with capping details.

COMPLEX FORMS AND INNOVATIONS

Formwork manufacture continues to evolve, and is now at an exciting juncture combining worlds of craft, technology and science. The epoxy resin coated EPS formwork elements supplied by Cordek to form the wonderfully curvaceous bowls of the Folkstone Urban Sports Park (CQ279, summer 2022) were produced using complex 3D computer modelling and millimetre-precise CNC 5-axis routing; whereas the elaborate and cathedralesque curves of the V&A Dundee (CQ265, autumn 2018) were constructed using bespoke pieces of hand-built timber formwork, supplied by Peri and sustaining the industry adage that good-quality concrete is often the result of good-quality timber craftsmanship. In both projects, the accuracy and complexity of the 3D curves and unusual geometries were key, albeit achieved through very different methods.

Whether mass-produced, bespoke, machined by robots or built by hand, formwork manufacturers across the board are routinely using 3D modelling

BELOW
At 168 Upper Street by Groupwork, original features of neighbouring buildings were scanned and recreated using a CNC 5-axis router in polystyrene. The formwork was assembled on site to create structural walls from pigmented concrete

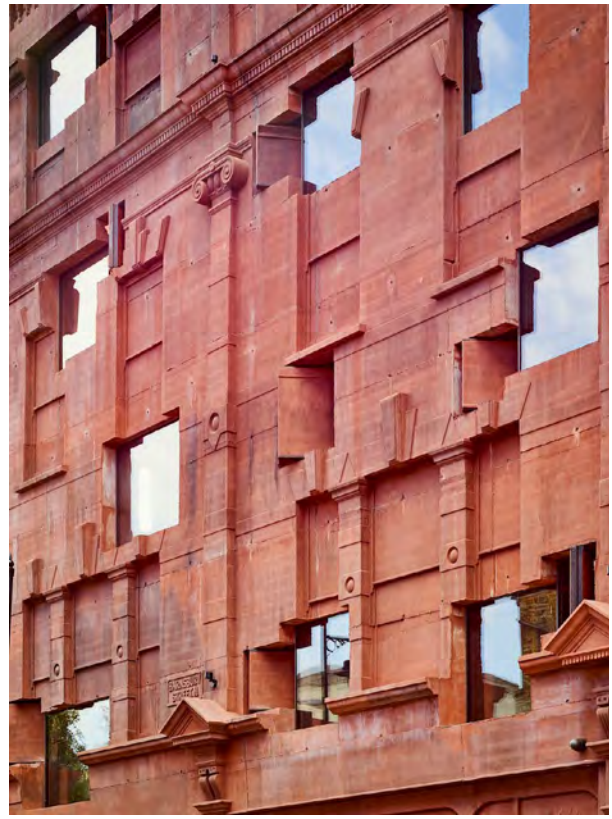

Photo: Timothy Soar

RIGHT
The soffit and walls of Laboratorio Espresso by DO-Architecture in Glasgow are lined with reused timber shutter boards from Steven Holl's Reid Building at Glasgow School of Art (below)

and augmented reality to enable architects, engineers and contractors to visualise the spatial relationship between formwork systems and their surroundings, thereby aiding early design and site coordination.

A great deal of innovation and research is also focused on material efficiency and sustainability, which in turn is creating new languages of architecture. The capabilities of digital engineering software paired with advancements in 3D printing technologies for formwork presented the opportunity to create ultra-slender structural slabs, placing concrete only where needed, at DBT's admirable Smart Slab project in Zurich (see page 30).

The importance of material efficiency is by no means limited to the concrete itself. Designers and contractors are increasingly appreciating formwork as a valued resource within the circular economy of construction rather than a disposable by-product. Projects such as Pear Tree House by Edgley Design, Hugh Broughton's IstructE headquarters and Laboratorio Espresso by DO-Architecture have imaginatively and successfully reused timber formwork boards to create beautiful interior fit-outs and external cladding. Innovations in fabric formwork are also opening the door to super-lightweight and easy-to-transport materially efficient formwork. Structure Mode's school project in Cambodia is a

Photo: John Wood Photowork, Arup

great example of this, with fabric offering a quick and simple solution that also engaged highly skilled seamstresses and tailors from the local community with the project.

Texture and pattern are seeing something of a renaissance in concrete as a means of creating sensory interest and architectural character but perhaps most encouragingly to promote and support biodiversity. The Mumbles Seahive project designed by Cubex Industries in partnership with Swansea University is exemplary of this. The design team used 11 standard patterns and two bespoke seaweed and oyster shell patterns from flexible form-liner supplier Reckli to create a series of ultra-high-performance concrete panels, which were then applied to the Mumbles sea defences. After just three months, colonisation of the panels by barnacles and other sea life had already begun – a genuine bringing together of craft, technology and science in the art of concrete formwork. ■

BELOW
The Mumbles Sea Hive project as Swansea University explores how cast concrete surfaces can encourage marine biodiversity by creating habitats for coastal species. The photos show the process of making the formwork, the formwork itself, the finished tiles and their colonisation by barnacles. The ultra-high-performance concrete had 60% recycled content

FINAL FRAME: THE LINE, AMSTERDAM

The delicate facade of Orange Architects' 72-home apartment building on Amsterdam's IJ waterfront include precast ultra-high-performance concrete (UHPC) elements that are just 60mm thick. The slightly tapered columns are up to 3.4m long, while the balcony decks are up to 6.5m with a cantilever of almost 2m from a reinforced-concrete slab. Supplier HiCon estimates that, based on environmental product declarations, using UHPC has reduced the facade's embodied carbon by 25%.

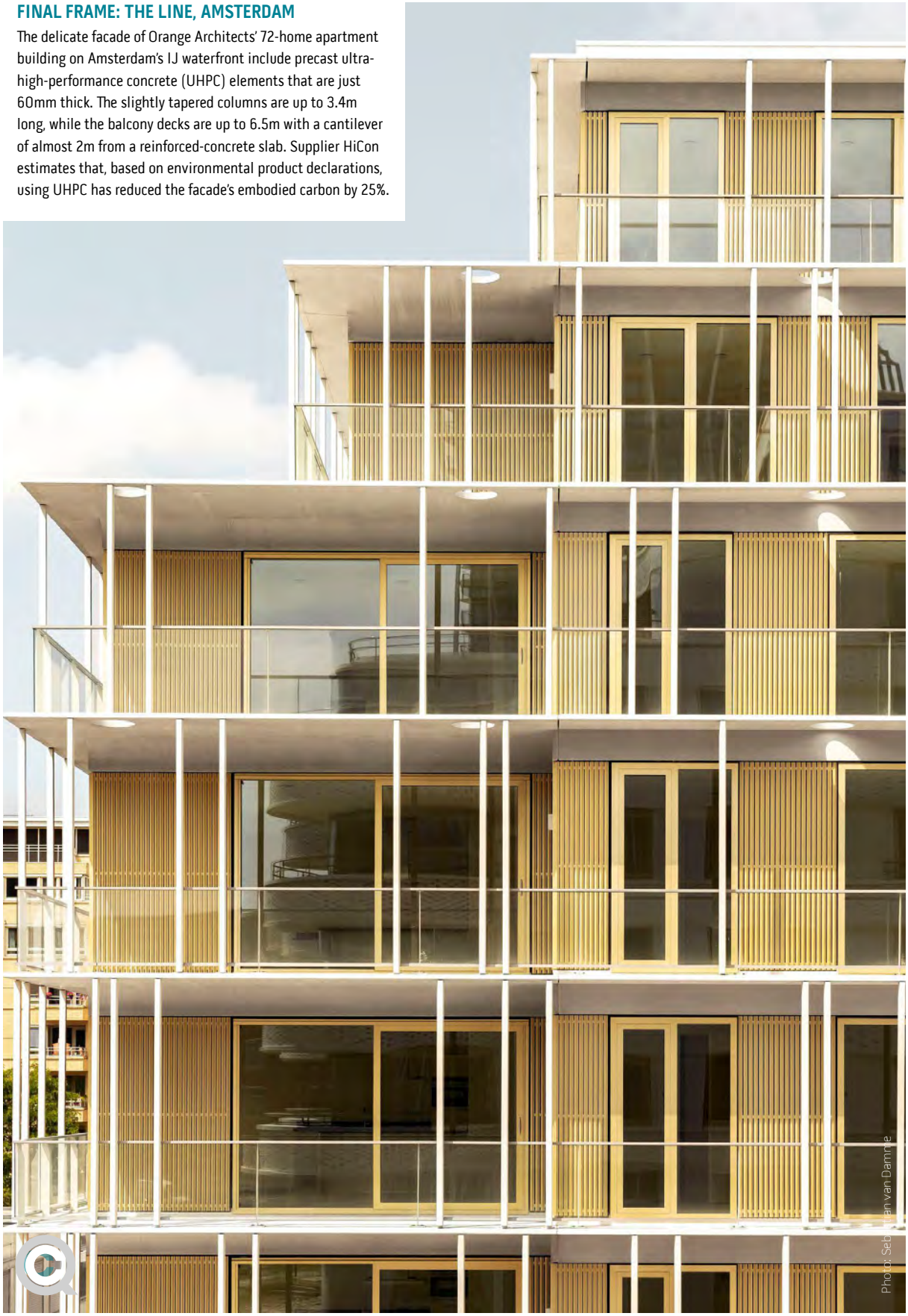

Photo: Sebastian van Damme