CONCRETE QUARTERLY

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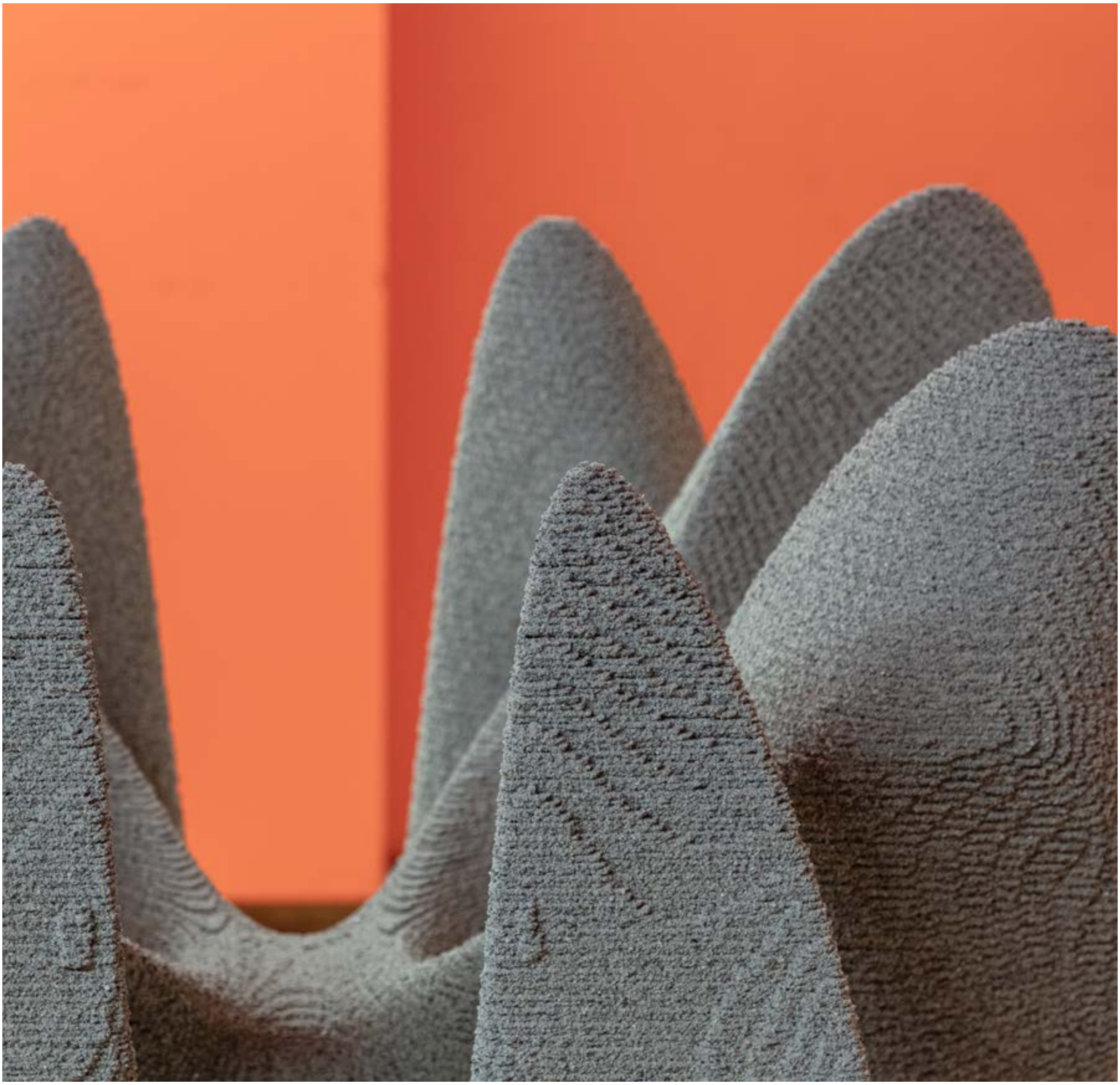

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Elaine Toogood
Senior director, MPA Concrete & The Concrete Centre

First cuts are the deepest

When it comes to carbon, the earlier you start, the bigger impact you can make.

At our events and CPD presentations, designers often ask about new products, and what to specify for the lowest-carbon concrete. It's an important question and there's always lots we can say: lower-carbon options are constantly expanding as innovations reach the mainstream and manufacturers decarbonise.

But if that's the first time they've considered embodied carbon, it's a major missed opportunity. As a design develops, opportunities become progressively more limited, moving along a continuum from "strategies" to "tweaks". By the time it reaches technical design, significant, unnecessary carbon may have already been embedded. This is a common complaint from suppliers, frustrated that high-carbon solutions have already been baked in by the time they are set the challenge of reaching carbon targets.

The first thing to consider, at concept stage, is material efficiency: could you achieve the same result with less? Experienced designers will have a rough idea of the cost implications of early decisions. There is a growing understanding of how aspects like form factor (the ratio between internal floor area and external surface area) affect energy consumption. What we haven't yet fully developed is an equivalent sense of the carbon impacts, or established rules of thumb for low embodied carbon design.

For concrete frames, our free spreadsheet-based CONCEPT tool can help, by illustrating how even small changes can impact carbon, cost and construction time. For precast, our forthcoming guidance document on low-carbon solutions will highlight the importance of aligning designs with manufacturing processes. Some of this is intuitive, and carbon can be analogous to cost, as with maximising repetition and standardisation. But a lot may not be – such as the impacts of window reveal depths and joint locations in precast cladding, or the greater efficiencies that can be derived by integrating services or facing materials.

The other way designers inadvertently embed carbon is by being overly prescriptive, and setting misguided or arbitrary criteria. Our Application article on page 38 explains how recycled concrete can be used as aggregate in new concrete – but also how this is often not the lowest carbon option, or the best use of demolition waste. It's always nuanced, because concrete is not a single product but a mix of many possible components, each bringing different properties and carbon values. That's why the best results happen when designers and makers work closely together. Our Origin Story on page 14 profiles the stunning tree-trunk columns that grew from collaboration between Squire & Partners and Thorp Precast at Tide Bankside, which also boasts (less visibly) Heyne Tillet Steel's highly efficient concrete frame.

We all have our parts to play, and it is incumbent upon designers to educate themselves and to understand the enormous influence they exert – starting with their earliest decisions. Perhaps an overall rule of thumb should be: if you're not thinking about carbon right from the beginning, you've almost certainly not achieved the optimal, lowest-carbon design. ■

IT'S ALWAYS NUANCED, BECAUSE CONCRETE IS NOT A SINGLE PRODUCT BUT A MIX OF MANY POSSIBLE COMPONENTS, EACH BRINGING DIFFERENT PROPERTIES AND CARBON VALUES

CONCRETE QUARTERLY

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On the cover:
Nereid 3D-printed marine environment by Zaha Hadid Architects. Photo: Luke Hayes

INNOVATION

MARINE ECOSYSTEM RENEWAL

ZAHA HADID ARCHITECTS' NEREID IS A 3D-PRINTED CONCRETE STRUCTURE DESIGNED TO RESTORE HONG KONG'S MARINE ECOSYSTEM BY CREATING THE PERFECT ENVIRONMENT FOR ORGANISMS TO THRIVE

The white dolphins are leaving the waters around Hong Kong, and the reasons are all too predictable: overfishing, pollution and excess surface vessel traffic.

"These problems have combined to degrade the marine environment, particularly the seabed, to the point where it is no longer able to support the numbers of fish the dolphins need," says Christos Passas, design director with Zaha Hadid Architects. "So we have looked at how we can use good design to help restore the seabed, and make it more conducive to sea life."

The result is Nereid, a 3D-printed concrete structure. When placed on the seabed, it will provide an optimal environment for the growth of phytoplankton and shellfish

"BY USING 3D-PRINTED CONCRETE, WE CAN CREATE A ROUGH, NATURALISTIC SURFACE THAT SUITS THE PLANTS AND ANIMALS THAT WILL ATTACH THEMSELVES TO IT"

– the foundation of the marine ecosystem's food chain. A 1m-high prototype, constructed by Hong Kong firm D-shape, was exhibited at this year's World Design Congress (WDC) in London.

"Using 3D-printed concrete provides a number of useful features," says Passas. "We can create an object with a rough, naturalistic surface that suits the plants and animals that will attach themselves to it. We can also easily mimic the features of natural reefs – for example, by making hollows in the structures where fish can safely lay eggs or hide from predators."

Almost any object left on the seabed will eventually attract sea

Photos: Luke Hayes

life of some sort: "But Nereid gives us the opportunity to intervene in a very specific way. For example, by providing safe hiding spaces of the right size, and at the right depth for a particular species."

Using printed concrete makes it relatively easy to adapt the design to respond to other challenges: "We can adjust the base so Nereid does not sink too far into a soft sea bed, or we can adjust the strength and weight to discourage trawlers, which can cause damage by scraping nets along the seabed."

It also offers logistical advantages: while solid concrete forms are very heavy, Nereid's outer shell is only around 20mm thick. "Larger forms can therefore be much lighter, and easier and cheaper to transport to where they are needed," says Passas. "And of course, non-solid structures can be much more efficient in terms of material usage."

The mix used to create Nereid has been carefully designed to be eco-friendly. D-shape deploys an unusual technology which, instead of printing pre-mixed concrete, lays down a layer of sand and cement before jetting it with pure water. "There are minimal additional binders or other chemicals involved – obviously a benefit when you are trying to restore a natural ecosystem." The mix is resilient to the chloride in seawater and also pH neutral: "Sea life prefers surfaces that are not too acid or alkaline."

Though Nereid was developed with the waters around Hong Kong in mind, Passas says it could be fine-tuned to suit other locations and ecosystems. "There could be

ABOVE
A 1m-high prototype, constructed by Hong Kong firm D-shape, was exhibited at this year's World Design Congress in London

ABOVE
Instead of printing pre-mixed concrete, D-shape's technology lays down a layer of sand and cement before jetting it with pure water

a variety of applications," he says. "For example, there's an underwater sculpture park off the shores of Cyprus. It is like a civic plaza, with statues of people on phones and of children playing. It is a great draw for recreational divers. With the flexibility 3D-printing gives us, you can easily imagine how Nereid-type structures could help create environments like that. They could be beautifully sculpted, and help marine life at the same time."

Nereid is well-named – after the sea nymphs of ancient Greece who were charged with protecting the oceans and the life they contained. If all goes to plan, Zaha Hadid's concrete Nereids could soon be luring the white dolphins back to the seas around Hong Kong. ■

Interview by Tony Whitehead

LASTING IMPRESSION

SUNAND PRASAD

THE FORMER RIBA PRESIDENT MARVELS AT MAJESTIC BRUTE POWER, GRAVITY-DEFYING LIGHTNESS AND THE POETIC ECONOMY OF FORM

I've always been fascinated by the two extremes of concrete. On the one hand, its sheer brute power, unmatched by any other material, and perhaps best epitomised by the Nazi U-Boat pens on the French Atlantic coast – built to withstand bombs and still indestructible today. On the other hand, it can be used to create structures of such lightness that they seem to be floating. I have always loved this poetic economy, and it holds valuable lessons when we need to find less carbon-intensive ways of building.

My first choice is one of the most monumental concrete structures ever built, but also a precursor to some of the lighter and more poetic. The Hoover Dam is a classic example of the material at its most primeval and powerful, built to hold back the full force of the Colorado River. The sheer quantity of concrete used is staggering: three million m^3, enough to make a slab 1km by 1km and as high as a house. The aim wasn't primarily aesthetic, but architects were bowled over by the way concrete could create this sweeping monolithic surface – industrial but on a geological scale. It showed

BELOW
The Hoover Dam was designed by Gordon Kaufmann and Henry J. Kaiser, and constructed between 1931 and 1936

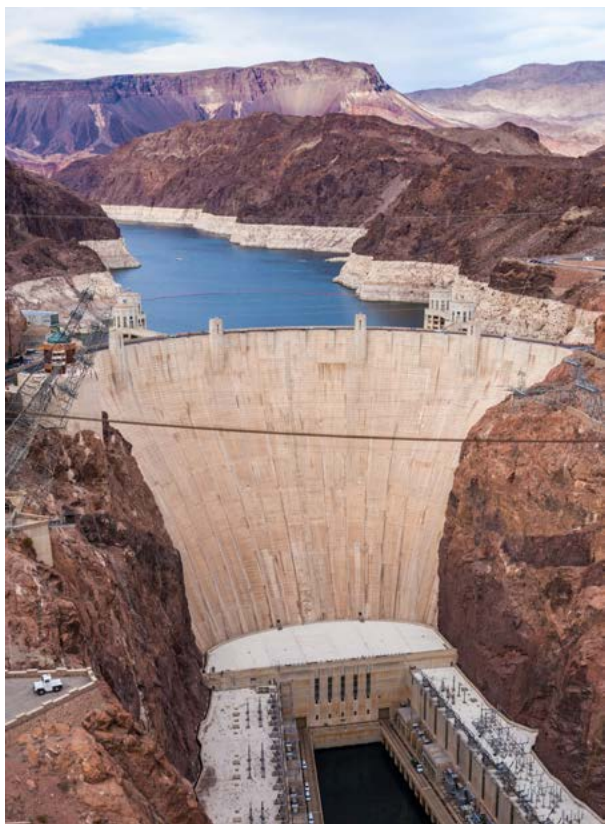


Photo: Ron Buskirk / Alamy Stock Photo

Photo: David Cornelius / Alamy Stock Photo

ABOVE
The Salk Institute for Biological Studies in La Jolla, California, designed by Louis Kahn and completed in 1965

how it could work in combination with form, weather and light to spellbinding effect.

At the Salk Institute, the research laboratory set on a bluff overlooking the Pacific in La Jolla, California, Louis Kahn's use of concrete is more consciously aesthetic, but it speaks to the surface and finish of the Hoover Dam. The pozzolanic mix has a warmth and smoothness to it, with the colour and texture changing subtly in different lights. Salk has a mysterious primal quality that only great architecture can produce: that ability to bring sky and Earth together in a particular way that we humans find awe-inspiring.

The Hoover Dam's beauty also lies in its geometric clarity, with

Photo: Simon Webster / Alamy Stock Photo

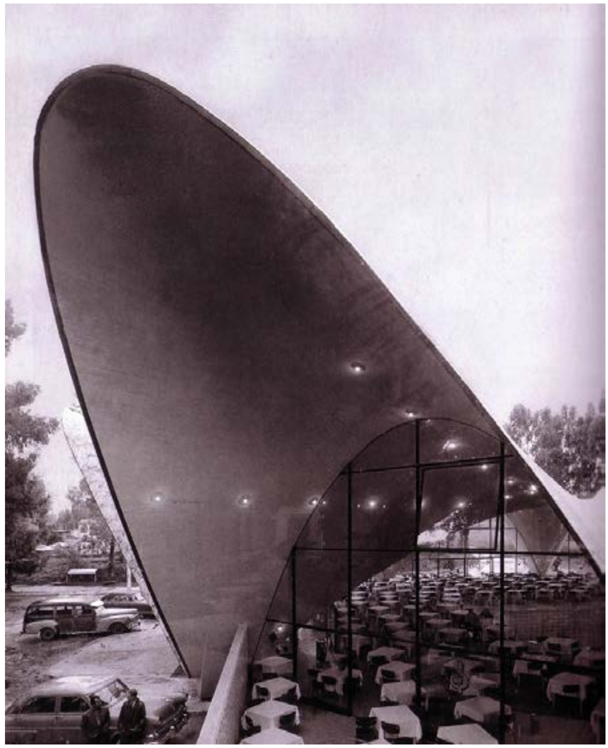
ABOVE
Inside one of the cooling towers at Willington, Derbyshire. Also known as the Five Brothers, they were constructed in 1950

a form derived entirely from engineering logic – a horizontal arch locked into the sides of the canyon by the weight of the water. I studied engineering before changing to architecture, and I still love the idea of finding poetry in the purity in the logic of structure. It's there in the shape of power station cooling towers too. The hyperboloid gives these structures their strength, allowing for very thin, structurally economic walls. It also creates an iconic silhouette, as well as a majestic space inside – a direct inspiration, as it happens, for Corbusier's Palace of the Assembly in Chandigardh. There were once 240 cooling towers in the UK, but now only 37 remain. It would be a terrible shame if they were all to disappear.

The most poetic of all engineers of concrete was perhaps Félix Candela. His concrete shells are just astonishing. When you look at a building like the Los Manantiales restaurant in Mexico City, it's hard to believe that it's the same material as the U-Boat bunkers. The shell, comprising four intersecting hyperbolic paraboloids, is only 40mm thick. It's mind-blowing. And it has lasted – the restaurant is still in use today, 70 years after it was built.

As a practice, we have worked with structural engineer Webb Yates, exploring methods for reducing carbon with composite timber and concrete structures. In its structure for the Solera factory in Valencia, designed by Fernando Olba, the composite is with steel, though not in the familiar prestressed or post-tensioned form where the steel is hidden. As well as creating the floor plate, 150mm-deep hollowcore concrete planks with a 100mm topping act as the compressive top chord of a truss carrying a massive factory floor load, with exposed steel underneath taking the tension. The approach reduced the amount of steel by 30% and concrete by 50%, and has lent a humble electrical components factory a delicate sort of grandeur. ■

Sunand Prasad is principal at Perkins & Will, co-founder of Penoyre & Prasad, and a former RIBA president. Interview by Nick Jones



Photos: Fernando Olba; via rkett.info

TOP
Los Manantiales restaurant in Mexico City, designed by Félix Candela and completed in 1958

ABOVE
Solera electric components factory in Valencia, Spain, designed by Fernando Olba and Webb Yates, completed in 2008

Photo: Andy Stagg

ORIGIN STORY

TIDE BANKSIDE

SQUIRE & PARTNERS WAS INSPIRED BY THE HISTORIC THAMES RIVERSCAPE TO DESIGN AN ORGANIC, 'ERODED' FACADE FOR ITS NET-ZERO OFFICE BUILDING. IT JUST HAD TO WORK OUT HOW TO BUILD IT ...

The south bank of the Thames between Southwark and Blackfriars bridges must be one of the most narratively rich stretches of river in the world: a place of Roman traders, Viking warlords, Elizabethan theatres and bearpits, Dickensian wharves and warehouses, all before its modern-day reinvention as the Bankside cultural quarter, anchored by the twin flagships of Tate Modern and Shakespeare's Globe.

TIDE Bankside, located immediately behind the Globe, has been consciously woven into this story. The 12-storey building is recognisably an office block, but its brickwork piers and columns are unlike any commercial facade you've ever seen: gnarled, twisting trunks that seem to have washed up on the river's muddy shore.

Tim Gledstone, senior partner at architect Squire & Partners, had observed how Bankside's built environment was in constant dialogue with the river, and wanted the new building to engage with this gently shifting landscape. "If you go down to the Thames, you can see all of these brick piers and timber posts that have just eroded, like bits of driftwood. That's what we wanted to accelerate, so that the building feels bedded in."

Gledstone and his team initially sculpted the columns in clay, evoking the way that saltwater gradually carves channels and rivulets into rock. Then they scanned the design and imported it into Rhino software. The original intention was to cast the forms in precast concrete using bespoke moulds. "We thought that it would be pushing the technology a bit, but that it could be done." They also wanted to use aggregates from the Thames to create "a local dirty mix, with sandy pigments and little flints and stones you find along the river".

Then, two weeks before the scheme was due to go before the planning committee, a problem arose. "Southwark's new design officer said, 'I like everything you've done here, but I want it to be in brick.' I had no idea how we were going to do it, but our client told us, 'just say yes and we'll figure it out later'."

The practice tested out a number of approaches. "We came up with the idea of just using headers, or making the design more pixellated, but that flattened the geometry too much. Everyone agreed that prefabrication was the only way to do it properly."

That was when they turned to precast cladding specialist Thorp Precast. "We quite like doing mad, complicated jobs," says founding director Harvey Thorp. "When the team from Squire came up and

BELOW
A late planning decision stipulated that the undulating facade columns and piers be clad in brick

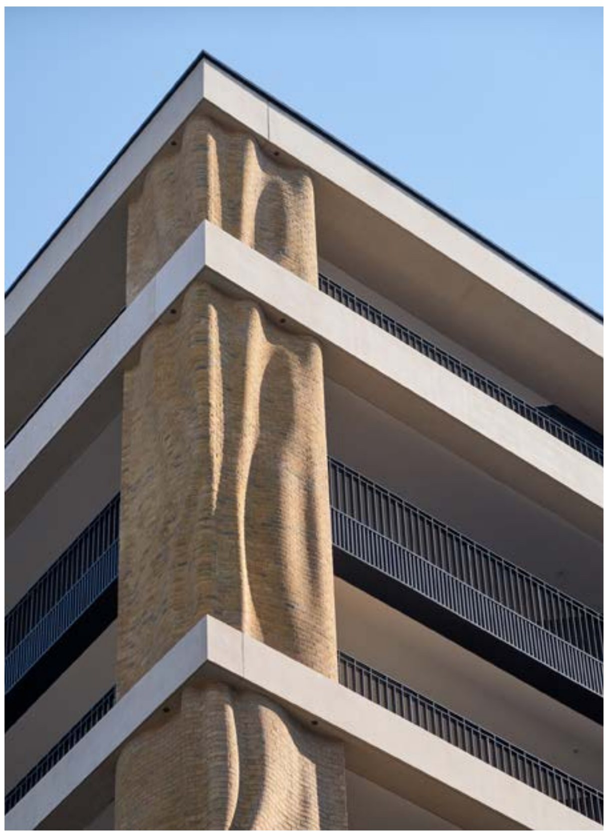


Photo: Andy Stagg

showed me the images of what they wanted, I said, 'I think I know exactly how I could do that'."

Thorp's vast Stoke-on-Trent factory is equipped with a five-axis CNC machine, which cuts in three dimensions, as well as being able to tilt and rotate the cutting medium. The plan was to import the digital design and then cut each brick to the designated profile using a water jet, then set the bricks in precast panels. Using water to accelerate the eroded aesthetic and expose the softer inner brick added to the "romance" of the design, Gledstone says.

Once the bricks were cut, each was allocated a "passport" to indicate its precise location on the panel. They were then placed in a polystyrene mould, CNC-cut along the same digitally coded contours as the bricks, to hold them in position while a backing layer of concrete was poured, up to 300mm deep. Where thinner panels were required, ultra-high performance reinforced-fibre concrete was used, reducing the depth to as little as 50mm.

BELOW
The London stock bricks were cut using a water jet, with garnet added to the stream to act as an abrasive cutting edge

Photo: Gareth Gardner

Photo: Gareth Gardner

The key was to maximise the use of each brick and each mould, both to eliminate waste and to make the plan stack up financially. "We referred to it as the mirror image, or the butterfly – if we cut one brick, we would use the negative too," Thorp says. They could also turn the bricks upside down: "So from one cut, you have four potential patterns. We set some rules for the thickness and depth of the cuts, and Tim's team went away and worked on the different variations."

Some elements required an even more inventive solution. The corner column on the junction between Park and Emerson streets – which Gledstone and Thorp refer to as "the stiletto" – is three-dimensional and visible from all sides, with nowhere to conceal joints. This was cast vertically in four-sided sections, allowing the brickwork bonds to turn the corner rather than simply stopping at the end of a panel. Each section was about 2m high with a hollow core. On site, the sections essentially acted as permanent formwork: lowered by crane over vertical reinforcement, before being filled with in-situ concrete.

Despite its appearance, this is an extremely robust building, designed to last for 180 years. "We wanted a

ABOVE
A completed panel is inspected at Thorp Precast's Stoke-on-Trent factory before being loaded onto a transporter

PROJECT TEAM
Architect Squire & Partners
Structural engineer Heyne Tillett Steel
Services engineer Hoare Lea
Main contractor Kier
Cladding designer and manufacturer Thorp Precast

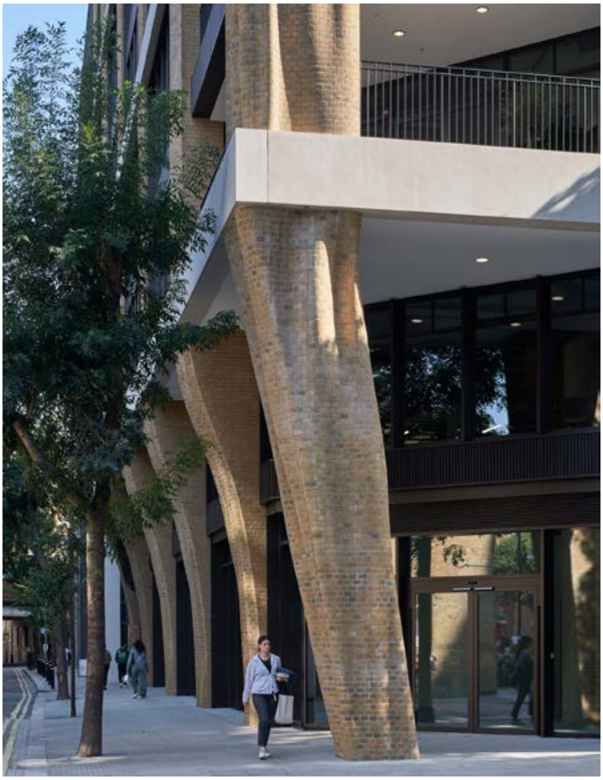
high-performance, low-carbon frame that could evolve over generations," says Gledstone. "It has solid bones and uses high-quality, long-lasting materials."

The in-situ concrete frame has been described by Mark Tillett of structural engineer Heyne Tillett Steel as "probably the most sustainable RC structure of this scale in London", thanks to the use of an industry-leading 65% GGBS mix and local aggregates. Its piled raft foundation also helps to reduce material and, consequently, the building's embodied carbon. This has been measured at 493kg/CO_2e/m^2 (stages A1-A5), 17% below the LETI 2020 best practice target.

In operational terms, the building contains 14,000m^2 of grade A workspace, and has achieved NABERS 5* and BREEAM Outstanding ratings. Its energy consumption has been measured at 55kWh/m^2/year, in line with the UK Green Building Council's net-zero carbon interim energy target for 2030-35.

The eventful history of Bankside suggests that a lot can change in 180 years – the only certainty is that the Thames will keep on rolling. TIDE Bankside's loose-fit grid has been designed to be adaptable to a variety of uses, including life sciences, retail and residential. Whatever the future holds, it's ready to go with the tidal flow. ■

Interview by Nick Jones



Photos: Andy Stagg, Gareth Gardner

ABOVE
The "stiletto" corner column was cast vertically in five sections with a hollow core

TOP
It was lowered by crane onto the reinforcement, before in-situ concrete was poured to form the core of the structure

From the archive: Spring 1971
HYPERBOLIC HUDDERSFIELD

In 1971, brutalism went to market. Huddersfield market, to be precise. The Queensgate hall brought the shock of the new to Yorkshire, taking the traditional requirements of the market stall – shelter, natural light, flexibility – and turning them into something concrete and monumental. Designed by Leeds-based J Seymour Harris Partnership, the hall took the form of 21 double-curved hyperbolic paraboloid ("hypar") shells, like a parade of upturned umbrellas caught in a blustery West Riding shower.

CQ was particularly impressed by the scale of the roof: "It lends height and dignity to the hall, the board-marked shell soffits providing a perfect neutral canopy for the complex colour and detail below." Each shell was supported by a single column, placed off-centre and varying in height from 3.3m to 7.6m. This made the structure asymmetrical, lending it a "more sculptural" effect, CQ noted. The shells cantilevered 10m in one direction and 7m in the other, with a concrete thickness of 76mm and 178mm respectively "to preserve equilibrium".

The formwork for the 72-tonne shells consisted of four timber units, one for each shell face. At about 1.5 tonnes, these were extremely heavy, ensuring a good bond between timber and concrete. This resulted in continuous markings that "emphasised the paraboloid curves". The units were raised into position by chain hoists on steel trolleys and the shells were cast in one operation, "seven shells being obtained from each of the three completed forms".

There was nothing particularly new about the hypar form – modernist architects had exploited double curvature on everything from cooling towers to cathedrals, and Felix Candela had long used hypar umbrellas to cover commercial space. But as the 20th Century Society notes, Candela's shells brace one another; in Huddersfield, each functions independently. This is thought to remain unique.

The market was grade II-listed in 2005, and after being threatened with redevelopment, is being refurbished as a food hall and covered library, set to open next summer.

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Photos (unless otherwise stated): Hufton + Crow

ONLY CONNECT

The Stephen Schwarzman Centre for the Humanities is Oxford's largest ever construction project and the world's first Passivhaus concert hall. Tony Whitehead finds out how it was designed and assembled from 3,000 precast parts

The residents of central Oxford had become accustomed to the large building site next to the famous Radcliffe Observatory – supposedly a new facility for the university. For months, not much seemed to be happening. Then suddenly....

ABOVE
The facades were constructed offsite from 326 concrete-backed panels clad in local stone and handmade brick

"A friend of mine lives nearby," says Andy Barnett, principal with Hopkins Architects. "She couldn't believe the speed it came out of the ground. It's a four-storey, 23,000m^2 building, but the whole envelope went up and was weatherproof in just ten weeks. That's faster than the average kitchen extension."

This time-frame is all the more remarkable when you consider that the Stephen Schwarzman Centre for the Humanities is the university's largest ever building project, and a complex, high-specification building. As well as extensive study areas, seven libraries, tutors' offices, an exhibition gallery, two cafes and a bar, it contains four impressive performance spaces including a 500-seat concert hall, a 250-seat theatre, a 100-seat cinema, and a smaller sound-lab or practice space. The concert hall is designed to provide world-class acoustics, and all four performance spaces have sophisticated "box-in-box" acoustic separation built into the structure.

If that were not enough, it is also the largest building of its type in the UK to achieve Passivhaus certification – one of the most demanding environmental standards in existence, requiring unusually high levels of airtightness and exceptional efficiency in both embodied and operational carbon.

All in all, it is the kind of project that could easily have taken three or four years to construct, yet the total build time was just 30 months. Barnett says that the speed of delivery was almost entirely attributable to the approach taken by the contractor, Laing O'Rourke, and its use of modern methods of construction.

The structure and facades are made from 3,000 prefabricated concrete elements, which were manufactured offsite while the foundations and basement levels were being constructed.

"The university wanted quick construction and a totally reliable completion date," explains Barnett. "That was one of the main reasons we went for predominantly precast concrete – offsite manufacture gives you that control, partly because you are less affected by the weather."

"THE WHOLE ENVELOPE WENT UP AND WAS WEATHERPROOF IN JUST TEN WEEKS. THAT'S FASTER THAN THE AVERAGE KITCHEN EXTENSION"

It also marries well with the technical demands of Passivhaus, he adds. “Offsite prefabrication enables elements to be constructed to tight tolerances, and that really helps when you are aiming for a very airtight building.”

Acoustic separation was another early consideration: “Academic teaching can’t be disrupted by sounds from a concert, so the solidity and sound-containing qualities of concrete made it a likely frame material from the start.”

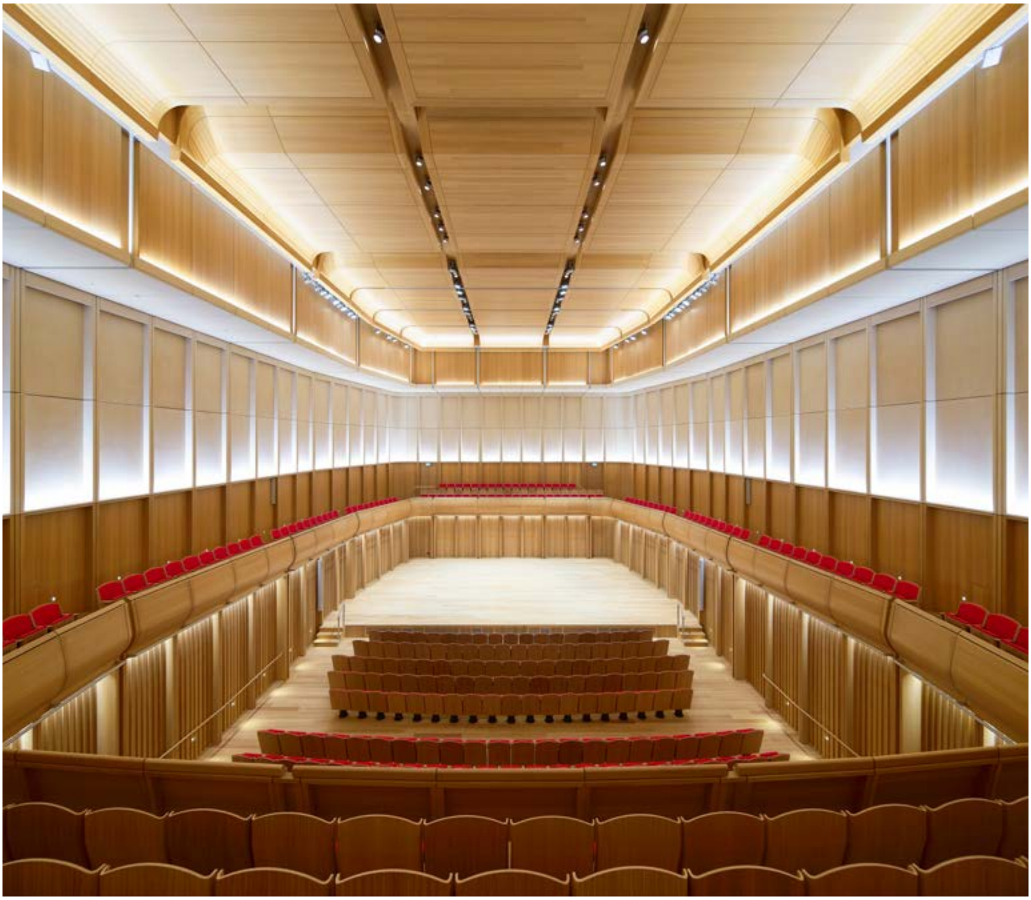
This early hunch was proved correct when structural engineer AKT II modelled the frame in steel, concrete, cross-laminated timber and various hybrids. Assessed against a number of metrics including cost, floor-to-ceiling heights and carbon efficiency, concrete was the clear winner. But the building was originally conceived with an in-situ frame, and only became precast at stage four, when Laing O’Rourke came on board.

“The completion date was very important to the client,” says Valentina Galmozzi, AKT II’s design director. “It had to be August 2025. With so many different departments moving from 26 locations to the new building, you can imagine the problems if it was incomplete at the start of the academic year. Changing from in-situ to precast was quite straightforward though. We didn’t really have to change any of the thicknesses of the columns or slabs, it was all in the detailing of how the elements went together.”

Much of the building is arranged on a 6m x 6m grid, with some much larger spans for specialist areas such

Photo: French + Tye

ABOVE
The curved beams surrounding the Great Hall were cast in steel moulds to ensure the detailing was as crisp as possible (see pages 32-33)



ABOVE
The walls of the main concert hall are lined with 230 glass-reinforced concrete panels and soffits. Each wall panel is subtly curved to enhance the acoustics

as the concert hall. "The grid size stems from the dimensions of the tutors' offices, the smallest of which are 3m x 3m," says Galmozzi. "These take up much of the space in the upper floors of the building. We didn't mind having the relatively large number of columns this grid involves as they are naturally hidden in the office walls. The small spans allow slimmer slabs, which saves material and carbon."

The majority of the frame is constructed using rectangular precast columns and precast twin-wall elements, the latter comprising outer and inner slim reinforced concrete panels connected by a steel lattice, into which

ready-mixed concrete is poured. Their use enabled the construction of continuous, solid walls while still benefiting from rapid assembly of relatively lightweight panels.

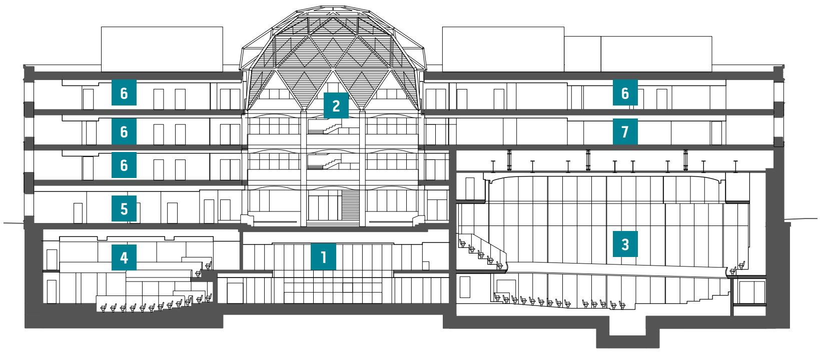
A similarly hybrid precast/in-situ approach was used for the majority of the floors, which were constructed from lattice slabs, many of them 6m x 3m to fit the grid. "These were 75mm-thick slabs with a lattice of rebar protruding from the upper side," says Galmozzi. "Once in place the slab is completed by pouring a 225mm layer of concrete on top. Many of them were identical, so there was a lot of repetition and they could be produced very efficiently."

As well as being relatively cheap to produce, lattice slabs are substantially lighter than solid elements, making them easier to transport and crane into place. They also allowed Laing O'Rourke to increase the use of GGBS cement replacement to lower the project's embodied carbon.

"There were several different mixes of concrete in the building and the percentages of GGBS in each varied, as the contractor wanted to optimise the use in each case," says Galmozzi. "Because GGBS needs longer curing time, the maximum percentage in the precast element of the lattice

ABOVE
The performance spaces are all "box in box" construction, acoustically separated from the main structure

SHORT SECTION (EAST TO WEST)



1 Foyer
2 Great Hall
3 Concert hall
4 Theatre
5 Seminar spaces
6 Departmental offices
7 Oxford Internet Institute

GROUND-FLOOR PLAN

1 Lobby
2 Great Hall
3 Rehearsal rooms
4 Learning centre
5 Cinema
6 Cafe
7 Institute for Ethics in AI
8 Seminar spaces
9 Lecture theatre
10 Bodleian Humanities Library

ABOVE
The exposed concrete in the Great Hall has a "pale gold" colour, with pigments added to balance the pale tone of the GGBS

slabs was about 30%. Any higher would slow the factory production too much. But for the concrete poured on site, the percentage could be much higher, bringing the overall slab percentage up to about 40%."

High proportions of GGBS can sometimes slow the programme when used in a standard in-situ frame, she adds, but here the lattice slabs acted as their own formwork. "Below the slabs were a few props, needed only until the poured concrete sets. With no formwork to strike, potential delays due to slow curing largely disappear."

By maximising GGBS throughout, Laing O'Rourke calculated that the embodied carbon of the building had been reduced by 544 tonnes CO_2e.

More bespoke structural approaches were required to construct the sophisticated performance spaces, each of which had to be acoustically separated from the main structure.

Located in the double-floor basement areas, these have larger spans of 12m,15m and 18m. "For these, we used steel beams or trusses to support the lattice slabs, and these created the floor above in the normal way," " says Galmozzi. "However, each performance area needed a lower ceiling – the top of the interior box – and for these we used hollowcore concrete planks spanning between another separate steel structure." The exception was the largest space, the concert hall. This has a stronger traditional ribbed-deck in-situ ceiling, from which a technical platform could be suspended.

The floors of these areas were separated from the floor slabs proper by placing a second layer of precast floor slabs on thick rubber acoustic bearings, on top of solid concrete blocks.

Inside the main concert hall, the walls are lined with 230 glass-reinforced concrete (GRC) panels and soffits. The largest of these are 2.5m high and weigh less than 0.5 tonnes. Each GRC wall panel is subtly curved to enhance the reverberation acoustics, and houses a fabric "blind", which can be variably lowered to adapt them to the requirements of a particular performance. It is a world-class refinement, in a world-class building.

PROJECT TEAM

Architect Hopkins Architects
Structural engineer AKT II
Main contractor Laing O'Rourke
Piling and structure Expanded
GRC supplier BCM GRC

Photo: Simon Kennedy

CAST IN STONE

A timeless Oxford facade – made in Worksop

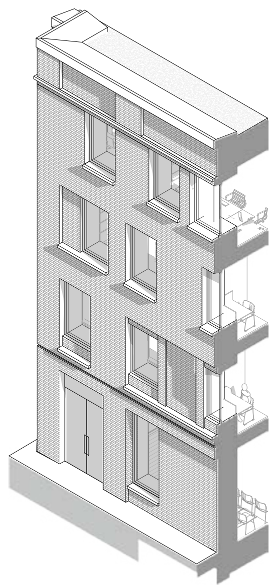
Clad in local Clipsham stone and handmade brick, it is obvious from first glance that the Stephen Schwarzman Centre for the Humanities is a very high-specification building. It has a timeless look, very much in keeping with its illustrious neighbours: the similarly stone-faced Radcliffe Observatory and the Oxford University Press.

Though they look as if they were laid by hand on site, the facades were constructed offsite, from 326 concrete-backed prefabricated panels. Like the columns and slabs of the structure, these panels were made in steel moulds.

"Unlike timber moulds, these can be reused almost indefinitely, avoiding timber waste," says Alex O'Gorman, senior project manager at contractor Laing O'Rourke. "In addition, the moulds were adjustable, so the size of the units could be altered without the need for new ones."

The majority of the facade panels comprised a slim reinforced concrete back of 100mm, faced with

TYPICAL FACADE BAY



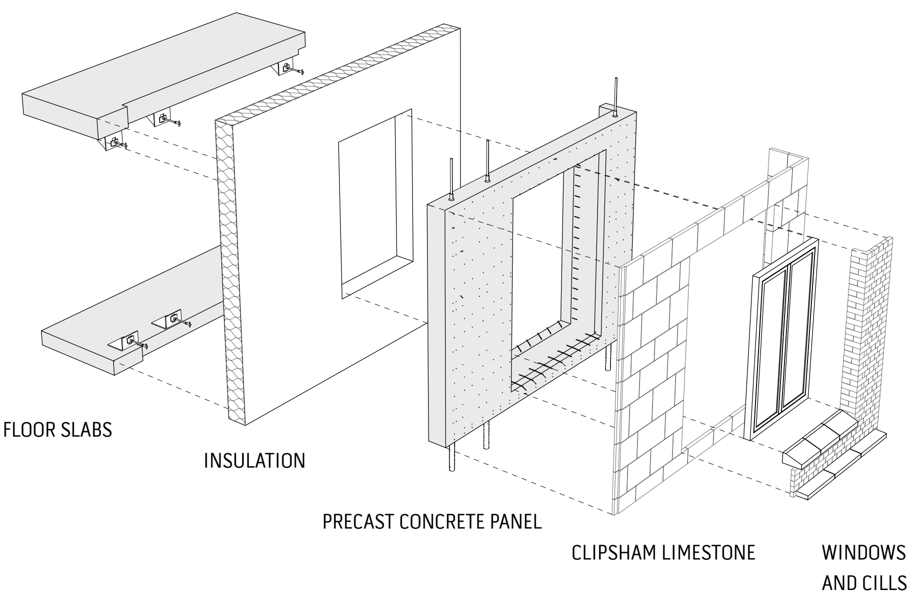
50mm of stone or brickwork. “In total, there were 18,500 pieces of stone and 160,000 bricks, but none of these materials had to travel far,” he says. “The stone is from Rutland, the brick from York and the cement from Ketton – all within 100 miles of our fabrication facility in Worksop.”

The panels of the upper floors were typically 3.3m x 6.7m, arranged in landscape orientation, and 3.5m x 5.4m for ground-floor panels in portrait orientation. Weight varied from 8 to 12 tonnes, with the heaviest unit 13.4 tonnes. “Panels with windows were delivered with the glazing already fitted,” says O’Gorman. “In factory-controlled conditions, we can prefabricate to the very close tolerances required for Passivhaus airtightness. They also fitted together, via vertical and horizontal connections, with hardly any gaps at all, helping to achieve the architect’s vision of a monolithic facade that looked hand-built, rather than made up of sections.”

The panels were self-supporting – forming a stacked rather than a hung facade. “Being just tied back to the frame helps with cold bridging, and taking the weight off the frame enabled it to be slimmer and lighter, saving material and further lowering embodied carbon.”

Photo: Simon Kennedy

LAYERS OF THE STONE FACADE PANELS



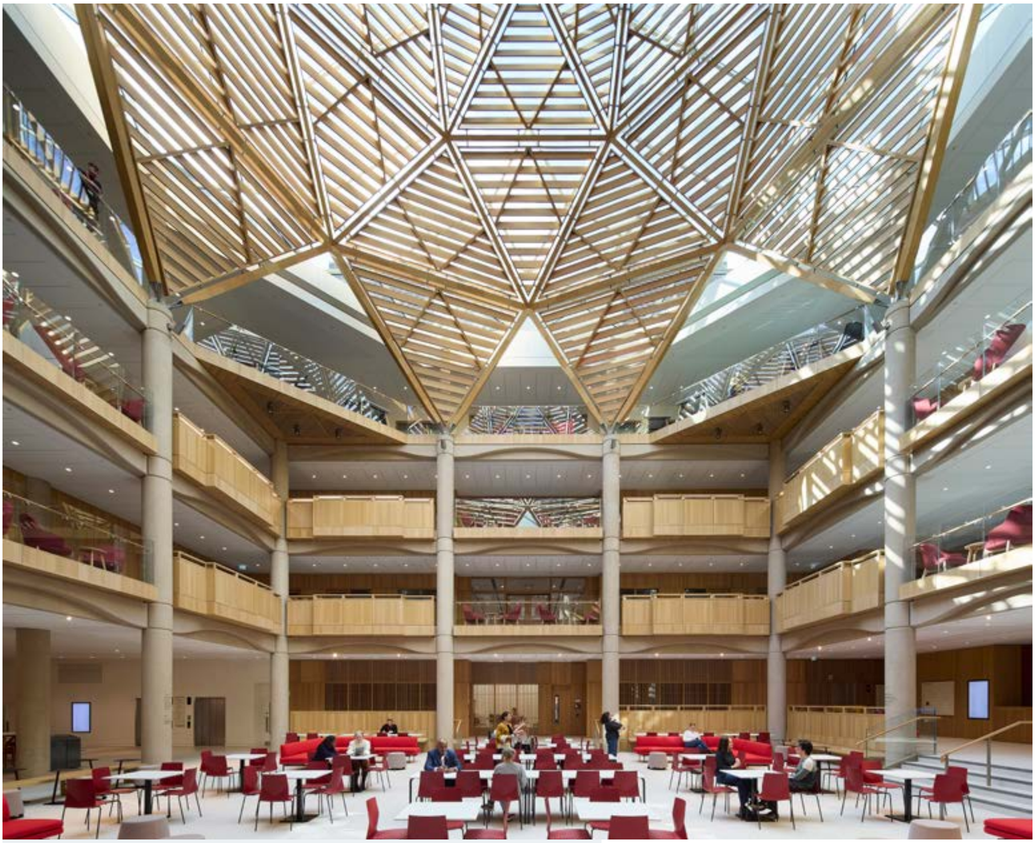


Photo: Hufton + Crow

GOLDEN CIRCLES

Designing and manufacturing the columns and beams

The interior of Oxford University's new humanities building continues the themes of the exterior, being similarly high-spec with oak panelling and more stonework. But exposed concrete plays more of a starring role, particularly in the Great Hall – a dramatic full-height, multipurpose circulation area, topped by a 60-tonne timber-framed dome.

The dome is supported by 12 circular pillars, 600mm in diameter, rising from the ground floor all the way to roof level. "The concrete has a beautiful, pale, almost golden colouration," says Hopkins' Andy Barnett. "It had to be right. The look and feel of the building has a lot to do with the colour palette – so the brick, the stone, the oak and the concrete all speak to one another."

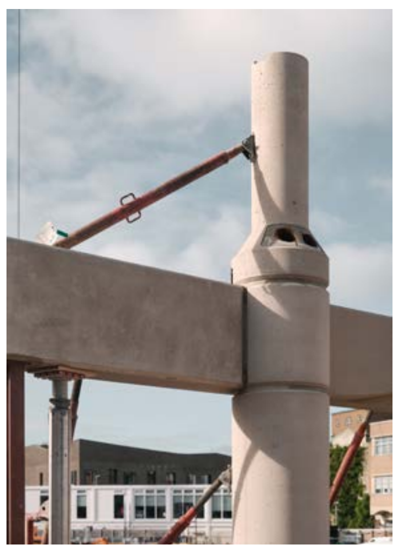


Photo: Hopkins Architects

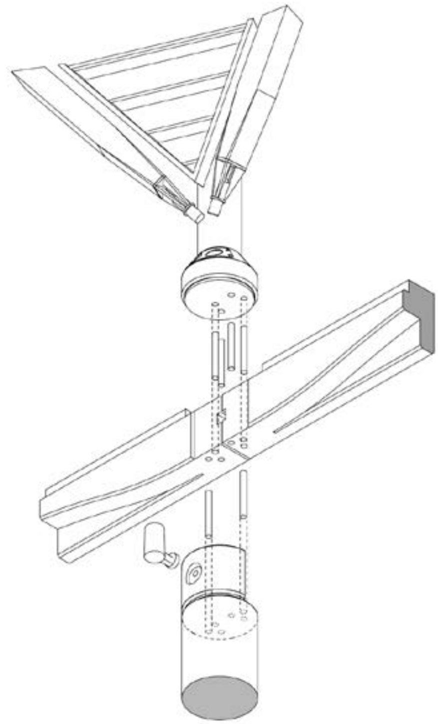
"The colour and texture of the columns was determined by the choice of aggregate, but also by adding pigments," says senior architect Kitty Byrne. "We started off with dozens of A4-sized samples, then narrowed it down to a few larger ones, and then eventually storey-height mock-ups."

She explains that the pigments enriched the GGBS concrete in the columns, which tends to produce a paler tone. "We also worked with Laing O'Rourke to develop the steel moulds. We wanted the pillars and beams to de-mould as crisply as possible."

Spanning between the Great Hall columns is a series of elegantly curved precast beams made from the same pale golden concrete. "We originally designed this arrangement with separate column, node and beam elements," says Byrne. "But Laing O'Rourke were keen to reduce the number of elements to make the process more efficient. It means you need fewer deliveries, fewer crane lifts and so on."

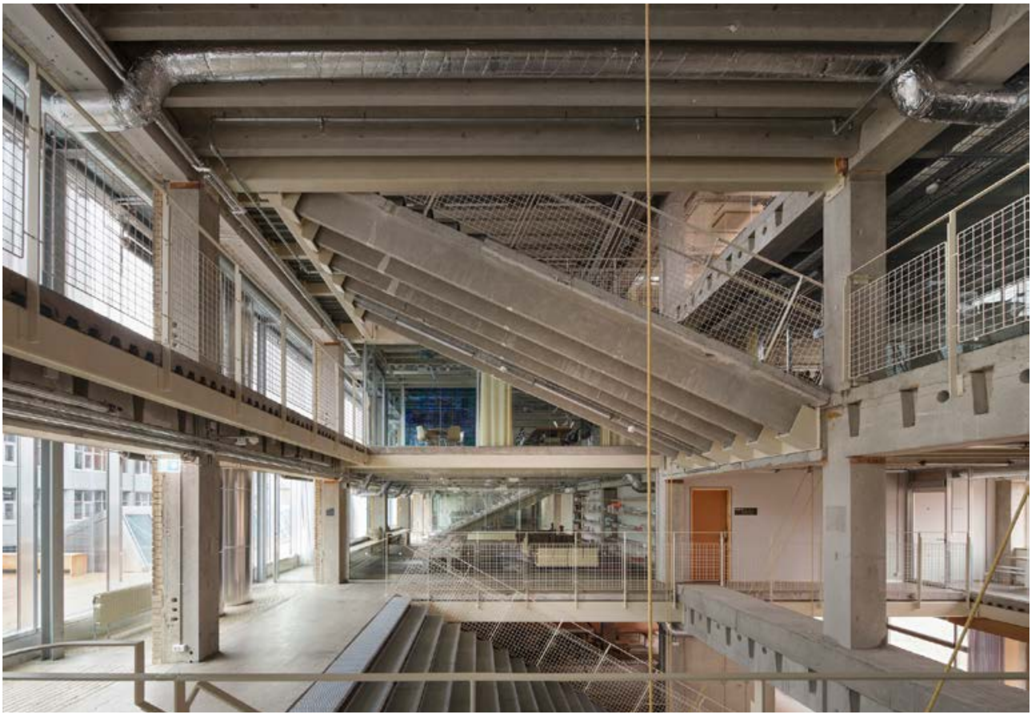
Her solution was to integrate the nodes into the columns, leaving a cut-out at the top rear of each column into which beams could be slotted. "We spent a long time detailing the chamfers and joints. When it's all pointed up, you can't tell what is a real connection and what's not – so we got that efficiency without compromising on the appearance. I think it was worth the effort."

Most visitors would agree. The Great Hall is stunning – an architectural pièce de résistance in which the grand pillars and undulating wave of concrete beams play a key role. ■



ABOVE
Detail of the precast column and beam connections in the Great Hall. The beam slots into a cut-out in the top of each column

Photo and drawing: Hopkins Architects



ROPE TRICK

At Thorajev 29 in Copenhagen, Pihlmann Architects has turned a 1960s warehouse into a multi-use space for arts organisations, reusing 95% of the building materials.

The most eye-catching interventions are the three wide processional staircases, which have been cut out from the precast concrete slab and tilted downwards to connect the four floors together.

The team tracked down the concrete manufacturer's original drawings of the precast elements from 1966. "This gave us very clear

Photos: Hampus Berndtson

and accurate information relating to the pretensioned rebar inside the TT beams," says Isabella Priddle, an architect at Pihlmann. From this data, the engineers designed a steel brace that was inserted at each end of the 1.2m-wide beams, preserving the tension in the rebar.

One of the tenants has added an artwork of yellow ropes and red handles to the stairs. "It plays on the idea of being able to pull the slab back up, but it doesn't actually move anything," says Priddle. "It really feels like a piece of the building though – everybody tries to pull on those red handles."

READ THE FULL STORY
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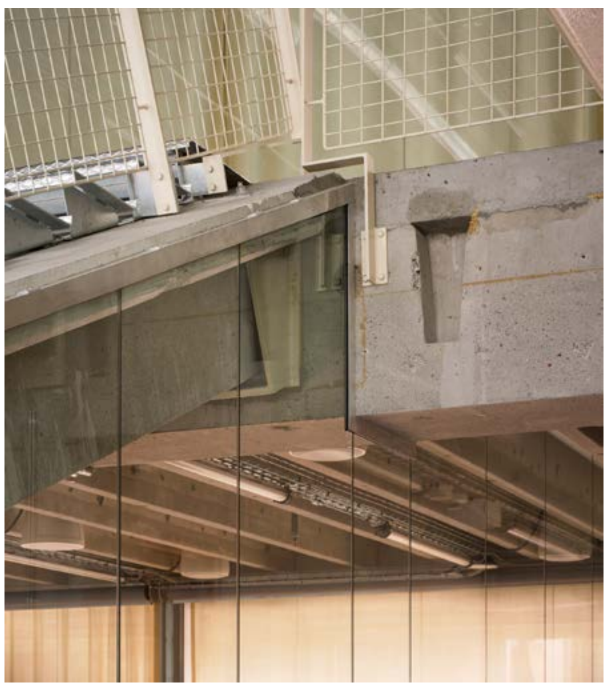

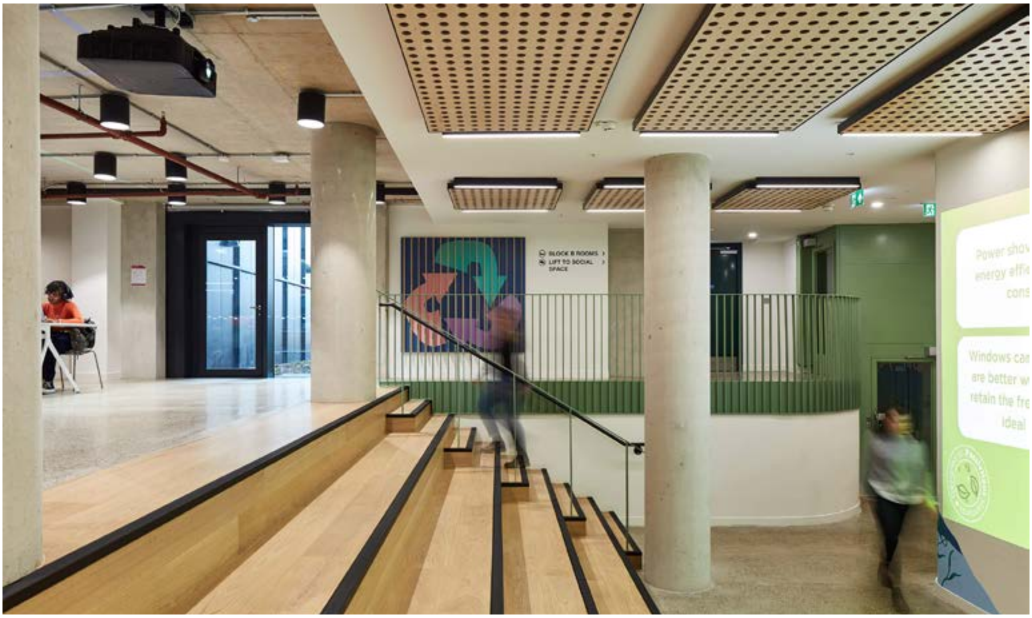

NEW DAY DORMS

Allford Hall Monaghan Morris' Urbanest Battersea has been certified as the largest Passivhaus development in England.

The three student residential towers have an in-situ concrete structure with relatively small spans between columns, minimising perimeter downstand beams, which helps to prevent thermal bridging through the facade. The short spans also limited deflections, which can pose a challenge to airtightness.

READ THE FULL STORY
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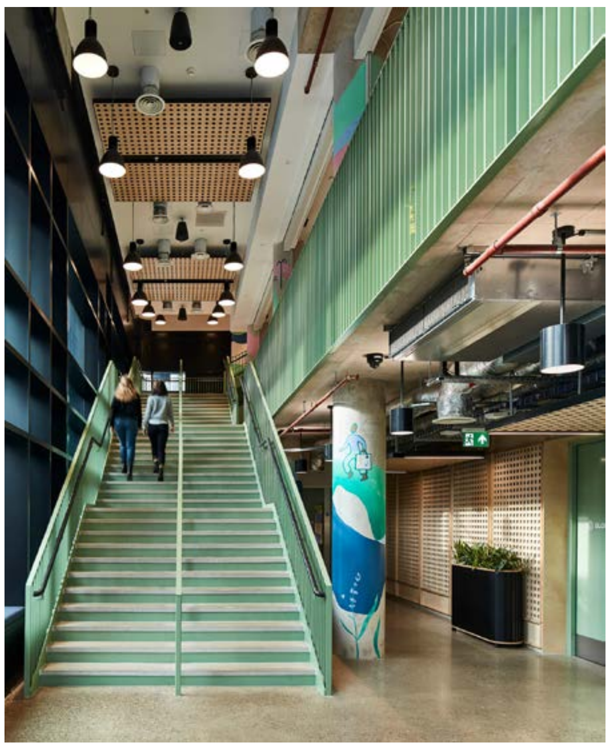

Photos: AHMM

HONEST JEAN

Designed by Dominique Coulon et Associés, the St Jean de Luz Cultural Centre in south-west France is a dramatic sequence of in-situ concrete volumes, containing a theatre, music school and studios.

These facilities project into a central atrium in a series of steps and overhangs, with the main stairwell cantilevering 4.2m. It was only once the whole building was complete that the temporary supports could be removed, "very carefully and in a precise order", to account for the deflection of the concrete.

READ THE FULL STORY
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Photos: Eugeni Pons

Some 38.5 tonnes of crushed concrete material were incorporated as recycled aggregates into the concrete for 40, 50, and 60 Charter Street (pictured), part of the Wood Wharf Phase 3 development at Canary Wharf, east London

Photo: Dylan Garcia / Alamy Stock Photo

Recycled aggregates in concrete

In a circular economy, recycled crushed waste concrete has an important role to play – not just in sub-base and fill, but as an ingredient in fresh concrete. Andrea Charlson explores when (and when not) to use it

Over 90% of the UK's hard construction waste is recycled, typically in unbound applications such as sub-base and fill. Currently, about 5% is used as aggregate in new concrete, but there is potential to increase this proportion. A number of research projects are exploring ways to enhance the properties of recycled aggregates and expand their use within concrete.

Recycled aggregates produced using current recycling practices do not always behave in exactly the same way as natural stone aggregates. Their substitution must therefore be carefully considered, taking a range of factors into account, such as performance, carbon targets and availability.

As always with circular economy approaches, it is essential to take a whole-system view, balancing material properties and environmental impacts, to determine the most appropriate solution. Seeking advice from suppliers early in the process can be beneficial for achieving this balance.

What are recycled aggregates and how can they be used?

The British Standard on concrete specification, BS 8500, differentiates between recycled aggregate and crushed concrete aggregate.

Recycled aggregate (RA) is often used as a catch-all term, and is defined as "aggregate resulting from the reprocessing of inorganic material previously used in construction". There are very few limits on its constituents and its composition can vary considerably.

Crushed concrete aggregate (CCA), on the other hand, must be composed of at least 90% concrete. This results in a more consistent product, which is much simpler to use in a range of potential applications.

Both RA and CCA can be classified as either coarse (greater than 4mm in diameter) and fine (less than 4mm) aggregates.

Coarse CCA is generally uniform enough to be introduced into most concretes with minimal additional assessment. Although BS 8500 does not exclude the use of fine CCA, fine RA or coarse RA, they are more variable, so satisfying the standard requires project-specific testing to confirm performance.

In practice, when discussing recycled aggregates in concrete, this generally refers to coarse CCA.

The Concrete Centre document "Specifying Sustainable Concrete: Aggregates" provides further details of definitions and constraining criteria for use in concretes.

How do recycled aggregates affect structural performance?

CCA is a combination of the original natural aggregate and the residual hardened cement paste from the first use. As such, it affects the performance of concrete in a number of ways.

BS EN 1992-1-1:2023 Annex N: Recycled Aggregates Concrete Structures lists a number of different properties used in the design of concrete structures that may need to be adjusted when recycled aggregates are used. These include compressive strength, shear resistance and deflection calculations. The UK national annex, when published, will provide guidance on exactly how these properties should be adjusted, based on the use of coarse CCA, and it will make reference to the need for testing when using fine CCA, fine RA and coarse RA.

It is important that the use of recycled aggregates is discussed with the whole project team and that they are not specified in isolation without considering their impact on performance.

Recycled aggregate and embodied carbon

Counterintuitively perhaps, recycled aggregates do not necessarily lower the embodied carbon of concrete, and they can increase it.

Photo: Canary Wharf Group

ABOVE
At Canary Wharf Group and Kadans Science Partner's One North Quay development in London, the team recovered 2,500 tonnes of crushed concrete material from the demolition of a 100-year-old piled quay structure – shown stockpiled prior to being crushed

There are a couple of reasons for this. First, because some recycled aggregates are more absorbent than natural aggregates, this can increase the amount of water required in the concrete, with the knock-on effect of increasing the cementitious content, the predominant source of concrete's carbon emissions.

Secondly, sorting demolition material, and ensuring that it conforms to standards, involves more processing than is required for natural aggregates. For this reason, recycled aggregates typically have a higher A1-A3 (cradle to factory gate) embodied carbon value than natural aggregates extracted from quarries.

One positive carbon aspect for recycled aggregates is that they may be available closer to concrete production sites than natural aggregates (see table below). In these cases,

How transport distances affect embodied carbon

	Cradle to gate (A1-A3) $kgCO_2e$/tonne	Total transport distance by road in km	Transport (A4) $kgCO_2e$/tonne	Total $kgCO_2e$/tonne
Recycled aggregate	6.05	0	0	6.05
Natural aggregate	4.36	19	1.69	6.05
Recycled aggregate	6.05	20	1.82	7.87
Natural aggregate	4.36	39	3.51	7.87
Recycled aggregate	6.05	40	3.65	9.70
Natural aggregate	4.36	59	5.34	9.70

The table illustrates the potential impact of transport on the embodied carbon of natural and recycled aggregates, and the relative distances that each would have to travel to reach the same embodied carbon, irrespective of its use.

The following carbon factors have been used, sourced from the Inventory of Carbon & Energy (ICE) V4.0 database:

- Natural aggregate from virgin land-won resources, bulk, loose: 4.36$kgCO_2e$/tonne
- Recycled aggregate, no heat treatment, bulk, loose: 6.05$kgCO_2e$/tonne
- Transport by road, 33t articulated per tonne-kilometre: 0.0912$kgCO_2$/tkm

Recycled aggregates often travel shorter distances than natural aggregates, with some being processed on site during concrete production. The table shows that when recycled aggregates are sourced at least 19km closer than natural aggregates, they will have a lower A1-A4 embodied carbon.

they may have a lower embodied carbon, after transport is included. Suppliers will be able to advise on the implications and optimum balance for a specific application.

Displacing demand

Recycled and secondary aggregates already make up 30% of the UK aggregates market, using over 90% of UK construction and demolition waste. This means that specifying recycled aggregates in concrete does not necessarily reduce extraction of natural aggregates – it may just divert material from applications where it can be used more effectively.

It is recommended that recycled aggregates are only used in concrete when they are more locally available than natural aggregates, or can be delivered using low-carbon transport. The greatest opportunity could be on urban and suburban sites, where less backfill is needed and there is more likely to be a surplus of demolition waste. These sites are also usually further from extraction sites producing natural aggregates.

Innovations

A number of initiatives are exploring alternative high-value applications for recycled aggregates, to expand their potential use and exploit their ability to absorb carbon dioxide.

Accelerating carbonation

Concrete naturally absorbs carbon dioxide throughout its lifetime, reabsorbing some of the process

Photo: Canary Wharf Group

ABOVE
The Wood Wharf project pioneered the injection of carbon dioxide into the remaining demolition concrete from the quay, using technology developed by Neustark to enable permanent carbon sequestration. These carbon-negative aggregates were used in temporary works structures for the construction of One North Quay (pictured)

emissions from cement manufacture, and acting as a long-term carbon sink. This occurs slowly during a structure's service life, and much more quickly when it is demolished and the concrete crushed, increasing the surface area. A number of innovative solutions are exploring ways to accelerate or increase this ability, through specialist crushing techniques and by curing CCA with carbon dioxide in a form of carbon capture.

There are suggestions that these techniques also improve the properties of the aggregate, potentially reducing water demand. This in turn removes the need for extra cement and can lower the embodied carbon of the resulting concrete.

Recovering concrete fines

Techniques are being developed to separate concrete back into its constituent parts, effectively deep-cleaning the aggregate by mechanically removing the hardened cement. The Mineral Products Association is part of a research team looking into the technical potential of the resulting material, which is known as recycled concrete fines (RCF) and can be used to make new, lower-carbon cement or as a supplementary cementitious material.

The additional processing necessary to produce RCF may also result in a cleaner coarse CCA, which could in future be determined to perform closer to a natural aggregate.

Andrea Charlson is senior sustainability specialist and circular economy lead at The Concrete Centre

Visualisation: Canary Wharf Group

ABOVE
CGI of One North Quay. Designed by Kohn Pedersen Fox, it is set to be Europe's tallest purpose-built commercial laboratory building

FINAL FRAME: HOLY REDEEMER CHURCH, TENERIFE

The Holy Redeemer Church and Community Centre of Las Chumberas, designed by Fernando Menis, has been named World Building of the Year at the World Architecture Festival in Miami. Walls of chipped concrete, mixed with local volcanic aggregates, serve as structure, form and finish, as well as absorbing heat and controlling acoustics.