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The Concrete Centre

CONCRETE QUARTERLY

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Introducing the Concrete Centre's tool for helping designers to find the most material-efficient structural solution

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

Scandi *gris*

There's quite a Scandi vibe to this issue of Concrete Quarterly, with our cover story and innovation feature both highlighting examples from Denmark. It's not unusual for us to include projects from other countries – we actively seek out inspiration from around the world. This is particularly the case when it comes to sustainability, as cracking net-zero is absolutely a global issue. Local conditions may be unique, but designers and supply chains in every country face the same challenges.

Scandinavia is renowned as a leader in this field – it's no coincidence that the world's first cement plant to be fitted with industrial-scale carbon capture is in Norway, where Heidelberg Materials' Brevik facility has reached mechanical completion. That can-do spirit is also on show in GXN's (P)recast project, an ingenious way of extracting slabs from end-of-life public housing and using them as precast planks in new homes on the same site (page 6).

Both carbon capture and component extraction will be part of a net-zero concrete ecosystem, but they are long-term endeavours. Fortunately, there are plenty of opportunities to reduce carbon that designers can seize right now. Calcined clay is a big one, and you can see it in action in Copenhagen, where architect BIG has used its own HQ as a test bed (page 16). Here, 30% of the cement in the in-situ concrete was substituted, reducing its embodied carbon by 25%. Clay is abundant in many places around the world, including as a waste stream. It's less energy-intensive to produce than cement, with no process emissions. It can already be specified in the UK under BS 8500, so the BIG HQ is a fantastic proof-of-concept that will hopefully be an inspiration to many.

One of the barriers to using alternative cements is that they can take longer to reach strength requirements. Where programme constraints won't allow this, technology can help: on the Capella building in London (page 28), contractor Laing O'Rourke used smart sensors to provide real-time data on how the concrete was curing. This revealed that the speed of strength gain was faster than expected, and enabled a tweak to the mix to use even more GGBS.

THE BIG HQ IS A FANTASTIC PROOF-OF-CONCEPT THAT WILL HOPEFULLY BE AN INSPIRATION TO MANY

Material-efficient design is another area where apparently minor changes can make a big impact. Our Concept tool (page 30) helps designers to quantify the impacts of early-stage decisions on grid spacing, loading and structural systems. These can be dramatic: in our theoretical example, the embodied carbon of the concrete structure of an office building is cut by 42% before the concrete specification is even considered, by reducing the imposed load and column spacing, and switching to a waffle slab.

Of course, an even more efficient way to design is to reuse an existing concrete structure. Uncovering the original waffle slab was the key to reinventing an unloved 1970s Liverpool tax office as a high-concept apartment building (page 29). So while it's always nice to bask in a little Scandi style, we can also find plenty of inspiration closer to home. ■

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On the cover: BIG HQ in Copenhagen by Bjarke Ingels Group. Photo: Laurian Ghinitoiu

Photos: GXN

INNOVATION

(P)RECAST

A CROSS-INDUSTRY TEAM INCLUDING THE DANISH TECHNOLOGICAL INSTITUTE AND GXN HAS EXTRACTED PRECAST SLABS FROM A 60-YEAR-OLD BUILDING AND REUSED THEM IN NEW HOUSING. COULD THIS BE THE FUTURE OF ESTATE RENEWAL?

ABOVE
The slabs were removed from a housing block in Gellerup. The 6,000-home estate is the largest in Denmark and is undergoing a major regeneration programme

In October 2023, 42 hollowcore slabs were removed from a condemned housing block on the Gellerup estate, just outside Aarhus in Denmark. It's part of a major programme of renewal – like the UK, much of Denmark's social housing was built rapidly in the mid 20th century, and many of those buildings are now being demolished. What's different about this particular redevelopment is that 30 of those slabs will have a second life, in new terraced homes built on the same estate.

It's all part of a research initiative known as (P)RECAST, which was set up to explore the process of reusing structural elements, from extraction to storage to reinstallation. "We

THE ONLY DIFFERENCE FROM ANY OTHER INSTALLATION IS THAT THE ELEMENTS WEREN'T PRODUCED A MONTH AGO. THEY WERE PRODUCED 60 YEARS AGO

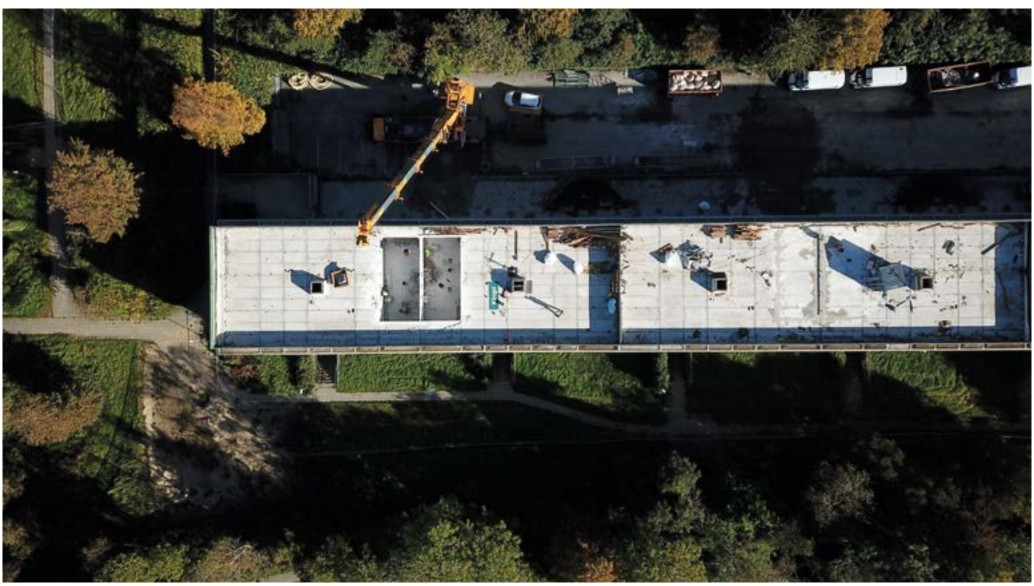
managed to secure an agreement with a precast supplier working on the new buildings at Gellerup," says Bjørn-Tore Johannesen, sustainability engineer at GXN, which has been involved in the project from the start. "So it was a perfect circle."

There are 13 organisations involved in (P)RECAST, and if that sounds like a lot, it's because the challenges are logistical as much as technical. The team includes demolition companies, manufacturers, engineers, sustainability consultants and developers, among others, each taking a deep dive into methodologies and commercial strategies for their part of the value chain.

Danish public housing is an ideal test bed. The vast majority was built within a short time window from 1960 to 1980, assembled from standardised designs using precast concrete slabs and walls. With so many buildings coming to the end of their service life at the same time, a solution for reusing their components could be a game-changer for future housing renewal projects.

The first step was to identify elements for removal. GXN, a design-driven research studio founded by architect 3XN, developed a screening tool, based on the existing process of environmental screening prior to demolition. "We started with quite a simple Excel spreadsheet, then we added as much data as we

BELOW
Internal and external support systems were erected, before the slabs were lifted out by crane



Photos: GXN

could about the condition and dimensions of the element, giving us a traffic light system for whether or not to pursue it," says Johannesen.

The screening tool provides a basis for data flow throughout the project. Architects can connect it to 3D-modelling software, and structural engineers can easily see the known technical capabilities of each component. But first, it enables demolition contractors to plan the deconstruction strategy.

The slabs were 180mm thick, 1.2m wide and 4.2m long – as with most hollowcore slabs used in Denmark in the 1960s, they were made with mesh reinforcement, which limits the structural span. The team carried out a series of test extractions. They investigated methods of removing the slabs using machinery that was already on site, such as diggers and trucks, but concluded that the most viable approach was to erect internal and external support systems, before cutting the joints and lifting the slabs out by crane. "It's an expensive process, and not budgeted for in conventional demolition," says Johannesen, "but on a bigger scale you could minimise the costs."

Initially the extracted elements, each of which weighed about 2 tonnes, were taken to a storage facility 20km away. Testing was then carried out on sample slabs at the Danish Technological Institute in Taastrup. They were assessed for shear and flexural load-bearing capacity, as well as deflection under short-term and long-term loads.

The testing process revealed that the loadbearing capacity was greater than the declared capacity from 60 years ago. Even so, the team needed to find a "sweet spot" in the new buildings where the structural demands on the slab wouldn't be too high. The slabs were now 4m long – they had lost a few centimetres during the extraction process and had then been precisely cut in preparation for reinstatement. This was sufficient for their use on the upper floor of the new terraced housing,

Photo: Danish Technological Institute

ABOVE
The slabs were assessed for shear and flexural load-bearing capacity, as well as deflection under short-term and long-term loads

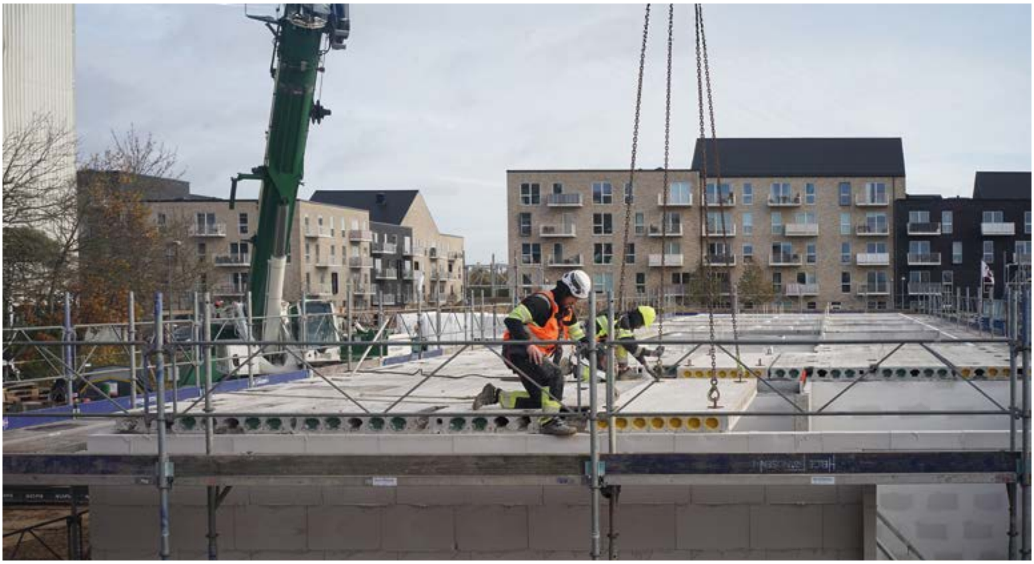


Photo: GXN

with one slab used per building alongside new hollowcore slabs. "In technical terms, they could be used in more structural locations," says Johannesen. "But that would require a standard way of documenting that they're fit for purpose, which we're currently lacking."

The reinstallation process was relatively simple. The thickness and width of the slabs were unchanged: there had been no screed topping in the original structure, and the team had been able to cut the longitudinal joints and remove the mortar cleanly. They just needed new lifting anchors and plastic sleeves to receive the load-transferring connections. "The only difference from any other installation is that the elements weren't produced a month ago. They were produced 60 years ago." The undersides of the slab will be plastered and painted.

The next step is to make the case for new regulations, to enable element reuse on a larger scale. Meanwhile, GXN is extending its research to the commercial sector, and in-situ concrete. It has been working with developer British Land on the extraction of a portion of a floor plate from a 1970s London tower, with the aim of studying its potential for reuse as precast planks in another application. As GXN says, it's not just about recycling a material, it's about preserving specific performance qualities. If Gellerup is any indication, 50-year-old concrete still has plenty of performance left to give. ■

Words by Nick Jones

ABOVE
The hollowcore slabs are being reinstalled alongside new precast planks in new-build terraced homes on the Gellerup estate

PROJECT TEAM
Danish Technological Institute, GXN, Aarhus University, Søndergaard, Tscherning, COWI, Per Aarsleff, Peikko, Hi-Con, AP Pension, Brabrand Boligforening, Dansk Standard, Dansk Beton

LASTING IMPRESSION

MIKE JAMIESON

HOW A BRUSH WITH BASIL SPENCE LED THE TATEHINDLE DIRECTOR ON A PATH TO COCKFOSTERS TUBE STATION, VIA LIVERPOOL METROPOLITAN CATHEDRAL

When I was at university in the late 1980s, the high-tech influence was really strong. But then in my year out I went to work for Andrew Merrylees Associates in Edinburgh. Andrew was a former partner of Basil Spence, so I began to explore the work of Spence and his contemporaries in a bit more detail. That put me on a different trajectory.

One building that I visited then, and have been back to many times since, is Frederick Gibberd's Liverpool Metropolitan Cathedral. It's a unique space in the city – radically modernist in character but with a peace and calm to it. This is partly down to the purity of the structure: a circular plan allows everyone to see the altar, while above, boomerang-like trusses are held together by two vast ring beams, all exposed internally. The trusses are attached to 16 flying buttresses, which rise up the cone-like exterior to the crown-like lantern – an iconic presence on the skyline. Concrete is also used quite unusually to frame the 3cm-thick stained glass, designed by John Piper. The interplay between glass and concrete, modern artworks, iconography and structure, make it a unique space in the city.

Photo: Ian G Dagnall / Alamy Stock Photo

ABOVE
Metropolitan Cathedral of Christ the King, Liverpool, by Frederick Gibberd & Partners, 1967

Train sheds are sometimes referred to as the cathedrals of the industrial age, but it's not what you usually think of when you think of Charles Holden's stations on the London Underground. These buildings, built in the 1930s and 40s, were a crucial part of the all-encompassing identity that Frank Pick developed for the network, from the iconic map to the design of the trains. The ticket halls were usually brick boxes – square like east Finchley, circular like Arnos Grove, or even octagonal like Bounds Green. Cockfosters, though, breaks from that mould. Opened in 1933, it's a classic railway shed but on a smaller scale. Instead of a steel roof on brick pillars, it is a symphony of pale exposed concrete. The central section is double-height with clerestorey windows and flanked by aisles lit by glass block skylights. Angular portal frames repeat in pairs all the way along the structure, with wooden benches tucked into the narrow bays. The entrance lacks any real street presence, but as you move down to the platform it's really quite atmospheric. It almost feels like it's wrong to make too much noise.

My last choice is a recent building, but one I just really enjoyed. Stanton Williams' UCL Marshgate is playing a leading role in reshaping higher education, mixing collaborative "vertical neighbourhoods" with public areas where anyone can have a coffee. The quality of the detailing is first rate, both internally and externally. The boardmarked concrete is so crisp, and the way that shadows rake across it from the atrium above is really lovely. ■

Mike Jamieson is design director of TateHindle

Photos: Hufton + Crow; RIBA Collections

TOP
Cockfosters London Underground Station, by Adams Holden & Pearson, 1933

ABOVE
UCL Marshgate, London, by Stanton Williams, 2023

From the archive: Autumn 1969

THE BRUTALIST II – THIS TIME IT'S PRECAST

Here's the pitch: our hero (let's call him Marcel) is a tortured but visionary Hungarian-born architect, trained at the Bauhaus but seeking to rebuild his life in post-war America. He is driven by a single obsession: the precast concrete structural facade ...

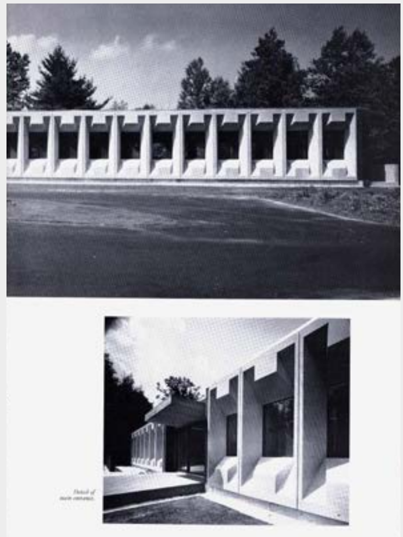
Brady Corbet's movie *The Brutalist* has caused something of a stir in the architectural community. Feathers have been ruffled by its semi-fictionalised depiction of the legendary modernist Marcel Breuer, and the artistic licence the director has taken concerning his 1950s masterpiece, the St John's Benedictine monastery in Minnesota.

But what if Corbet had focused his storyteller's gaze on Breuer's later years instead? A glance through the *Concrete Quarterly* archive suggests it may have made for a less controversial tale, albeit with a slightly heavier emphasis on modular construction techniques.

Take the 1969 Torin Corporation headquarters in Torrington, Connecticut – billed as "the latest example of Breuer's continuing search for a beautiful and appropriate expression of the precast concrete structural wall". There would have been drama ("deep shadows are cast that accentuate the rhythm of the facades"), and a twist in the tale ("weathering is likely to increase and enhance the general effect"). "Rather spectacular", was CQ's verdict.

Our correspondent was particularly impressed with the efficiency of the precast design, based on a single repeated module, "appearing to kill several birds with one unit". Each was structural, self-finished externally and internally, housed mechanical and electrical equipment, and provided a degree of sun control.

In other words, Breuer had arrived at a solution as succinct as it was elegant. So, perhaps most importantly, had Corbet decided to embrace the possibilities of precast, there would have been no danger of *The Brutalist*'s bladder-straining three-and-a-half hour run time.



Photos: Schnepp Renou

ORIGIN STORY

RECIPROCAL HOUSE

NORMAN FOSTER'S FIRST PROJECT WAS AN EXTENSION IN NORTH LONDON. NOW GIANNI BOTSFORD HAS BUILT A HOUSE TO GO WITH IT

Like a game of architectural whispers, Reciprocal House is a response to a response. In 1969, Norman Foster extended a Victorian mews cottage, tucked behind a pub in Hampstead. It was one of his first built projects – a lightweight single-storey structure of steel lattice beams, concrete blocks and large-span glazing. "The owner used it largely as a space to entertain and host parties," says architect Gianni Botsford. "After he died, the new owner wanted to update the house and appointed us to explore a range of different options."

Botsford's response has been to replace the cottage – which was by now fairly rundown – with a two-storey structure within the same volume and footprint, connected to the Foster extension. The new house's minimal industrial palette – including exposed concrete walls and soffits – is the main "reciprocal" gesture, echoing Foster's stripped-back aesthetic. But ghostly traces also remain of the original house, not just in the Victorian bricks, which have been repurposed as paving, but also in the angled elevations – a reference to the cottage's mansard roof.

Botsford began with a forensic analysis of the site, which is surrounded by tall trees and back gardens. The client needed a space that would not be overlooked, while also allowing long views out, and sun and daylight in. "We wanted nature to lead the design process," says Botsford.

Through a series of physical study models, a formal response began to emerge. The sloping elevations would counterbalance the powerful presence of the Foster structure, while framing views and leaning back from the canopy of the trees. It also became clear that this trapezoidal form should be built from in-situ concrete. "It worked from a structural point of view, because of the angles, and was practical because the site was difficult to access. And it has a very nice relationship with the blockwork of the extension."

Perhaps counter-intuitively, concrete also helped to draw the natural landscape into the home: "All the windows are oriented very carefully in the skylights, and concrete tempers that light so well. In this climate, it's also an ideal thermal buffer. It all came together as a solution that made sense."

Botsford worked closely with structural engineer TALL to optimise the frame. The largest floorplate, which spans 8m across the ground floor, is 300mm deep, but the two upper floors and external walls are just 150mm. Because of the angled pours, they chose a self-compacting mix, with a test carried out first on a 2m x 1m section of the ground floor wall.

The concrete is exposed throughout the interior, and has a quietly crafted appearance. "We wanted it to be a background. There was no attempt to make it legible, or express the bolt holes or formwork," says Botsford. GGBS has lightened the colour and phenolic-faced plywood has left a smooth finish. Apart from circular downlights in the soffits, there are barely any penetrations in the concrete – sockets are located in floor boxes and wall lights are placed

ABOVE
The Foster extension, before and afer

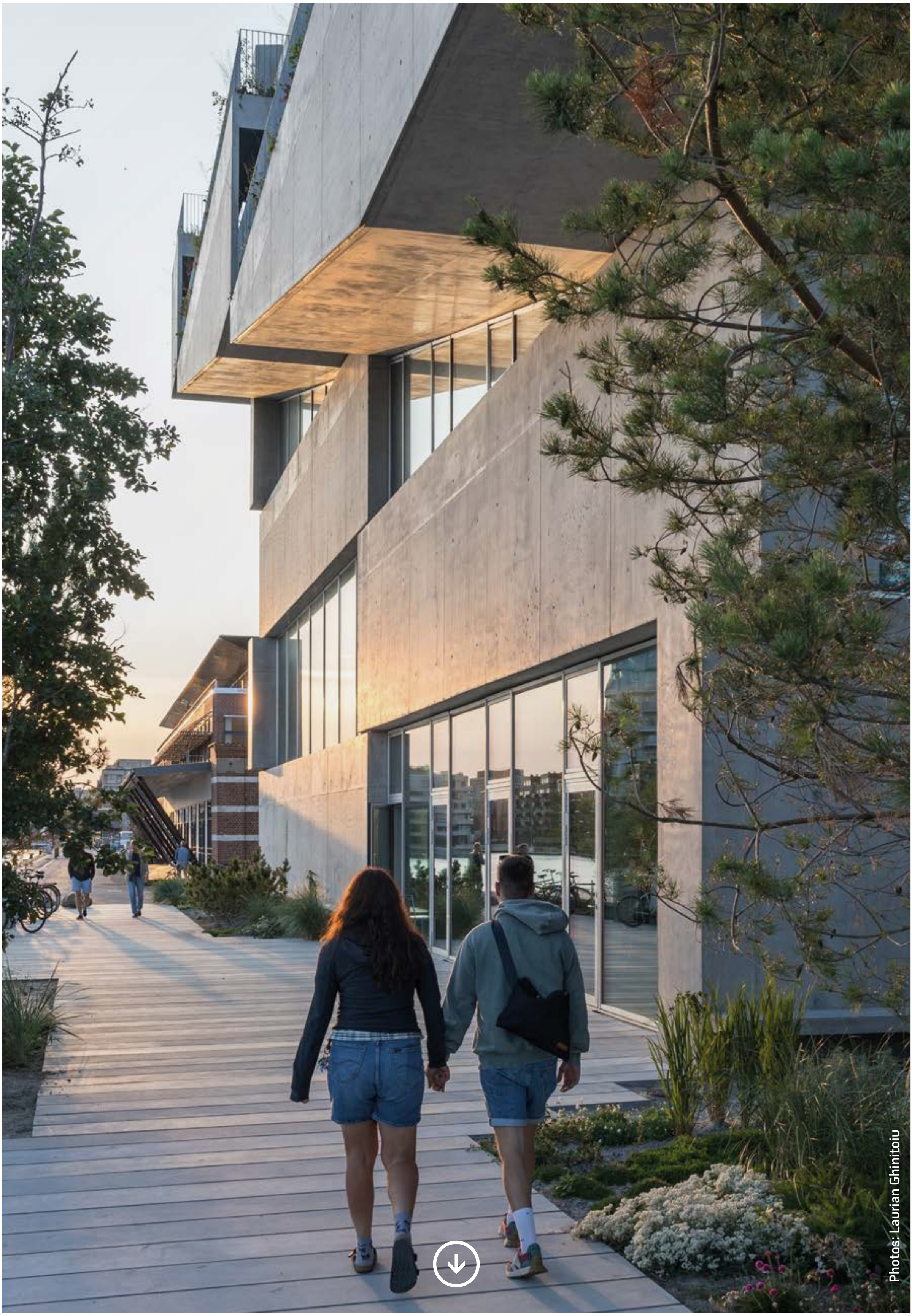
RIGHT
A spiral staircase rises through the heart of the house, emerging beneath a circular skylight

on partitions. The exposed structure is complemented by bespoke aluminium furniture and fittings, including a central spiral stair. "The house has no corridors. The staircase connects everything."

The staircase and the concrete spaces that it connects are also at the heart of the nature-led heating and ventilation design. The house is all-electric and uses an air source heat pump for heating, but also works in tune with the seasons. In winter, sunlight pierces through the bare trees to passively warm the structure, slowly releasing that heat into the home overnight. In summer, with the house shaded by branches in full leaf, the spiral becomes a funnel for passing breezes, which circulate over the cool concrete before rising up to the skylight. "With concrete, you expose it to open windows and fresh air, and it just works in a very natural way." ■

Interview by Nick Jones

ABOVE
The trapezoidal form was partly inspired by the mansard roof of the original cottage (below)


Photos: Laurian Ghinitoiu

NEXT BIG THING

Bjarke Ingels Group's Copenhagen base harks back to the brutalist era, while heralding a new dawn for calcined clay concrete.
By Nick Jones

Bjarke Ingels has always cultivated a reputation as a trailblazer – the freewheeling, globetrotting creator of vertical film studios, twisting bridges and rooftop ski slopes. Now, for his own practice's headquarters in Copenhagen, he has done something less showy but arguably more radical, completing the first building in Denmark made from calcined clay concrete.

ABOVE
The external structure comprises 28 "mega-beams" stacked alternately with full-height glazing

Situated at the head of the Sundmolen pier on Copenhagen's North Harbour, the Bjarke Ingels Group (BIG) HQ is an unambiguously concrete structure. Seven storeys high, it takes the form of a distorted cube, with one side sliced off at an angle as the pier narrows to a point. The frame is comprised of 28 "mega-beams" – enormous sections of exposed concrete, 20m long and 4m high. These are stacked alternately with expanses of full-height glass and meet like interlocking fingers at the corners of the building. On each elevation, two of these solid sections, triangular in shape, protrude from the frame. These support terraces and a 140m-long stairway that winds around the building from the ground to the roof.

The building has been described as "neo-brutalist" and certainly captures the defiant spirit of 1960s modernism ("historically ugly" was the verdict of one local politician). But it's hardly an outlier in the North Harbour's post-industrial landscape of repurposed siloes, warehouses and apartment buildings. Concrete was the obvious solution in the harsh marine climate, with the building facing out onto the Oresund strait separating Denmark and Sweden.

"The design intent was for it to be raw and industrial looking," says Andrea Hektor, director of BIG Engineering, the practice's structural team, and BIG CPH Sustainability. The original plan was to assemble it from off-the shelf precast concrete elements, which are used extensively throughout Denmark for everything from housing to car parks. "We wanted to take something very standard and then use it in a very non-standard way," she explains.

However, the sheer scale of the elements made mass production unviable. Instead, the mega-beams were cast in situ, but with a similar build-up to a precast sandwich panel, with a layer of insulation between a loadbearing inner leaf and a thinner outer leaf. This meant that both interior and exterior surfaces could be left exposed, in keeping with the brutalist aesthetic. The fact that casting on site offered less control over

WE WANTED TO TAKE SOMETHING VERY STANDARD AND THEN USE IT IN A VERY NON-STANDARD WAY

ABOVE
A black staircase zigzags through the heart of the space. The half-floorplates are made from prestressed double T-plate units

the eventual finish was seen as an added benefit. "If there were blemishes, we were happy to accept that."

The switch to in-situ concrete also gave BIG a greater say over the mix. The designers were anxious to reduce the embodied carbon of the frame, but also wanted to move beyond accepted approaches such as using fly ash or GGBS as supplementary cementitious materials (SCMs). As by-products of industrial processes not used in Denmark, neither were locally available.

In the role of its own client, BIG was in a unique position to explore novel solutions and take on the risk of adopting them, potentially helping to establish a wider market. So, instead, the team specified concrete made with calcined clay as an SCM. In Denmark, calcined clay concrete had been used on civils projects such as bridge piers, but never on a building, let alone a piece of statement architecture.

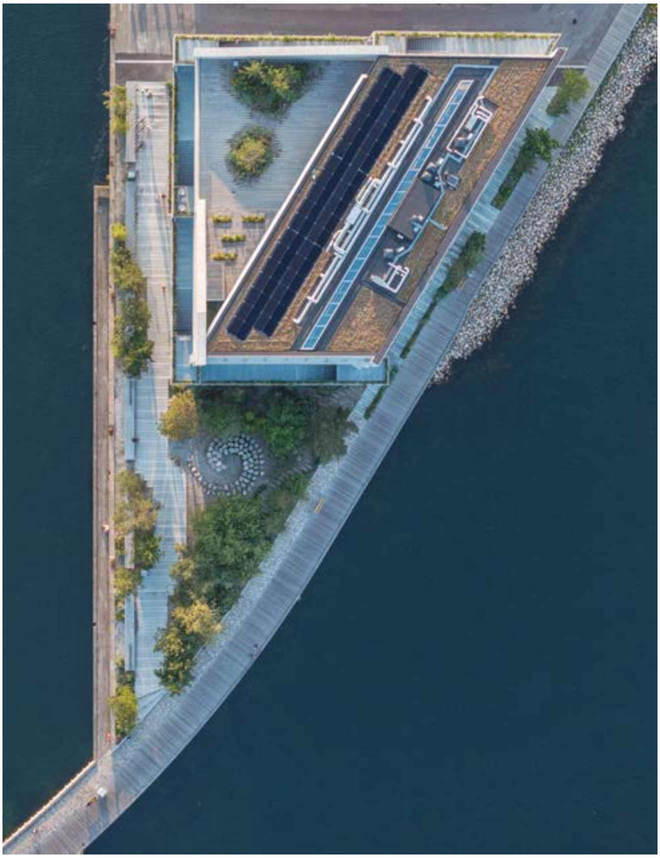
As a binder, calcined clay has a number of advantages over cement. Clay calcinates at 700-800°C, compared with 1,500-1,600°C for limestone, the main raw ingredient of cement clinker. Because it doesn't contain carbon, no carbon dioxide process emissions are released

ABOVE
The open-plan spaces have been designed to frame views of the North Harbour

during the chemical reaction. As a result, calcined clay generates roughly a quarter of the carbon emissions of limestone-based clinker. In Denmark, it also has the advantage over more common SCMs of being an abundant natural material.

The mix specified for the BIG HQ, marketed in Denmark as Futurecem, replaced 30% of the clinker with calcined clay. BIG says this has reduced the embodied carbon of the concrete by 25%. "We could have reduced the embodied carbon more by replacing cement with fly ash or GGBS," says Hektor. "But how do you ever push the industry towards greener solutions – solutions which are not reliant on other high-emissions industries – if we don't try alternatives?"

As it had never been used in a building context, BIG undertook a series of additional tests to verify the Futurecem's performance. "There were concerns about whether it cured at the same speed as conventional concrete, and it had never been tested for longer-term freeze-thaw effects in this sort of environment," says Hektor. "Because we were the client and there was the desire to make it more sustainable, the additional time



ABOVE
The rooftop contains a planted terrace and a solar array. It overlooks a 1,500m^2 park at the tip of the pier

spent on testing was considered an acceptable risk. With another client, it would have been a longer conversation."

BIG also built a scaled mock-up of one of the mega-beams to get a better understanding of the concrete's workability and aesthetics. The density of reinforcement needed in the thinner outer leaf required a self-compacting mix, resulting in a couple of minor adjustments to the formulation. These included the addition of a curing agent, which ensured that the curing time was unaffected by the calcined clay. In keeping with the utilitarian spirit, standard steel formwork was used, leaving a smooth finish. The tone of the concrete is slightly browner than usual, which the architects were happy with. Apart from an anti-graffiti sealant, it has been left as struck.

The industrial feel continues inside the building, which aims to recreate an open warehouse-type space across multiple levels. At 4,800m^2, it is double the size of BIG's previous studio, an old industrial hall in the Norrebro neighbourhood with high ceilings and a single workspace. The challenge was to maintain those visual and physical connections in a far smaller floor plan of roughly 40m x 40m and within a building height of 27m.

The answer again involved structural innovation. A single central column rises through the full height of the building. Described by the architects as its "totem pole", this is made from different varieties of granite and marble, the type of stone changing on each level.

ABOVE
The building is organised around seven half-floorplates supported on a single central column of natural stone

In-situ concrete beams – cast from the calcined clay mix – radiate like 20m-long spokes from this column to the perimeter structure. On top of these sit the floorplates, or more accurately, half-floorplates. Each level is like an oversized mezzanine, occupying just half the available space and cutting across the central column from different angles. This generates a variety of oblique sightlines across the whole building.

The floors are made of off-the-shelf prestressed double T-plate units, typically used for car parks. These were precast from a standard cement-based mix. The T profiles are 600mm deep and span up to 17m. "We spent a lot of time doing vibration analysis to make sure there weren't any issues with bounciness," says Hektor.

↓

ABOVE
The building contains 4,500m² of connected workspace. The wooden "book wall" conceals services such as lifts and toilets

A black steel sawtooth staircase zigzags through the heart of the space, but the rest of the services, including lifts, toilets and vertical risers, have been pushed to the north end of the building behind a full-height wooden book wall. This is part of a strategy to reduce visual clutter, allowing the views over the harbour to take centre stage. The soffits are unadorned, apart from simple strip lights. The external stair acts as a fire escape and eliminates the need for sprinklers. Acoustic felt, placed between the T profiles, is precisely colour-matched to the concrete.

The building is primarily heated and cooled by geothermal energy. This is provided via a network of 222 precast concrete energy piles, each 14m deep. A heat pump increases or decreases the supply temperature as needed, and any surplus heat is stored in the piles. The system is designed to deliver 132MWh of heating a year – 84% of the building's needs – with the remaining demand met

ABOVE
The pier has been landscaped with native, wind-tolerant shrubs and trees such as oaks and pines

through district heating. With its open layout and thermally massive concrete structure, the building lends itself to natural cooling, but any additional needs will be covered by the geothermal system. Electricity is also generated by a rooftop PV array.

BIG says the building will be energy-positive in operation, and it has achieved DGNB Gold, the second highest ranking in Denmark's rating system for ecological, economic and sociocultural sustainability. The development also contributes to the area's biodiversity, replacing a former parking lot with a 1,500m^2 park of native, wind-tolerant shrubs and trees. But its main contribution to sustainability is arguably something less showy. By taking on the risk of testing out a new product, BIG has helped to establish a domestic market for a viable long-term cement replacement. ■

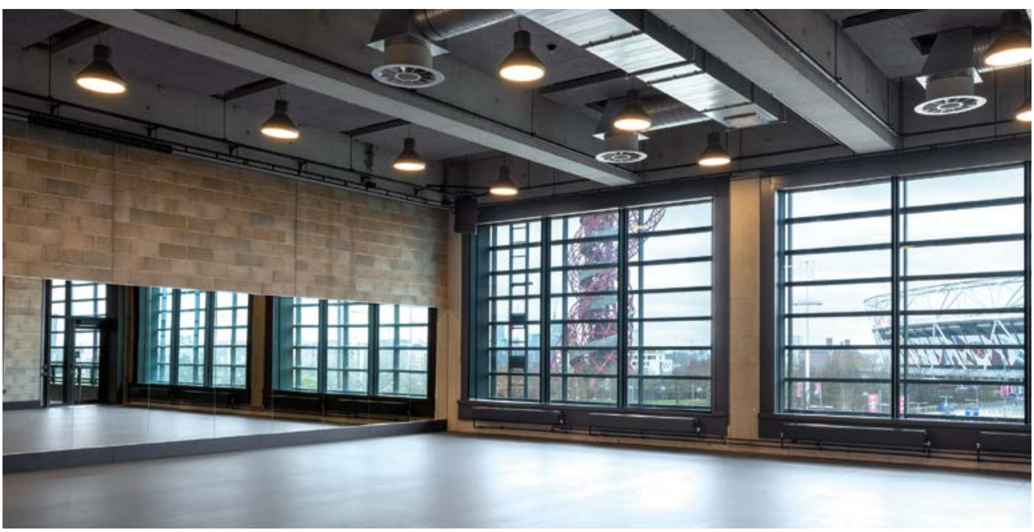
PROJECT TEAM

Architect Bjarke Ingels Group
Structural engineer BIG Engineering
Contractor LM Byg
Concrete supplier Unicon

RHYTHM MACHINE

The new Sadler's Wells East by O'Donnell + Tuomey might just be the hardest working building in showbusiness. The building – the latest addition to the East Bank cultural development on the former Olympic Park – houses a 550-seat auditorium, six large dance studios, a hip-hop school, and a public foyer with café, bar and community performance space.

The structure of the BREEAM Excellent building has been designed so that the facilities can all be used at the same time, requiring high levels of acoustic isolation. It also has to cope with a challenge perhaps unique to this type of building: the vibrations arising from large groups of people moving in step, sometimes to different rhythms in different parts of the building all at once.



Photos: Peter Cook

In order to contain all of this music and motion, the team specified a concrete frame for the auditorium, fly tower, public areas and most of the dance studios. The studios are all 15m x 15m, and this became the basic organising principle of the building design. "The 15m spans were part of the brief from Sadler's Wells," says Jackson. "They know what makes a great studio, and 15 is the magic number."

READ THE FULL STORY
concretecentre.com/cq

STRONG SILENT TYPE

Allies and Morrison has completed Capella, one of the final pieces in the 20-year King's Cross regeneration programme.

The muted, "intentionally picturesque" facades of the 14-storey residential building belie an innovative construction approach, which sped up the programme and enabled a higher proportion of cement replacement.

SmartRock sensors from concrete supplier Heidelberg Materials were attached to the reinforcement of the concrete frame, to generate real-time data on the curing process. This revealed that it was gaining strength more quickly than predicted, which accelerated the striking time and shutter turnaround.

It also enabled the team to tweak the mix design to increase the proportion of GGBS. This lowered the embodied carbon content of the concrete by 10kg/m^3, saving more than 34 tonnes of CO_2e.

READ THE FULL STORY
concretecentre.com/cq

Photos: Billy Bolton

RETRO ROCO

Photos: Richard Chivers

SODA Studio has reworked a 1970s tax office in central Liverpool as a high-concept apartment building, with a cinema, gym and some of the best views in the city.

The starting point for this reinvention was the first-floor slab. "When we first visited, it was just a very dated, typical office from that period," says Vincent Hon, the project architect for SODA Studio. "The ceilings were quite low, and it still had the original suspended tiles." As they removed these, however, they found a waffle slab, still in good condition. "It was a beautiful structure," says Hon. "That really began to inform the design."

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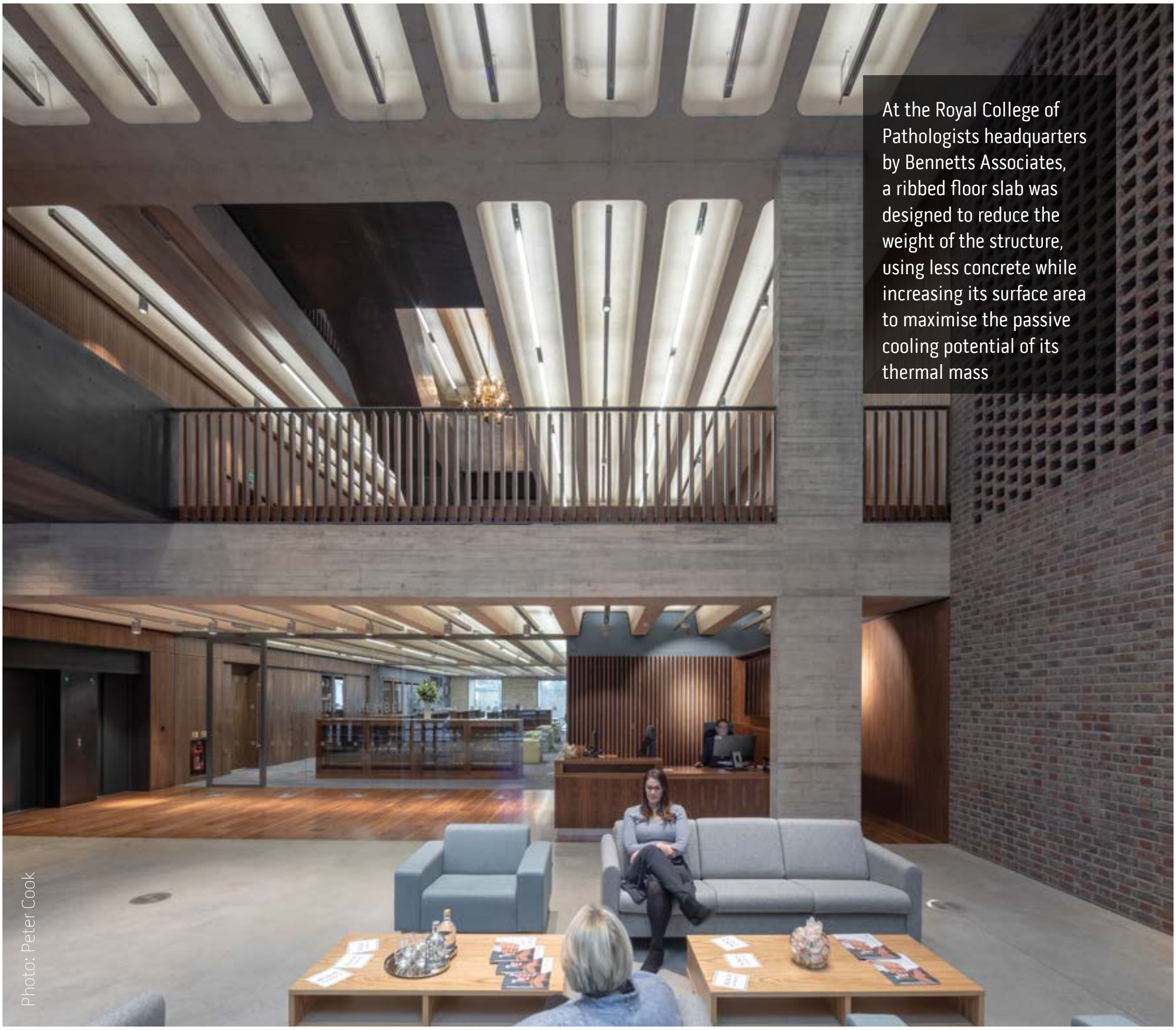


At the Royal College of Pathologists headquarters by Bennetts Associates, a ribbed floor slab was designed to reduce the weight of the structure, using less concrete while increasing its surface area to maximise the passive cooling potential of its thermal mass

Cutting carbon with Concept

The embodied carbon of concrete structural frames can vary widely. Emily Halliwell introduces a tool to guide designers to the most material-efficient solutions

Concept is a free spreadsheet-based design tool from The Concrete Centre. It enables users to compare a wide range of concrete frame options, ranking them in terms of carbon, cost or construction time.

As its name suggests, Concept is intended to be used early in the design process, when there is the greatest scope to reduce embodied carbon by amending design criteria, reconsidering space planning and exploring different construction methods.

At concept stage, it can be difficult to quantify the impact of changing grid spacing, loading or framing type, so the tool offers a simple way to compare different options.

As Concept can quickly generate element sizes and comparison data, it may also be useful whenever there is an opportunity to consider alternative frame types, loads or spans.

Optimising structural design: the key principles

Optimising the amount of material in a concrete frame can make a significant difference to its embodied carbon. Concrete frames can be designed in many different ways, and there are many parameters to consider when improving material efficiency.

- **Grid spacing:** Smaller grid spacing and corresponding shorter spans typically lead to reductions in the required structural depth, and therefore in material quantities. The aspect ratio of each bay also impacts efficiency. Square bays are typically more efficient for two-way spanning systems; for one-way systems, rectangular bays are usually more efficient.
- **Loading:** Reduced loading also leads to reductions in structural depth. For this reason, excessive or blanket allowances for loading associated with finishes and services should be avoided. For building services and plant rooms, they should ideally be based on the weight of the equipment that will be installed, using data from the manufacturer. Live load allowances should be discussed with clients, particularly where project requirements exceed those of the Eurocodes.
- **Structural systems:** The best framing solution for each case depends on a number of factors, including building use, load and span. Typically, deeper systems, such as ribbed

slabs or slabs on beams, are more materially efficient than shallow systems, such as flat slabs. Where long spans, high loads or irregular layouts are necessary, it is important to select the optimal solution. For example, beams can be used to support large point loads or to accommodate irregular grids. Flat slabs are more appropriate for regular column grids, and are not suitable for large point loads.

Structural systems that incorporate voids, such as ribbed and waffle slabs and precast hollowcore slabs, minimise the use of concrete where it is not required. Permanent void formers can also reduce the weight of the structure and the volume of material needed for the structure and foundations. However, the increased depth associated with some structural systems can have implications for overall building height and the distribution of services.

Post-tensioning should be considered wherever long spans are required, or structural depth is critical. This increases strength by adding pre-compression into concrete after it has been cast, which means slabs can be slimmer. Post-tensioning is often used in flat slabs, but is also applicable to ribbed and waffle slabs, enabling even greater embodied carbon reductions. Hollowcore planks typically use prestressing, along with cores or voids along their length, making them structurally and materially efficient.

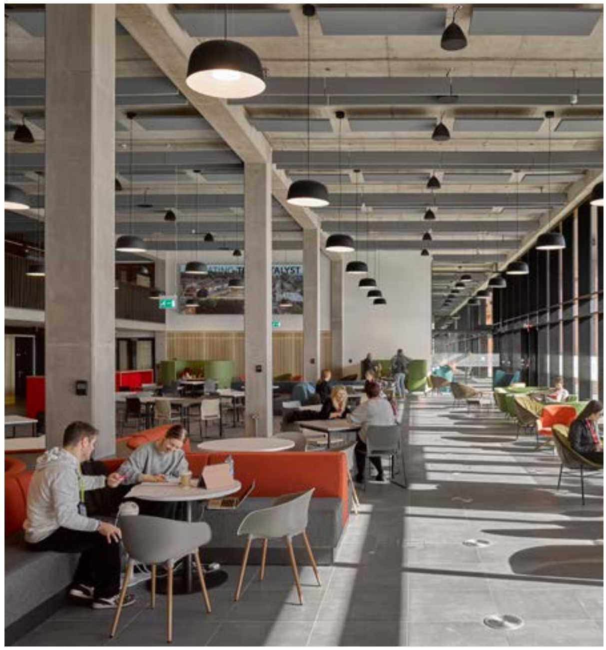


Photo: Dan Hopkinson

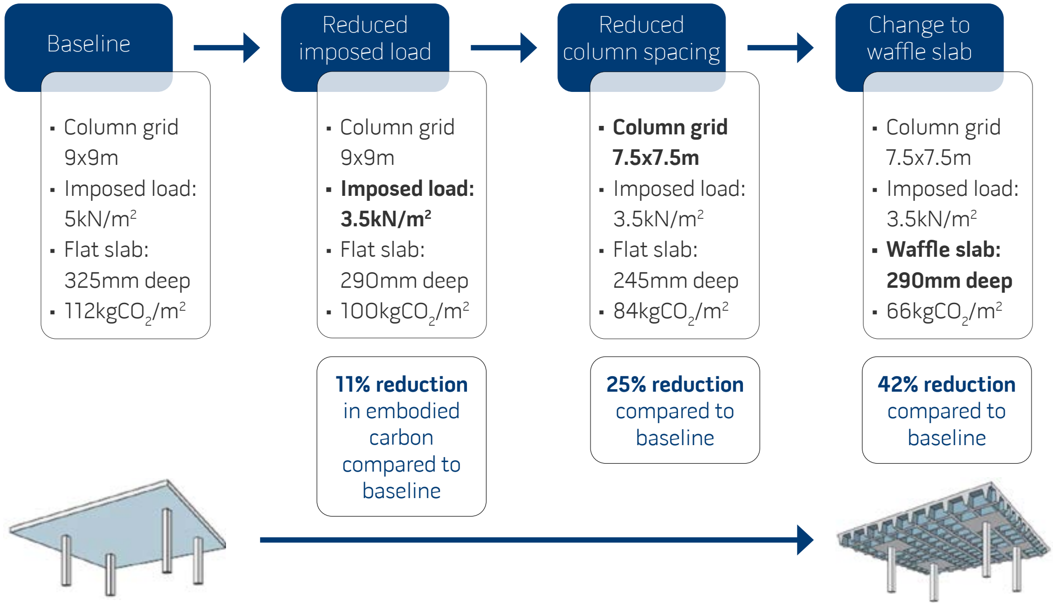
ABOVE
At Staffordshire University's Catalyst Building, by FCB Studios, post-tensioning combined with subtle coffers resulted in slab depths of 275mm

What can we learn from Concept?

Designers may be reluctant to propose significant changes in loading to a client, or much shorter spans. But smaller changes can also add up to big carbon savings.

In our first example, we look at how a series of recommendations can lower the embodied carbon of a baseline scheme by 42%, before the concrete mix specification is even considered. Taking an office building with five bays in each direction, each spanning 9m, we assume a typical office floor load of 5kN/m^2, made up of an imposed load of 4kN/m^2 and an allowance of 1kN/m^2 for partitions. A flat slab is selected, as flat soffits can simplify the installation of partitions and services.

Fig 1: Incremental changes make a big impact: worked example



Step 1: Reduce the imposed load
The UK National Annex of Eurocode 1 recommends an imposed load for offices of 2.5kN/m^2, with 1kN/m^2 for partitions, reducing the imposed load from 5kN/m^2 to 3.5kN/m^2. This means that the slab depth may be reduced, with smaller columns, leading to an embodied carbon reduction of 11%.

Step 2: Reduce column spacing from 9m to 7.5m
This allows the 1.5m planning grid to be used and is one of the options in the British Council for Offices' 2023 guidelines. The footprint of the building remains the same, but the number of bays is increased from five to six. In combination with the reduced imposed load, this results in a 25% reduction in embodied carbon compared to the baseline scheme.

Step 3: Change the structural floor type to a waffle slab
The combined changes in column spacing and loading mean that the proposed waffle slab solution is 290mm deep, compared to 325mm for the flat slab in the baseline scheme, resulting in an embodied carbon reduction of 42%. This also offers more space for floor build-up and services, or opportunities to reduce the overall building height. The increase in surface area provided by the waffle slab enables greater potential use of thermal mass for heating and cooling.

Consider wide beams when depth is critical

More material-efficient floor systems such as ribbed or waffle slabs are typically deeper than flat slabs. This can be a challenge on schemes where floor depth is critical – if building heights are limited by planning restrictions, an increased floor build-up could come at the cost of an additional storey.

Post-tensioning (PT) is a common solution to this. Another that is often overlooked is wider beams, which offers material efficiency with reduced depth. In our second example, we switch from beams 300mm wide and 525mm deep, to beams 2,400mm wide and 300mm deep. This reduces overall floor depth by 225mm, with only a 3% rise in embodied carbon. While further depth reductions are possible – for example, a 250mm-deep flat slab or a 200mm-deep PT flat slab – these significantly increase embodied carbon, by 23% and 15% respectively. Wide beams also reduce slab spans, allowing for a thinner slab and offsetting the additional material used in the beams.

Fig 2: Output from Concept comparing narrow and wide beam solutions

	One-way slab on narrow beams	One-way slab on wide beams
Building footprint (m)	24x32	24x32
Column grid spacing (m)	6x8	6x8
No. of storeys	1	1
Loading: Superimposed dead load (kN/m²)	1.5	1.5
Loading: Imposed (kN/m²)	2.5	2.5
Loading: Edge (kN/m)	10	10
Slab depth (mm)	170	140
Internal beam size (depth x width) (mm)	525 x 300 in Y	300 x 2400 in Y
Edge beam size (depth x width) (mm)	225 x 300 in X 450 x 300 in Y	225 x 450 in X 300 x 450 in Y
Overall floor depth (mm)	525	300
Reduction in floor depth	–	45%
Embodied carbon (tCO_2e)	50	52
$kgCO_2/m^2$	63	65
Increase in embodied carbon	–	3%


Photo: Tim Crocker

ABOVE
The studios at Mountview Academy in south London by Turner Works were built using pre-tensioned hollowcore planks

When longer spans are more efficient

Typically structural depths increase as spans rise, requiring greater quantities of material to span longer distances. However, this isn't always the case for solutions involving hollowcore planks. These are generally proprietary systems and come in fixed unit depths, which will have a maximum span for the specified load. Designers should consider using spans close to the maximum to make the best use of the material.

In our third example, we take a building with an imposed load of 7.5kN/m^2. When the hollowcore planks span 7m, supported by beams spanning 12m, the embodied carbon is 128.4kgCO_2e/m^2. Increasing the span of the hollowcore planks to 8.5m, supported again by beams spanning 12m, reduces this to 125.7kgCO_2e/m^2. This means a 21% increase in the span (and area of the bay) and a 2% reduction in embodied carbon. The supporting beams may be larger or need more reinforcement as the span of the hollowcore planks rises, but in this example the beam depths remain the same – 825mm. (Here, embodied carbon is compared per unit of area, because the footprint of the building changes with the span.)

Beyond the frame: what else do designers need to consider?

The Concept tool only considers life cycle stages A1-A3, also known as cradle-to-gate emissions, because this is when the most significant reduction in the embodied carbon of concrete can be achieved. The embodied carbon associated with the remaining stages – construction, use and end of life – is likely to be fairly similar for every frame.

The tool also only considers the structural frame itself – it does not consider cladding, finishes, fit-out or services. These can have a significant impact on embodied carbon, and so should not be overlooked when making comparisons. A whole-life carbon assessment is recommended to account for elements beyond, but impacted by, the structural frame, such as foundations, building height and service life, as well as the potential carbon savings from omitting finishes and using thermal mass for passive cooling and heating. ■

Concept Design Tool Version 5 can be downloaded from concretecentre.com/concept

FINAL FRAME: DÚN LAOGHAIRE BATHS

The renovation of the 19th-century baths at Dún Laoghaire has restored a lost connection between the town and sea. Led by DLR Architects Department, the remodelling includes a pier, accessible stairs, seating, green spaces and artists' studios. To minimise embodied carbon, new concrete elements contain 60% GGBS as well as local aggregates such as Dalkey granite and oyster shell. The original pavilion has been restored, boasting views over the new pier and a sculpture of Irish nationalist hero Roger Casement, gazing towards the horizon.

Photo: Ste Murray