CONCRETE QUARTERLY

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Elaine Toogood
Head of architecture, The Concrete Centre

Enduring logic

Building design has always involved juggling a range of different requirements and coming up with the most elegant solution within the constraints of budget, site and materials. But it's surely never been harder than it is today, when the designer's task is complicated not only by having to constantly improve on performance and energy consumption, but also by the moving nature of many of the targets, not to mention the high stakes of getting it wrong in a shifting world that feels increasingly perilous.

To prevent catastrophic climate change, we know we have to reduce both the operational and embodied carbon associated with our buildings – though we are still in the process of developing the targets for the industry to work towards. We also know that, whatever we do, our climate will continue to become hotter and wetter, and that extreme events such as floods and storms will occur with greater frequency. Here, the science predicting the conditions that future buildings will have to withstand is more advanced.

It might sound obvious but if a building is to be truly sustainable, it needs to sustain: to endure both in form and in usefulness. We cannot know for sure what needs any of our buildings might have to fulfil in the future, but we do know that the environment will become more challenging. Overheating is a growing, measurable risk, especially for an ageing population, as is flooding.

In this issue, we explore two key technical issues that show the weight of information that specifiers must consider. We look at methods for assessing the fire performance of concrete frames on adaptive reuse projects – a strategy that is becoming more common for lowering the whole-life carbon of developments. We also outline the results of an independent life cycle carbon analysis (LCA) of two notional apartment blocks, one with a reinforced concrete structure, the other made of cross-laminated timber.

IT MIGHT SOUND OBVIOUS BUT IF A BUILDING IS TO BE TRULY SUSTAINABLE, IT NEEDS TO SUSTAIN: TO ENDURE BOTH IN FORM AND IN USEFULNESS

Whole-life carbon is an important measure of a building's performance, but there is a dawning recognition that controlling peak energy loads within our buildings also has a role to play at a wider national level as we switch to more intermittent renewable sources. The study found that the concrete building's peak space heating load was on average 25% lower. The LCA's other striking takeaway was that, even before exhausting all opportunities for optimisation, the concrete structure was only slightly more carbon-intensive than the CLT one, while also providing all the well-understood co-benefits of heavyweight, mineral-based structures, such as resilience to flooding and overheating.

The direction of travel is clear: we need to reduce carbon in our built environment significantly and quickly. But we can't afford to do this at the expense of all the other hugely important functions that we need our buildings to perform, now and in the future – on which the evidence is equally impossible to ignore. ■

CONCRETE QUARTERLY

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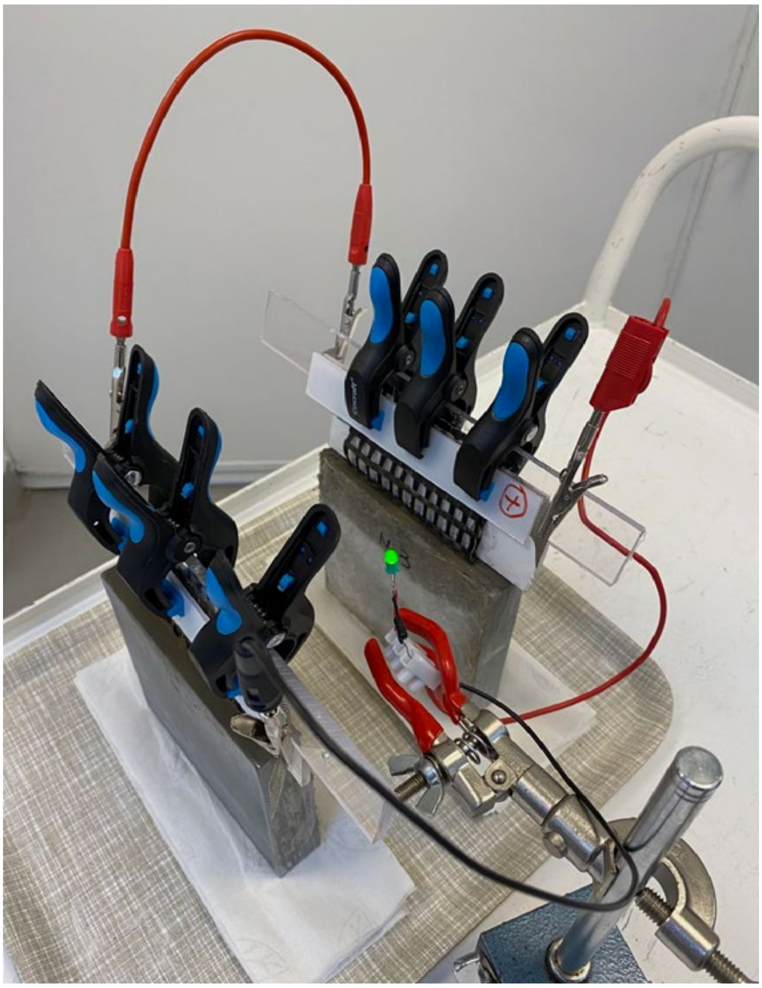
Inverness Justice Centre by Reiach and Hall Architects.
Photo by Keith Hunter

INNOVATION

CEMENT BASED BATTERIES

RESEARCHERS IN GOTHENBURG HAVE BROUGHT CONCRETE BUILDINGS ONE STEP CLOSER TO BEING ABLE TO STORE RENEWABLE ENERGY



ABOVE
Two concrete battery prototypes are connected, creating enough power to light up an LED lamp

Scientists in Sweden have developed the world's first rechargeable cement-based battery. The invention opens up the tantalising possibility that concrete buildings and structures could one day be used to store large amounts of renewable energy.

"Our research is at an early stage," says Dr Emma Zhang, at Chalmers University in Gothenburg. "But we can already see how a building with this technology could charge up with enough electricity from, for example, solar panels during the day, to power it during the night."

Previous attempts to make a cement battery have used simple metal plates and generated only insignificant current. "They were also unrechargeable," says Zhang. "We felt we could do much better."

Working with project supervisor Professor Luping Tang, Zhang developed a fine carbon-fibre mesh coated with iron for the anode, and nickel for the cathode, which was then embedded in a cement mix containing short chopped carbon fibres.

"The fibres increase the conductivity of the cement so it can work as an electrolyte," says Zhang. "They are about 3mm long, and make up 0.5% of the mix, which would result in a strong product if used in concrete." More fibres would increase the battery's efficiency, she adds, but might affect the workability of the concrete, so future research would focus on achieving an optimal balance.

The mesh too can be modified, says Zhang: "Our experiment used a 5mm square mesh, but this could be varied to permit concrete aggregate to fit through the holes. It might also be possible to use the mesh as a type of reinforcement."

Zhang's battery has achieved a capacity of 7Wh/m^2. "It doesn't sound a lot, but used in large structures it begins to add up. If we could improve capacity by five or ten times, which I hope we can with further development, then it starts to become a really useful energy store. Of course, concrete is already used to store energy in the form of heat. Our battery technology would enable concrete to store electrical energy as well. It could provide a useful power source for offshore structures, for example, or buildings in remote areas that do not have access to the grid."

Most importantly of all, perhaps, concrete batteries could help with the problem of intermittency – the uneven supply of renewable energy that results from natural variations in sunshine and wind speed. "So when renewables are not generating much electricity, power supplies could be boosted by energy stored in the fabric of buildings."

CONCRETE IS ALREADY USED TO STORE HEAT ENERGY. OUR BATTERY TECHNOLOGY WOULD ENABLE IT TO STORE ELECTRICAL ENERGY AS WELL

Zhang came to research the possibilities of a cement-based battery after leading studies into the electro-chemistry of cathodic protection for metals including concrete reinforcement. "I also have a background in polymers, so this research, which is undertaken within the Department of Architecture and Engineering, is a result of several different areas of study coming together to create something with exciting new potential."

She now hopes to experiment with different meshes and mixes to develop the workability and capacity of the cement batteries: "How long the battery remains rechargeable is also important. Concrete buildings can easily last 50 years and more, so ideally we would want our technology to match that kind of longevity." ■

LASTING IMPRESSION

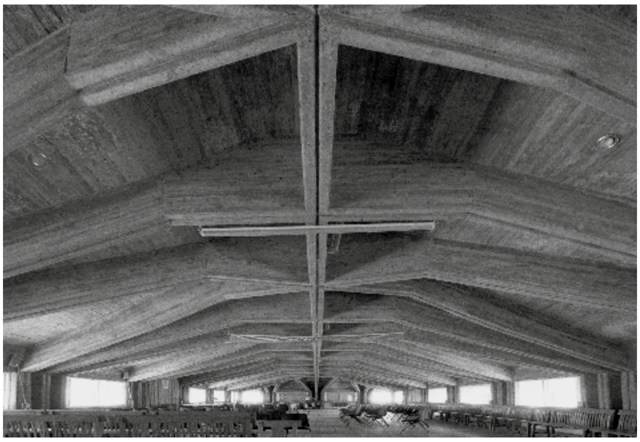
MARTA GONZÁLEZ RUIZ

A MADRID SCHOOL OFFERS A REMINDER OF HOW MATERIALS AND BUILDINGS SHAPE US FROM AN EARLY AGE

One of my earliest memories is of concrete. From the age of four until I was 18, I went to school at the Colegio Estudio in Madrid (1960), designed by Fernando Higueras. We would run from the classrooms to the dining hall, jumping and touching every beam. And I actually remember the feeling of the concrete in my hand – the rough boardmarking and the pattern of the wood.

Higueras was one of a kind – he was very flamboyant, very sarcastic and a radical thinker. Setting himself against the architectural fashion, he wanted to create places that would endure through time – an approach he shared with other Spanish architects, such as Alejandro de la Sota and Francisco Javier Sàenz de Oiza. You can see this in the way he celebrates structure, such as in the sculptural spans of beams in the school gym (above right).

The teachers encouraged us to experience the building and use it as a canvas. So I remember learning the metric system by going around the school, measuring things and drawing our own plans. The more you become aware of a building, the more you notice things like the grain in the concrete. These stick



Photos: Gonzalo Pérez; Lola Botia, courtesy of la Fundación Fernando Higueras

ABOVE
Colegio Estudio, Madrid, by Fernando Higueras, 1960

in your memory, and this memory shapes your future: it certainly inspired me to become an architect.

Another early school memory that resonates is the greenery. It was really important for Higueras to welcome nature into the building, so he created courtyards that connected to all the classrooms via very large windows. The way he brought together concrete and the natural world to create an environment where people feel welcome was ahead of its time. There's a housing block he designed in central Madrid called Viviendas San Bernardo (1967-75) with plants cascading from the facade. When I was young, I would pass it every day and it was always green. What I love about this is that, with the rise in biophilic design over the past few years, including PLP's own Park Nova tower under construction in Singapore, people have started to question all these renders covered in greenery: will this actually happen? Is it even possible? And the proof has been standing – in a dense, super-hot urban environment – for 50 years.

Higueras spent the last years of his life in a two-storey subterranean studio, top-lit by skylights, that he carved out of the ground behind his house. He called it the "RascaInfiernos", which means hellscraper. He boasted that the concrete structure kept a stable 25˚C temperature all year round, without heating or cooling. To implement passive strategies on contemporary architecture was, again, another idea that was ahead of its time.

Dr Marta González Ruiz is a director of PLP Architecture

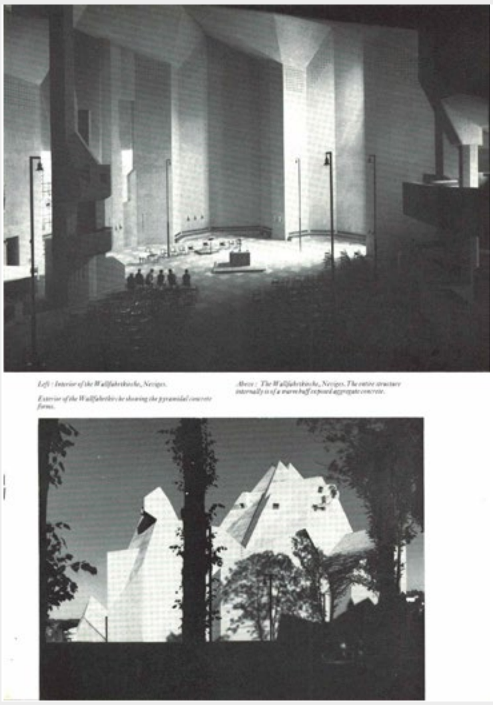
ABOVE
Viviendas San Bernardo, Madrid, 1967-75

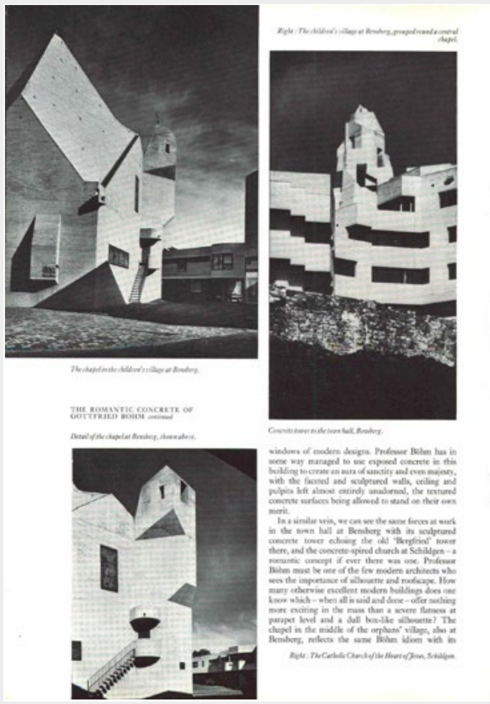
BELOW
RascaInfernios, Madrid, 1972 – now the Fundación Fernando Higueras

Photos: Lola Botia, courtesy of la Fundación Fernando Higueras

FROM THE ARCHIVE: SUMMER 1974

THE CONCRETE ROMANTIC

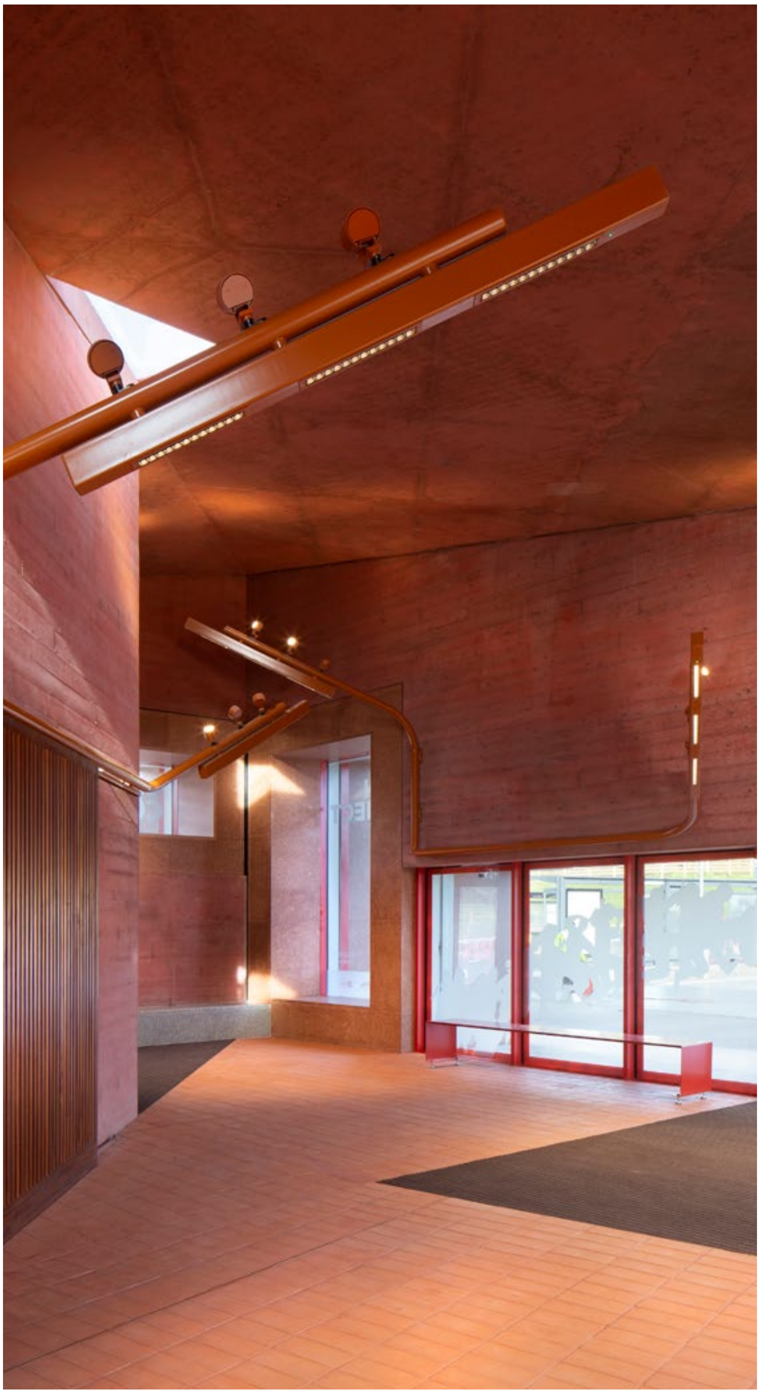




Some of the most astonishing buildings to grace Concrete Quarterly in the 1970s came from the imagination of Gottfried Böhm, who died earlier this year. At the time, CQ editor George Perkin could think of no other living architect "who has used concrete in a more romantic manner", citing the cathedral-like Mariendom (right) in Neviges, North Rhine-Westphalia as Böhm's masterpiece. "The church has a nobility and simple dignity about it which is unforgettable and, perhaps, all the more remarkable when one remembers that the whole structure is of exposed in-situ concrete inside and out. Internally a warm buff exposed-aggregate concrete is used, washed over in parts by glowing reflections from the dramatically brilliant stained glass windows of modern designs. Professor Böhm has in some way managed to use exposed concrete in this building to create an aura of sanctity and even majesty, with the faceted and sculptured walls, ceiling and pulpit left almost entirely unadorned, the textured concrete surfaces being allowed to stand on their own merit."

Perkin was also impressed with Böhm's use of roofscape and silhouette – in contrast with the "severe flatness" of other modern buildings – not only on religious architecture but at a domestic scale. At the Bensberg children's village, for example, the steeply pitched roof surfaces form an extension of the exposed in-situ concrete walls. "Nobody else, surely, has related roof to wall surfaces in this way." Above all, Perkin concluded, Böhm had an unwillingness to compromise with concrete. "He uses it boldly and continuously … to give a monolithicity which is the charm of all his buildings." ■

[Explore the full CQ archive at concretecentre.com/cqarchive](concretecentre.com/cqarchive)



ORIGIN STORY

COLIN TRANSPORT HUB

ALASTAIR HALL BRINGS A SENSE OF ARRIVAL TO THE END OF THE LINE IN WEST BELFAST

Colin is the kind of neighbourhood you could find on the outskirts of any UK city – waiting for investment. It's got a reasonably large population but it's just on the edge of the gravitational pull of the centre, and the money has never gone into creating decent places. The public space lacks clear purpose or function, or use.

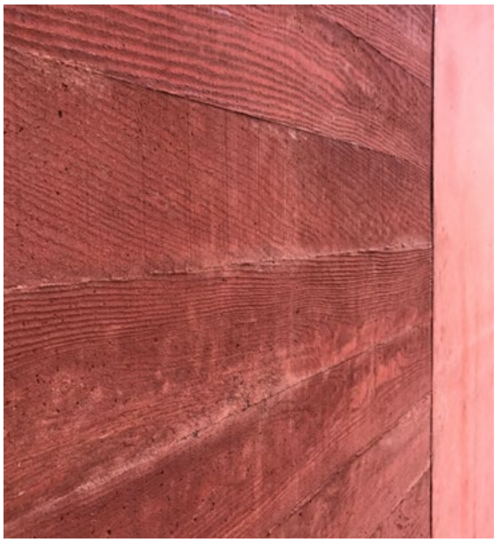
A couple of years before the transport hub project, we had been involved in a masterplan for the area. Belfast was investing in the Glider, a new rapid bus route connecting the east and west of the city, terminating in Colin, so we always knew there would need to be a point of arrival that required some definition and identity. The east end of the route includes a park & ride, with just a small building that lacked any serious architectural ambition.

ABOVE
The main hall has also been used as a venue for concerts

What made a real difference in Colin was the fact the community were really motivated – they weren't going to be short-changed. They didn't just want a terminus, but also a building that could provide identity and generate a sense of place. Even though it's just a single-storey building, we all saw it as an opportunity to put a stake in the ground, anticipating further investment.

It was almost as if we were trying to build the oldest part of the community last: the people and the neighbourhood were already there, but without a sense of centre and focus. For us, that lack of existing context meant we almost had to invent one. There was very little to latch onto by way of architectural character, and the site itself was just sprawling grassland.

Early in the design we proposed two squares imposed onto an otherwise quite nebulous site: one for a public space and one for a building. It was a bit like priming a canvas before you begin to paint – it gave us something to engage with. From there, we began to carve and manipulate a building form: giving height to one corner, curving the two more public-facing facades. We very deliberately avoided any sense of axes, or any of the architectural devices associated with formality. The idea was to be civic but also somehow informal. We had

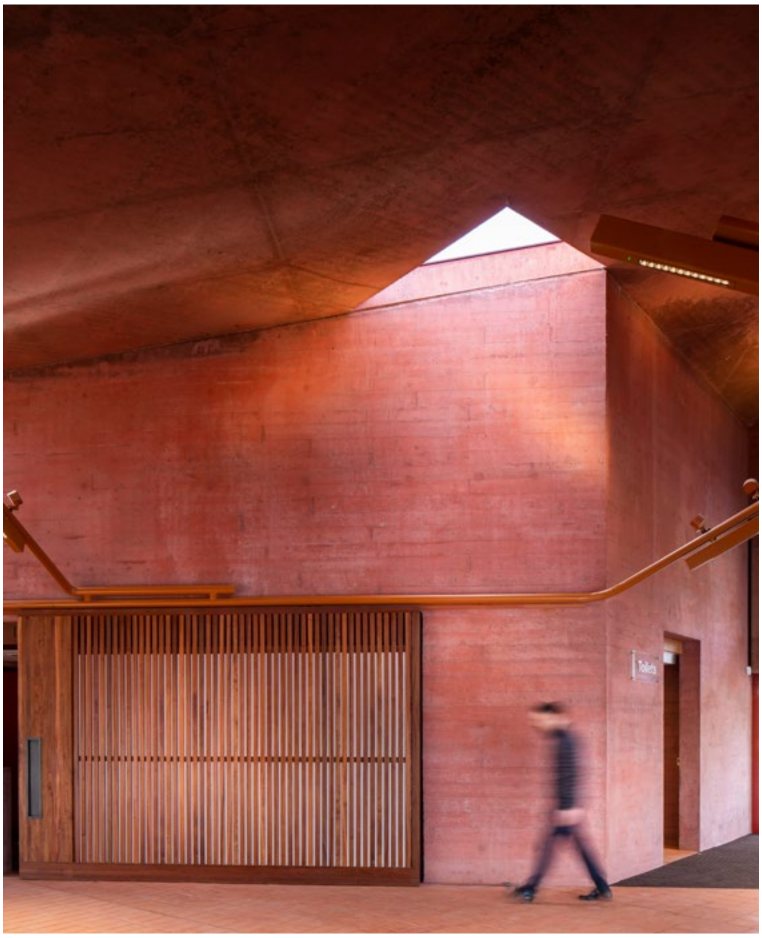


TOP
The granite-clad form rises in height towards the road

ABOVE
The timber formwork was sawn and planed but unsanded

RIGHT
Natural light is cast from above over the boardmarked walls

BOTTOM
An oriel window frames the red-concrete interior



Photos: Donal McCann / Hall McKnight

initially explored more of an abstracted classical language, but it just wasn't appropriate: this wasn't a historic centre, but a much newer kind of environment.

The materials, the character and geometry of the building all had to convey a sense of permanence and durability. The granite cladding and exposed-concrete structure were part of this language. The pigmented concrete evokes a sense of Belfast's traditional red-brick streets, which reach out from the historic city but fail to reach Colin. The housing here is often rendered or built in paler grey bricks. So the red concrete was both a connection to Belfast's history and an assertion of something permanent and new.

The walls were cast in situ and are boardmarked. It's quite a gentle texture – the boards were sawn and planed, but unsanded. You get a wash of top light running down some of the surfaces from the rooflights. The soffits are left as-struck – there's no boardmarking, but there's a lot of patination. We enjoyed the contrast with the more controlled finish on the walls.

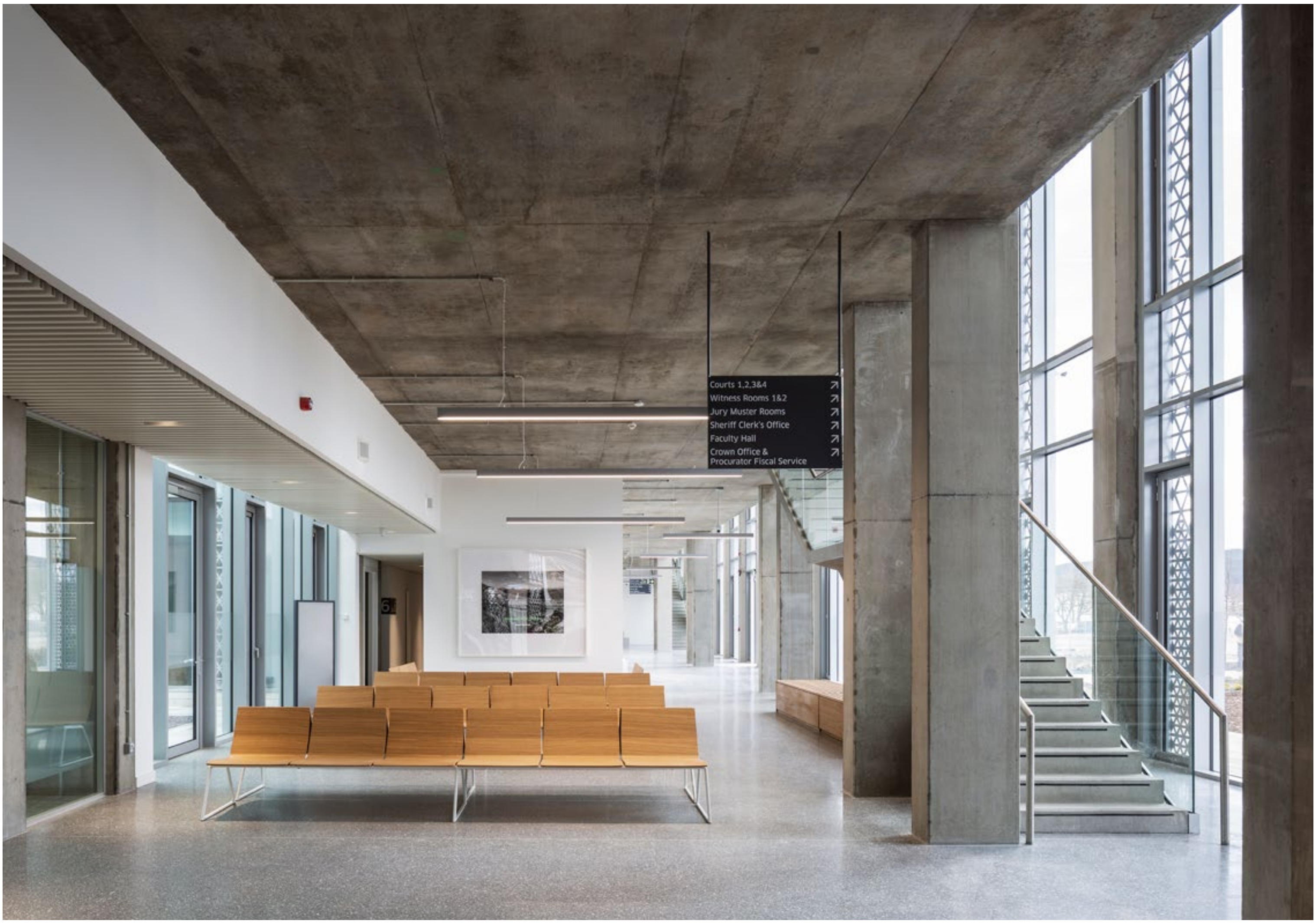
The main space has that acoustic character that feels like a public space, and it has been used for community events – I attended a concert there. When there are people inside, it tempers the reverberation time, and it has a really nice acoustic. Hopefully, people will be able to start using it more over the coming year, and further define it as a space at the centre of daily life. ■

Alastair Hall is a partner at Hall McKnight

Photos: Keith Hunter Photography / Reiach and Hall Architects

LAW OF GRAVITAS

Reiach and Hall's Inverness Justice Centre combines the honesty of an exposed in-situ structure with the civic dignity of a glistening precast colonnade, writes Tony Whitehead



Few buildings have quite so many roles to play as the new Inverness Justice Centre. It is the first of its kind in Scotland – a new bringing together of criminal and civil courts with a range of related functions including citizens advice, women's aid, victim support and social services. But it is also something of a frontier project, the first of a different type of development in an area of north Inverness, previously a rather featureless 'shed-land'.

ABOVE
Post-tensioning reduced the thickness of the flat slabs by 50mm, to 325mm

ABOVE
Rows of 7.2m-high precast columns form canopies at either end of the building. These were all manufactured as single units

"The planners are keen for the city to develop in this direction, and the Justice Centre is very much part of that plan," explains Neil Gillespie, director of architect Reiach and Hall. "So the design had to help open up the area to encourage new investment. Because of this, and because it is an important civic building with a serious purpose, the design needed a certain gravitas."

For this, says Gillespie, concrete was a natural choice: "Scotland is predominantly stone built, especially prestige buildings in cities. So unless you have a very generous budget, concrete is the material that can provide that minerality, weight, and a sense of permanence and civic dignity."

Looking at the impressive, 115m-long front elevation of the two-storey Justice Centre, it is easy to see what he means. Tall, white precast concrete pillars punctuate the rain-screen of the front facade, and continue as free-standing columns supporting sheltering canopies at either end of the building. They give the centre an appearance which is unmistakably classical, imposing, yet unfussy and essentially modern (see precast box). It is no surprise that it was named 2021 Public Building of the Year in the Scottish Design Awards.

But it was not just the "serious" look of concrete that led the Reiach and Hall team to specify it. "The exterior columns and cladding are precast, but the frame is in-situ concrete," explains Gillespie. "There are environmental reasons for that – the ceilings and columns are exposed

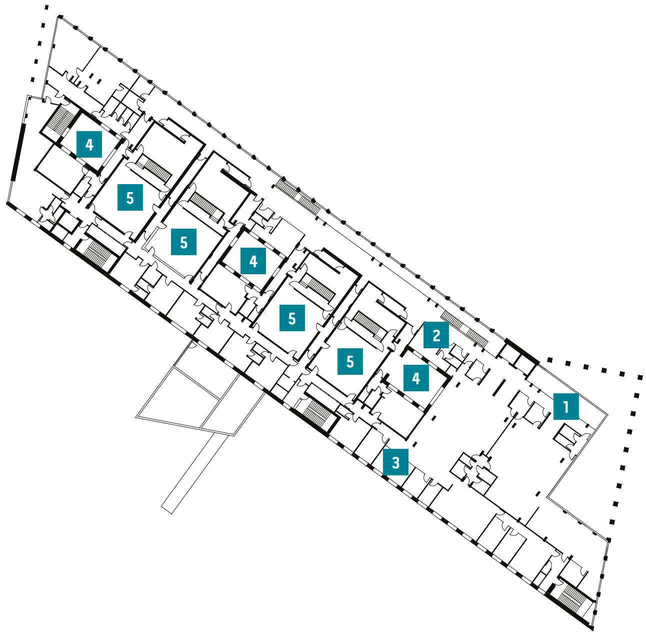
THE OVERRIDING REASON FOR CHOOSING CONCRETE WAS A VERY SPECIFIC SET OF ACOUSTIC CONCERNS

ABOVE
The triangular facade columns are attached, via a thermal break, to in-situ structural columns behind

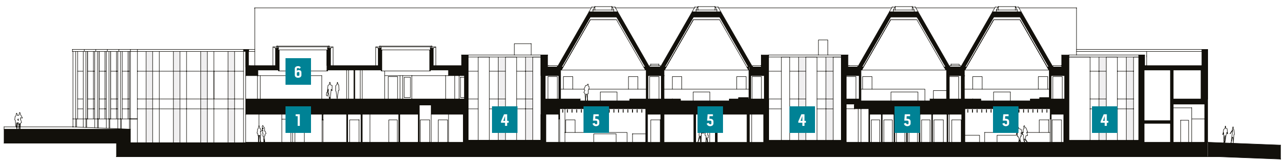
– so we are using the thermal mass of the concrete to even out temperature differentials and improve the efficiency of the heating and cooling system. But even more than that, and perhaps the overriding reason we chose concrete here, was because of a very specific set of acoustic concerns and requirements."

Courtrooms, he explains, have to be free from any kind of noisy distraction from outside – be that from an adjacent corridor, or from outside the building. "Trials can collapse if defendants can claim they could not hear what is being said," says Gillespie. "This was made very clear to us by the client. So we were very concerned about traffic noise – the centre is next to the four-lane A82 which can get very busy, and we are also next to a police station, so you have constant blue-light activity going on there."

This led to a favouring of concrete's solidity and mass to block out noise cheaply and effectively. "We were nervous of featherweight, contemporary construction styles of



the steel frame and stud partition type," says Gillespie. "We didn't have the budget to start building acoustic boxes within boxes, so we thought if we could have some solid concrete walls, together with a flat concrete soffit, then any partition walls could fit simply and snugly against the ceiling because there would be no complexity like downstands to work around. It's almost primitive – but it works."

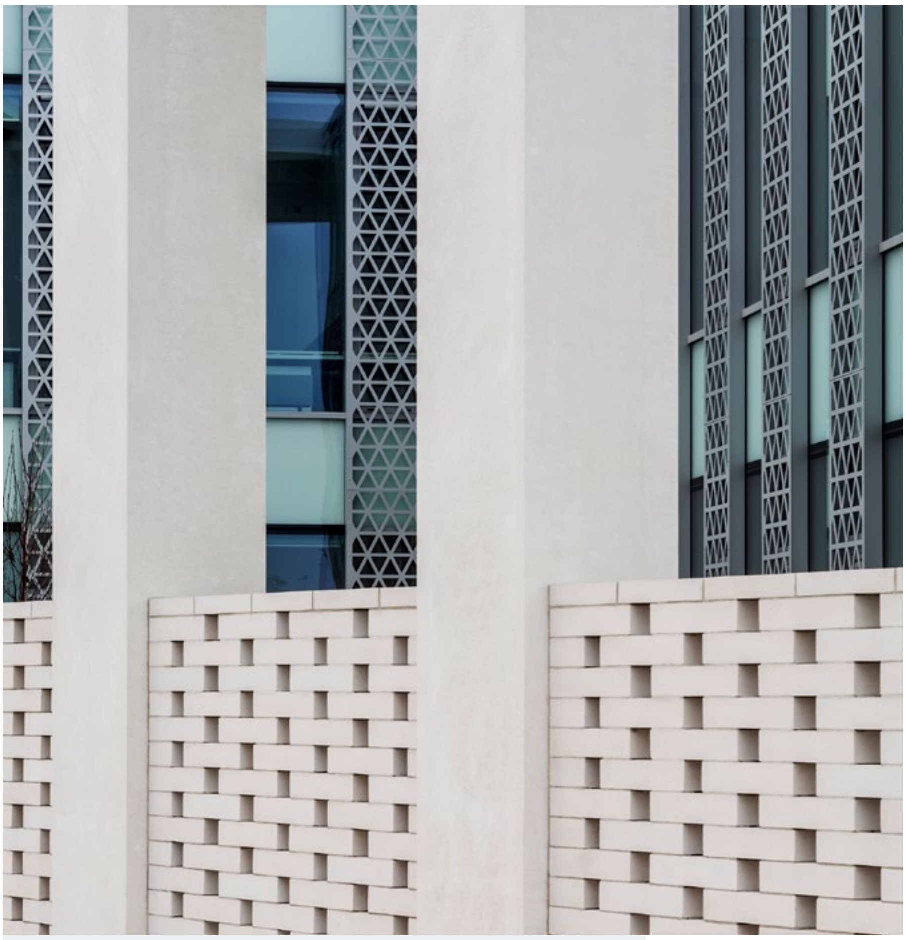


GROUND-FLOOR PLAN AND SECTION

1 Entrance
2 Waiting area
3 Offices
4 Courtyard
5 Courtroom
5 Secretariat

The building's reinforced concrete structure is arranged on what Gillespie terms a "tartan" grid. This was driven by the need for the courtrooms (two civil on the ground floor and four criminal on the first floor) to be column-free to enable all parties within them to see each other clearly. This resulted typically in 9.5m x 6.9m bays.

Adjacent to the courtrooms are associated rooms such as those used to accommodate witnesses. Though the courtrooms themselves have no windows to minimise distractions for the trial's participants, Gillespie



LEFT
460mm-long precast blocks form a low perforated wall between the free-standing columns

A finely judged facade

The defining feature of the Inverness Justice Centre is its long front facade, comprising 30 precast concrete columns plus a further 19 similar free-standing precast columns that support canopies at either end of the building.

Designed by Etive Consulting, and made by Plean Precast, the 7.2m-high columns were all manufactured as single units. "It made for heavy pieces. Those in the facade typically weighed 2.8 tonnes," says architect Neil Gillespie at Reiach and Hall. "But to erect them in sections would have created difficulties with getting the pieces wanted waiting witnesses and staff outside the courtroom to have access to natural light and ventilation. "So there are internal courtyards. The courtrooms and courtyards alternate, giving rise to a structure which, in a long building like this, looks a little like a ladder, or tartan, on plan."

Like the foundations, the columns and supporting sheer walls in the building were all constructed from a concrete mix containing an unusually high proportion of cement replacement. Replacing 70% of the cement with GGBS (ground granulated blast-furnace slag) saved around 360 tonnes of CO_2 compared with a traditional CEM1 mix.

Further carbon reductions were achieved via the specification of post-tensioned (PT) reinforced concrete slabs for the floors and roof slab. "The slabs make up about 40% of the concrete in the building, so we looked at how PT slabs might help make the structure more efficient," says Arup's Jeremy Grant, structural engineer on the project. "They span perfectly aligned – and they just look better as single units."

Those in the facade are not structural, being attached via a thermal break to slim, in-situ concrete columns behind them (see page 14). Each of these is 250mm deep, chamfered at the edges, and 680mm wide where it meets the widest section of the precast pillars. "The grid of the facade structure is completely different to that of the main building grid," says structural engineer Jeremy Grant at Arup. "We don't actually need an in-situ column behind each of the precast ones which are arranged at 3m intervals. On the plainer rear facade they are every 6m. But it was easier and visually better for the interior in-situ facade columns to reflect the rhythm of the exterior precast."

While it would have been possible to have the precast columns perform structurally, he adds, the hybrid column design naturally allowed for a thermal break between the two types of concrete. "Also, it meant that the in-situ and precast contractors had the freedom to operate almost independently as far as the structure was concerned."

While the free-standing precast units are square or rectangular in section, those in the facade are roughly triangular, 680mm x 350mm, arranged in a sawtooth pattern. They are made with Skye marble, a very white and reflective aggregate, says Gillespie. "Because the facade columns are not flat to the facade but canted, first one way, then another, you get a pleasing light effect as they reflect the rays of the low sun."

up to 9.5m with no downstands, so basic flat slabs would have to have been about 375mm thick – quite substantial to damp out noise and vibration. But by changing to PT we found we could reduce the thickness by 50mm."

It doesn't sound much, but a number of advantages resulted from the switch to PT slabs: "It saved 261m^3 of concrete which, quite apart from the material and carbon saving, means many less movements of vehicles carrying just 8m3 concrete at a time. You also save on reinforcement, and reducing the dead-load of the structure just makes it all much more efficient."

Grant adds that under normal circumstances, the slabs could have been even thinner, perhaps 300mm. "But we had to consider the effect, for example, of a crowd of people moving down a corridor outside a courtroom. We didn't want distracting vibrations to be felt inside, so 325mm slabs were the slimmest we could go to keep the response factor down to <4."

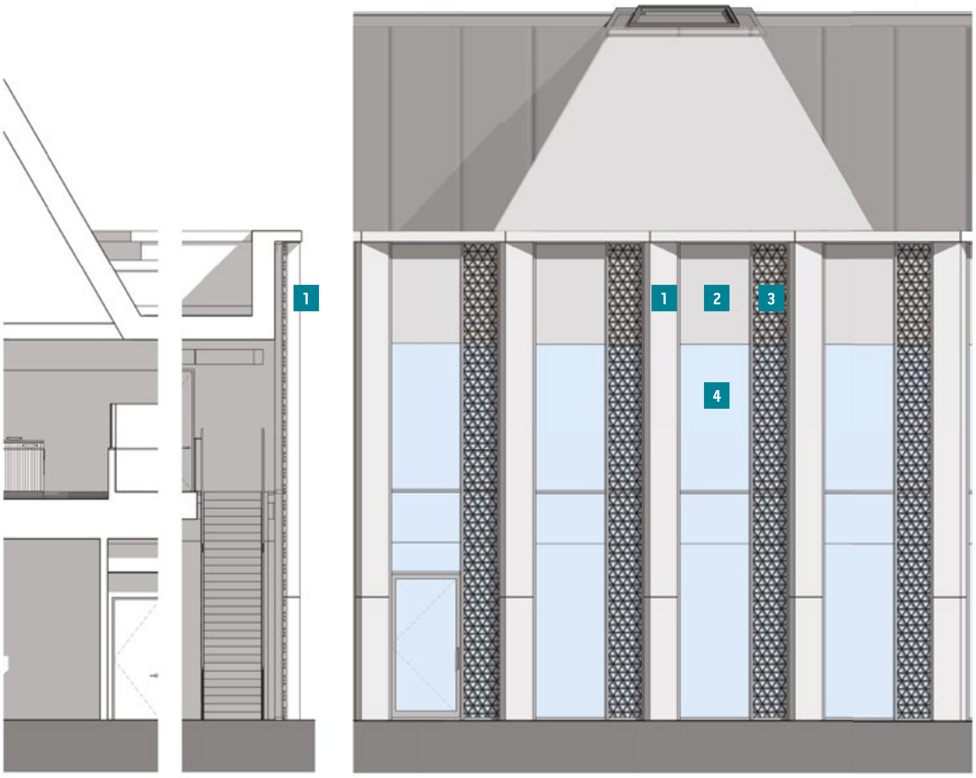
The need for sturdy floors was also a factor when it came to designing the grid's main columns. These are 800 x 300mm in section, and positioned at the edges of the courtrooms and courtyards. This results in rows of columns in a "double blade" configuration, the double columns running either side of the corridors that run past the courtrooms from the front to the rear of the building.

Complementing the white precast columns are matching pale precast cladding units over much of the non-glazed area of the facades. In addition, matching precast blocks or bricks, 460mm long, have been arranged to form a low perforated wall between the free-standing columns at one end of the building. "The blocks are arranged with spaces between, so you can see through the wall," says Gillespie "We originally designed it with larger spaces, but the client asked us to reduce the gaps to improve privacy for those inside the building. This typified a key challenge for us: reconciling the tension between creating a place with some openness and transparency as to the functions inside – justice must be seen to be done – but at the same time ensuring the centre provided security and privacy for those who need it."

"To maintain a consistent aesthetic, we kept the double-column arrangement even where it wasn't strictly needed," says Grant. "It did, though, come in useful when it came to designing a movement joint for this length of building." Arup decided to split the 115m-long structure in two, to accommodate inevitable expansion of the concrete due to changing temperatures. "The question was where to split it. A courtyard was considered as there was less structure to split, but a joint would have spoiled the look of the courtyard facades."

The solution was to place the 25mm joint along the length of a central corridor: "And because we had the double-blade column arrangement, we didn't need any additional support around the joint. We just cantilevered the two slabs towards each other from the columns on

LEFT
The courtrooms are column-free, enabling all parties within them to see each other clearly



NORTH FACADE

1. Profiled precast columns
2. Aluminium cladding panels – powder-coated to match curtain walling
3. Triangular-patterned perforated aluminium over-panel
4. Curtain walling

either side of the corridor. It's covered by the raised floor."

Inside, the exposed slabs and columns, together with some exposed services such as ducting for lighting, give the centre an almost industrial feel. However, the look is tempered by the use of steel and glass around the precast concrete staircases and also, especially in the courtrooms, by generous amounts of oak acoustic panelling.

The result is an aura of calm solemnity and functionality. Appropriately, Gillespie describes the finish as "honest". "Because of budget limitations, it's not the finest interior finish in the world – but when you see it against the stripped-back pallet of glass and oak it really starts to work." ■

PROJECT TEAM

Architect Reiach and Hall
Structural engineer Arup
Precast design consultant Etive Consulting
Main contractor Robertson
In-situ concrete contractor Careys
Precast manufacturer Plean Precast

LIFE BEHIND COLUMNS

Thirteen-metre-high in-situ concrete columns grace the 140m-long colonnade of the Cardiff Centre for Student Life, designed by Feilden Clegg Bradley Studios. A thoughtful detail on these elements is the recessed joint between the two pours, which is of the same height and depth as the joints in the stonework on the grade II-listed Main University Building opposite.

Photos: John Seaman Photography

While such classical allusions exude calm and order, this belies an array of tricky engineering and logistical challenges throughout the project. The site has an awkward footprint, hemmed in between a road and a railway line, and with a sewer running alongside the rail tracks, which needed to remain accessible. Partly due to these constraints, and partly because of the bespoke nature of the centre's wide-ranging programme, every single floorplate is unique.

PROJECT TEAM

Architect Feilden Clegg Bradley Studios
Executive architect IBI Group
Structural engineer Arup
Main contractor BAM
In-situ concrete Thames Valley Construction
Precast concrete Sterling Services

READ THE FULL STORY
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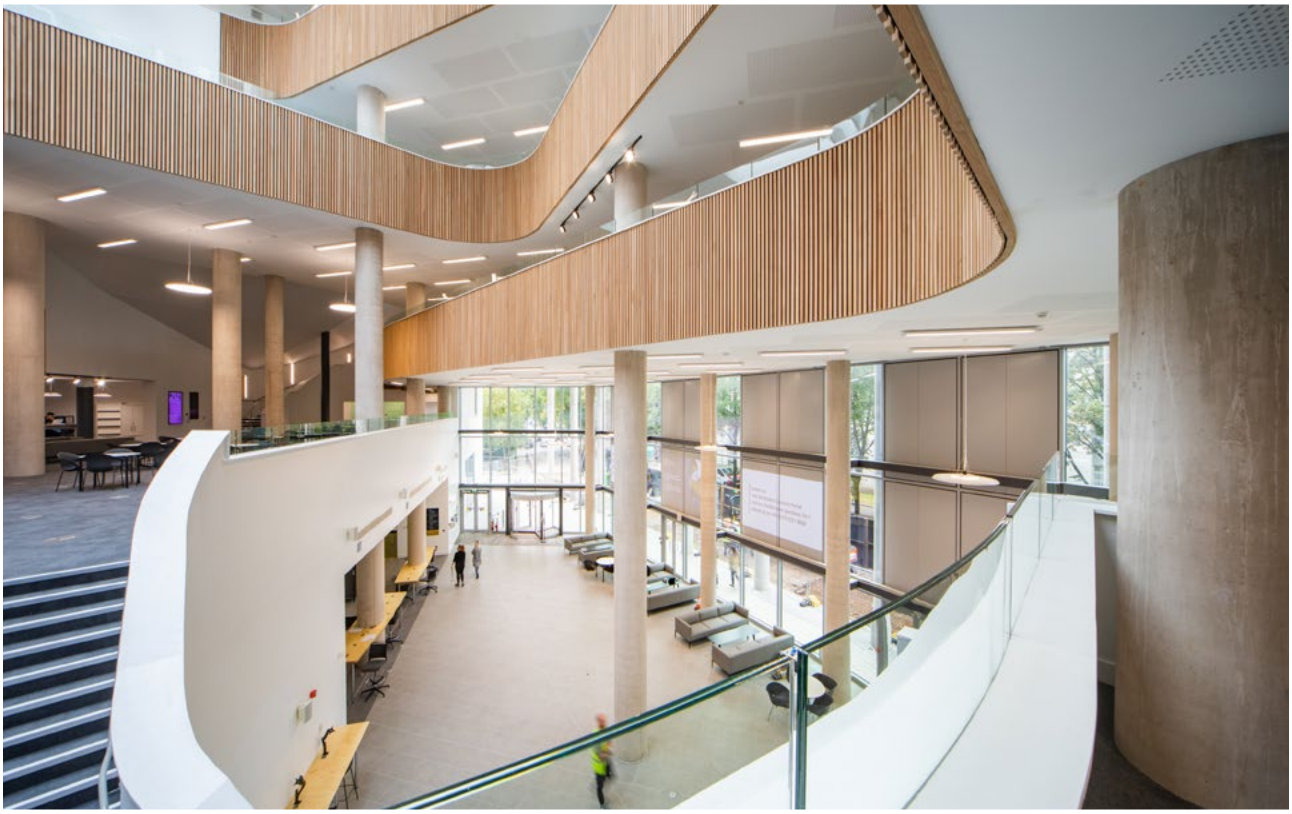

BIG SISTER

The brick facade of Apex Gardens in Seven Sisters, north London, is supported on 4,500m^2 of ultra high-performance fibre-reinforced concrete panels – a solution that reduced the amount of material needed by 60%, cut three months off the construction programme and, crucially for such a landmark building, enabled architect John McAslan + Partners to bring a greater level of detail to the brickwork.

The panels allowed the architects to play with depth in a way that is not usually possibly with brick slips, says Heather Macey, associate director at McAslan. "We wanted the window reveals to be as deep as we could possibly get them," she explains. "Because the cladding has a lighter build-up, we were able to fold the brick slip around the corner in a way that's insulated and not taking up too much space."

PROJECT TEAM

Architect John McAslan + Partners
Executive architect 3D Reid
Structural engineer Alan Baxter Associates
Main contractor Ant Yapi
Precast supplier Thorp Precast

READ THE FULL STORY
concretecentre.com/cq

Photos: Hufton + Crow

FORT BRAGG

The Sir William Henry Bragg Building is both a sensitive extension to a grade II-listed building, and a vast new 16,200m^2 resource, housing the University of Leeds' schools of physics and astronomy, computing and robotics, and engineering. Designed by ADP, the building's precast facade includes the imprint of fossilised limestone in a subtle echo of the grade II*-listed Portland stone Mining Building in front.

But inside are some of the most high-tech labs in the UK, with advanced electron microscope technology that needed to be completely shielded from vibrations. The in-situ concrete basement had to withstand even the faintest tremor from the neighbouring arterial road.

And if this suggests an immensely solid, immovable structure, above ground the BREEAM Excellent building's precast frame has been designed so that it can be taken down and reused in the future.

Photos: Paul Karalius

PROJECT TEAM

Architect ADP
Structural engineer Curtins
Main contractor BAM
Precast and in-situ concrete PCE

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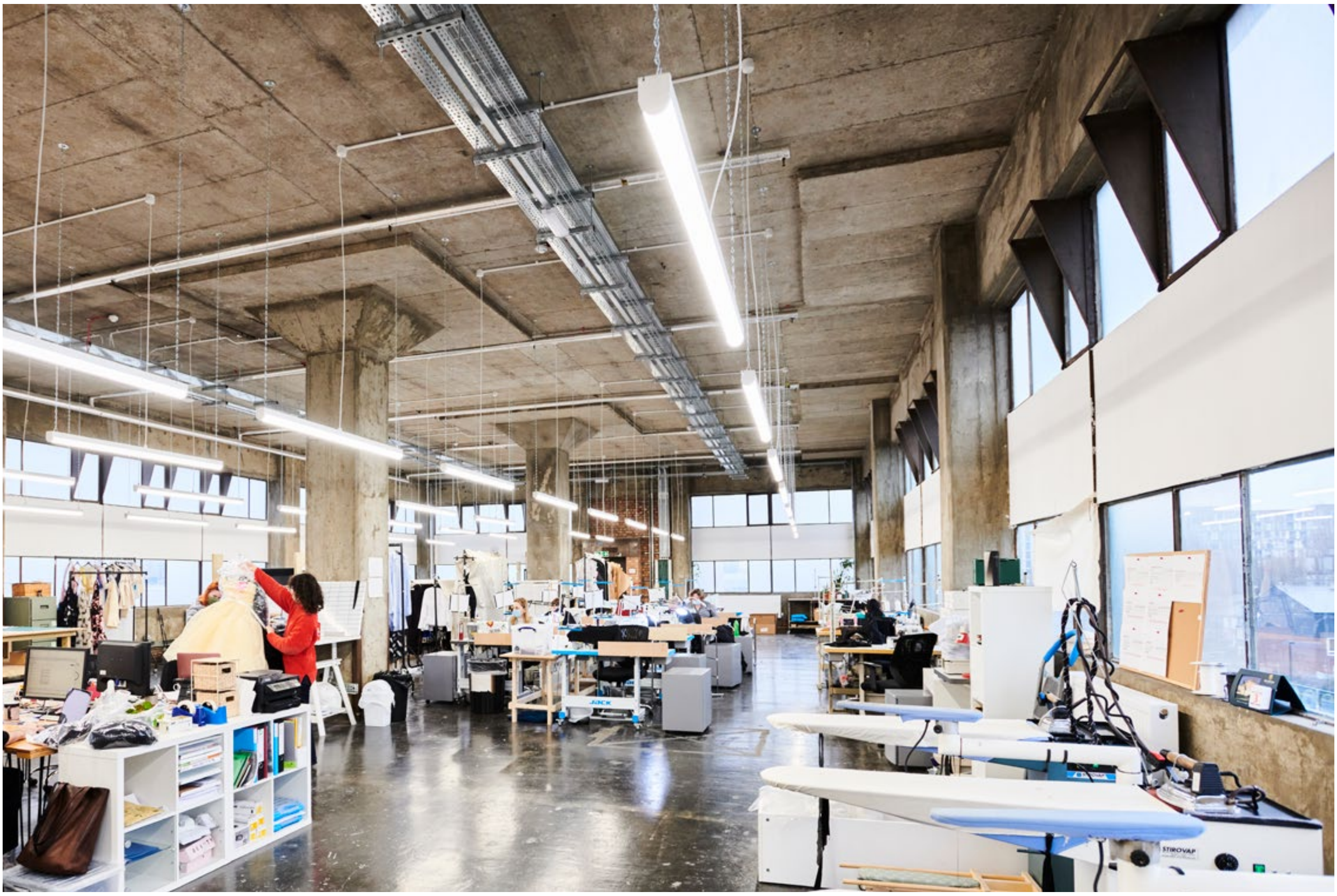

Fire performance: assessing concrete structures for reuse

With increasing numbers of concrete-framed buildings being adapted for new uses, it is vital to determine the fire resistance of the structure. Tony Jones of The Concrete Centre and Octavian Lalu of BRE outline the key assessment methods

Photo: Blake Ezra

It is hardly surprising that the reuse of concrete structures is becoming more common: the reuse of a structure is almost always the lowest embodied carbon solution, and concrete buildings can often remain useful well beyond their initial 50 or 60-year design life. But if the structure is to be significantly modified, or the use of the building changed, it is often necessary to assess the structural capacity of the building, including its resistance to fire.

In some cases, it may be enough simply to establish what the fire resistance is. However, the situation can become more complicated. If the use of the building is changing, it may be necessary to increase the period of fire resistance. Updates to building codes may also mean that the information used to design the structure no longer represents best practice. Indeed, the simpler methods in newer codes often take a more cautious approach because they cover a wider range of situations, which can lead to uncertainty.

Information required

The ideal situation for the designers of a repurposed building is to use existing as-built drawings; however, these are often not available and may not accurately represent the current condition. To carry out an initial calculation, the minimum information required is the dimensions of the element (beam, column or slab) under consideration and the distance from the concrete surface to the middle of the main steel reinforcement, known as the axis distance. This information can normally be obtained from a geometrical survey and a cover survey, which can be confirmed by inspecting localised "breakouts".

If it is not possible to justify the element's use based on this information, a structural fire assessment will be required, and this will need an understanding of the amount of reinforcement in the element, its strength and the strength of the concrete.

Photo: Ollie Hammick

ABOVE AND OPENING PAGE
At The Archives in north London, architect ROAR has converted a reinforced-concrete industrial warehouse into a creative and social hub, with a cafe, climbing centre, workspace and performance space

Simplified methods

When the fire resistance is unknown, an initial assessment can be made with minimal structural information. This can then be refined using historical test results from standard fire resistance tests, where they exist.

The most straightforward way to determine the fire resistance is from the tables in EN 1992-1-2, the current design code for fire design of concrete structures. These tables give a required section size and axis distance for a given fire resistance period. In some cases, the tables also include a factor that represents the degree of utilisation of the section during a fire – without further information, this should be assumed to be 0.7. If no information is available on the reinforcement layout, then initially slabs and beams should be considered as simply supported.

If the information on concrete strength and reinforcement strength and quantity is available, it may be possible to show a lower utilisation than 0.7, leading to smaller permissible section sizes, or to demonstrate that higher temperatures are permissible in the reinforcement, leading to a lower axis distance requirement. Both refinements are relatively easy to implement using the methods in EN 1992-1-2.

Although the sections considered in EN 1992-1-2 are generic, the withdrawn British Standard BS 8110-2 contains similar information for more specific types of construction that were common in the UK – for example, hollow pot floors. Where information in the withdrawn standard is superseded by the Eurocode, the latter should take precedence, but for these specific types of flooring, the approach in BS 8110-2 may be informative.

For certain floor systems, test information has been published and summarised in BRE's Information Paper 9/12.

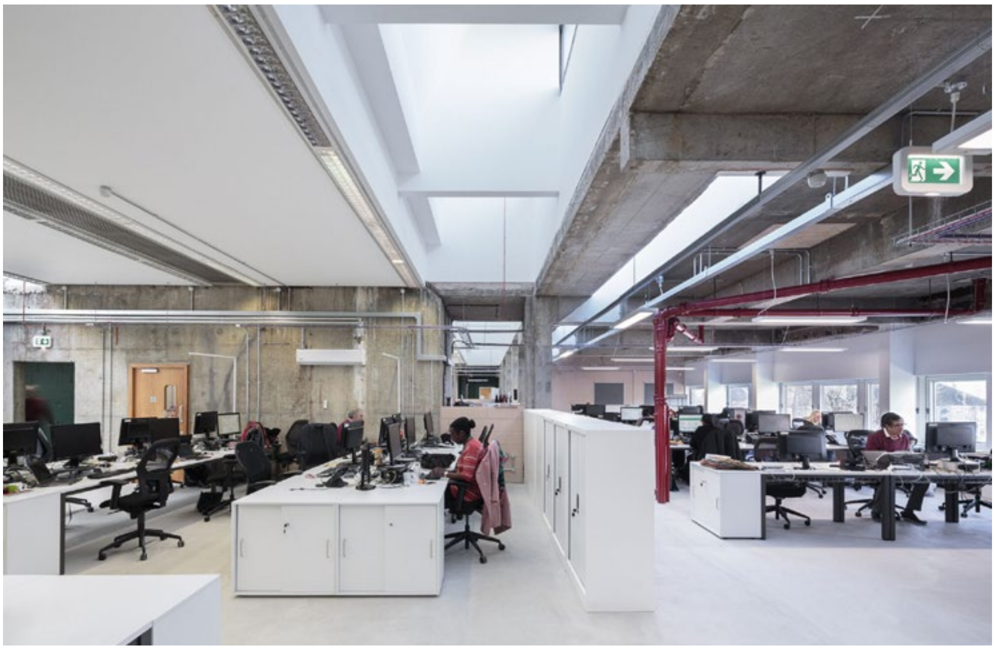
Photo: Dirk Lindner

ABOVE
Gort Scott's The Magistrates project in Walthamstow, north London, repurposed a brutalist 1970s courthouse as shared workspace, offices and a cafe

Following a site inspection to determine the main parameters of the floor system, this test information may be used to justify the fire resistance directly. The test information includes various historic precast and prestressed floor systems, hollow pot systems and wood wool slabs. It is important to establish the relevance of the test data to the existing floor being assessed.

Similarly, test information to support some of the tables in BS 8110 is summarised in reference document BR 468. If the section being investigated was within the parameters of the testing when constructed, this may provide an alternative justification.

Advanced methods

If relevant test data is not available, advanced numerical models can be used to more accurately calculate the fire resistance of existing structures. These complex computer codes require significantly more information about the existing structural materials – for example, the thermal and mechanical properties and the correct boundary conditions.

Advanced calculation models are often used when the part of the structure under assessment has a complex geometry or the complete structure needs to be analysed. The many assumptions and approximations in advanced calculation models are usually of a higher order of refinement than in simple calculation methods. This means that a higher degree of accuracy can be expected – which in turn can provide the opportunity to develop more economical designs, while maintaining acceptable levels of life safety.

Advanced numerical analysis is usually carried out in two stages: thermal and structural analysis. The temperature rise within a member is calculated in the first stage through heat transfer analysis. This first step is important since the temperature developed within the defined section will determine the capability of the member to carry the applied load. In the second stage, the time-temperature history is used as an input to the structural model to determine the mechanical response. The heat transfer calculations require knowledge of the geometry of the element, temperature-dependent thermal properties of the materials and the boundary conditions applied in the model. For materials with low thermal conductivity, such as concrete, it is important to determine the thermal gradients developed within the concrete section since these can influence the temperature rise of the main reinforcement, moisture migration, and development of thermal stresses and creep deformations.

The computer models can be validated against test evidence to show that the boundary conditions and the material properties selected are appropriate for the end-use application.

Photo: Eden Retirement Living

ABOVE
Ted Cullinan's grade II*-listed RMC headquarters in Thorpe, Surrey is being turned into retirement housing by architect Ayre Chamberlain Gaunt

Enhancing fire resistance

In some cases, particularly when an existing building undergoes a change of function, the fire resistance of a structural concrete member may need to be increased. This can be achieved by adding finishes to reduce the temperature of the main reinforcement bars. Where further measures are required, cementitious sprays, intumescent coatings or board types can be used. Care should be taken to ensure the protection layer retains its integrity for the duration of the design fire exposure.

Guidance on finish types (plaster or sprayed fibre) was provided in BS 8110-2. However, standard fire resistance test methods are now available to determine the contribution of applied fire protection materials to the performance of concrete structural elements in fire. The approach determines an equivalent thickness of concrete (in terms of thermal insulation) to be used in subsequent analysis. Again, further benefits may be achieved through the more advanced analysis methods. ■

A more in-depth version of this article is available at concretecentre.com

Photo: MICA Architects

ABOVE
MICA Architects' reinvention of Centre Point in central London as an apartment building involved extensive analysis of the concrete structure and cladding

Key references

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Take two buildings

An independently assessed life cycle analysis compared two apartment blocks – one with a concrete structure, one made of cross-laminated timber, but otherwise virtually identical. Below, we pick out five key findings

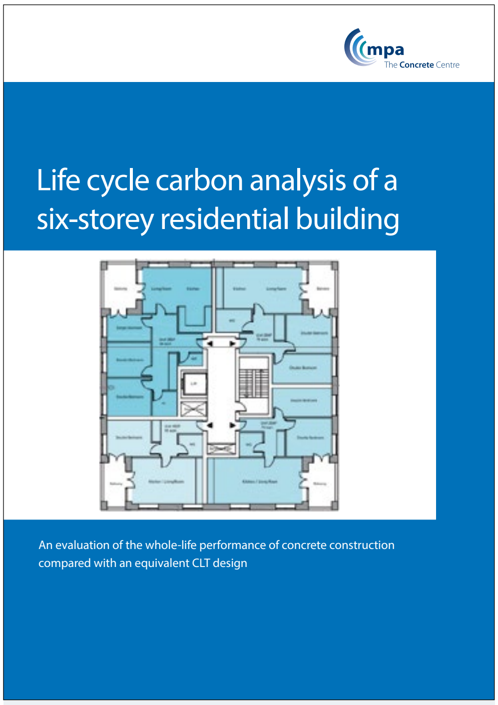
A concrete-framed building may not be significantly more carbon-intensive than a cross-laminated timber (CLT) one, according to a life cycle analysis (LCA) conducted on two notional apartment blocks. The concrete structure could also help to make useful carbon savings in a National Grid increasingly supplied by intermittent renewable sources.

These are two of the key findings of the LCA, which was commissioned by The Concrete Centre, with the aim of gaining a better understanding of carbon emissions over the lifespan of a relatively conventional concrete-framed residential building – and by extension showing how future designs can be optimised.

The analysis focused on two study buildings, one made of concrete, the other CLT. Both were 2,500m², six-storey blocks in London, containing 22 flats. They were of the same size, shape and layout, with the same functional requirements, and the same heating, hot water and ventilation systems, all designed to meet the Future Homes Standard.

The concrete building comprised a reinforced concrete (RC) frame, with exposed 225mm-thick slabs supported on a foundation of RC ground beams, pile caps and piles. The frame was made using a C32/40 concrete with 50% GGBS. The substructure works used an FND3 and FND4 concrete with 70% GGBS. The internal walls were made with concrete blocks finished with a wet plaster to maximise their thermal mass, which was also the purpose of exposing the soffits. The CLT building comprised 160mm-thick, five-layer panels for the floors, spanning unidirectionally onto 100mm-thick, three-layer loadbearing wall panels. These were finished with mineral wool insulation and plasterboard to provide the necessary fire resistance and noise transfer performance. This building was also supported on a foundation of RC ground beams, pile caps and piles.

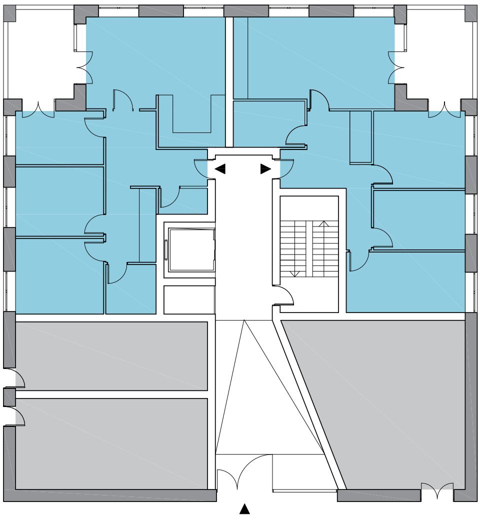
Analysis of the two buildings over a 60-year study period was carried out in early 2020, using IES ApacheSim for the dynamic thermal modelling and the OneClick tool for the LCA. Wherever possible,

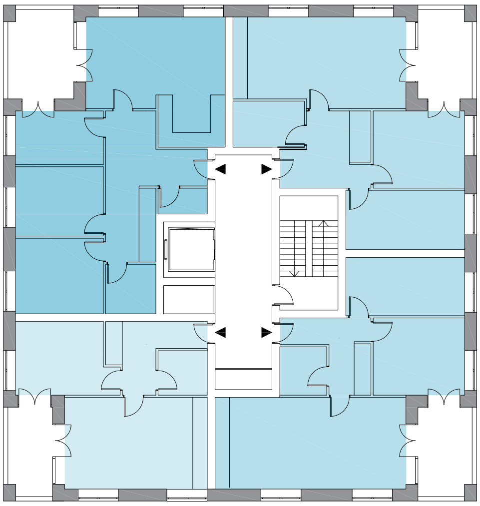


Read the full report

This article, authored by The Concrete Centre, draws on technical analysis completed by Max Fordham, on behalf of The Concrete Centre. The initial designs that formed the basis of the analysis were developed by Adam Khan (architect), Price and Myers (structural engineer) and Max Fordham (environmental and services engineer).

A full evaluation can be found at concretecentre.com





embodied carbon rates were determined using environmental product declarations (EPDs) for specific products. Where these weren't available, generic data sources were used such as the OneClick tool and the ICE database.

The results offer a practical insight into the relationship between embodied and operational carbon, and the interplay between different building materials, systems and design needs. The study also provided useful lessons on undertaking an LCA. Below we pick out some of the key findings.

ABOVE
Floorplans were the same for both buildings. They also had the same heating, hot water and ventilation systems

1

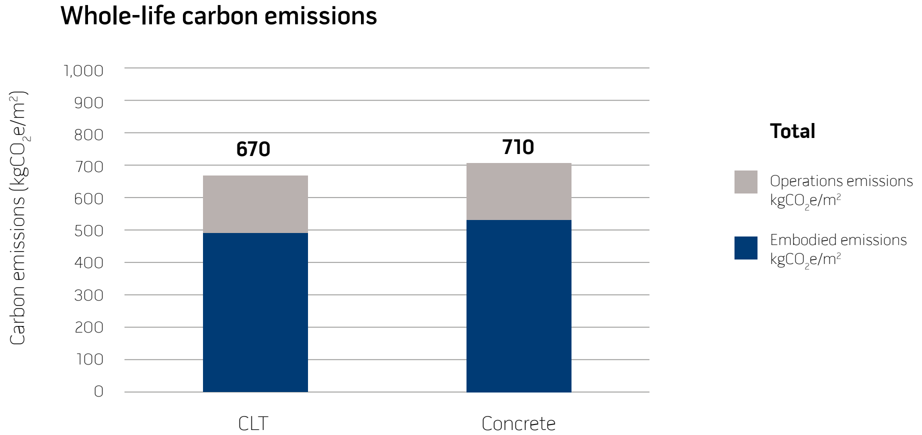
The concrete building's whole-life carbon emissions were only about 6% higher

The whole-life carbon emissions after 60 years were estimated to be around 710kgCO_2e/m² and 670kgCO_2e/m² for the concrete and CLT buildings respectively. Predicting whole-life emissions does, of course, come with a degree of uncertainty as it is looking many years into the future and depnds on LCA factors such as the future carbon intensity of grid-supplied electricity. But with this caveat, the difference between the average whole-life emissions was quite small, with the concrete building being only around 6% higher.

2

Both buildings meet the RIBA 2025 and 2030 Climate Challenge embodied carbon targets

The results also provide some insight into the relative



60-year lifetime, average grid intensity for operational carbon
CLT incinerated at end of life

contributions of operational and embodied emissions. In both the concrete and CLT buildings, embodied carbon was predicted to account for about 75% of the total – made up of approximately one-third structure, one-third services and the final third made up of architectural elements such as finishes and cladding.

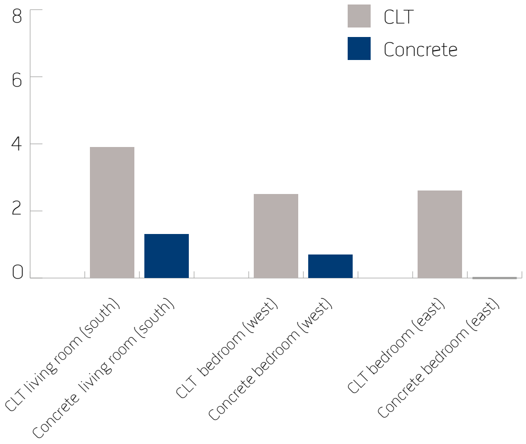
When the carbon emissions from the operational energy are excluded, the embodied impact of both buildings was around 500kgCO_2e/m², with the concrete building marginally higher. This meets two key industry benchmarks: the RIBA 2025 and 2030 Climate Challenge targets. The study built on this result by developing a "low2" scenario for the concrete building. This improved the carbon performance of the base design through seven material and system enhancements that worked within the fixed design constraints adopted for the study. These included increasing the GGBS in the superstructure from 50% to 70%, switching from PIR to EPS insulation and using a heat pump refrigerant with a lower GWP. Collectively, the changes reduced the embodied carbon to around 430kgCO_2e/m² using this data set.

3

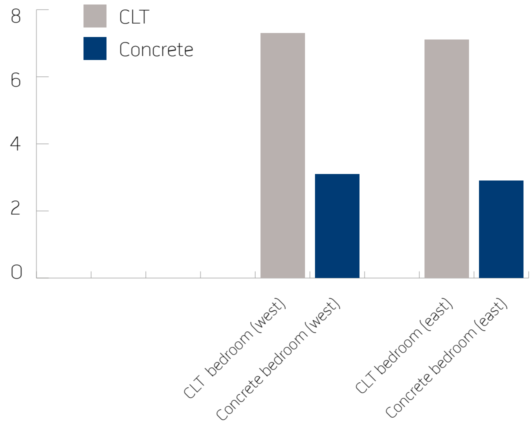
The concrete building had significantly better passive cooling

Both buildings adopted a high standard of solar shading and ventilation to reduce the risk of overheating as far as practicable, but the concrete design also made use of the structure's thermal mass.

Overheating analysis results: daytime
% of occupied daytime hours >28°C



Overheating analysis results: night-time
% of occupied sleeping hours >26°C



Overheating analysis using the CIBSE TM59 methodology found that, for the period 2020-40, the concrete building could remain cool by using this thermal mass, coupled with night cooling and some very low-energy ceiling fans. The CLT building, on the other hand, needed active cooling in summer, so includes an air-source heat pump, serving chilled water fan-coil units. By 2041-80, summertime external temperatures are anticipated to rise by around 1°C, and under these conditions, the concrete building also requires a small amount of active cooling.

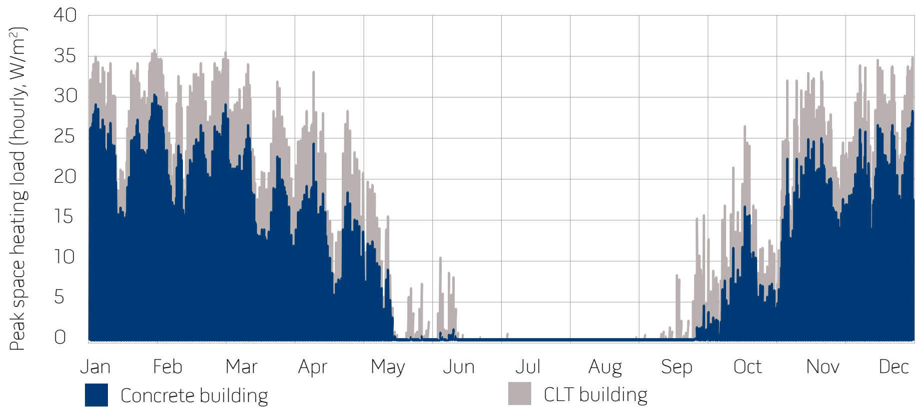
4

Operational energy consumption was about the same

The concrete building was predicted to use less energy for cooling than the CLT option and slightly more for heating, but overall the two balanced each other out and there was no significant difference in the total energy consumption for any of the time periods or occupancy scenarios. Overall energy consumption was close to 43kWh/m^2/yr throughout the 2020-80 period. This is reduced to 34kWh/m^2/y when energy produced by the roof mounted PV array is included.

It's worth noting that the study assumed a reasonable active cooling set point of 24°C for the modelling. In practice, occupants may of course opt for a lower setting closer to

Predicted peak space heating demand
(2020-40 time period, intermittent occupancy)



20°C, resulting in more energy being used for cooling. The extent of any increase is however likely to be more modest in the concrete building, with its better passive cooling performance.

5

The concrete building's peak space heating load was on average 25% lower

For the period 2020-40, the peak electrical load for space heating was on average 25% less in the concrete building, as a consequence of its higher thermal mass. When hot water heating was included, the total peak heat electrical demand was estimated to be around 15% lower than for the CLT building.

This matters because, by reducing peak electrical demand, the National Grid is better able to balance out supply and demand. This will become an important attribute of high thermal mass buildings, as they can be actively controlled to store and release heat in response to the peaks and troughs of renewable energy supply. In this way, the building's energy demand can be shifted away from periods of high grid carbon intensity – that is, when fossil fuels are needed to meet a shortfall in renewable power. The net result is carbon savings at a national level. ■

FINAL FRAME: MKM MUSEUM

A sculptural staircase, cast in situ from terracotta-pigmented concrete, connects the five levels of Herzog & de Meuron's extension to the MKM Museum Küppersmühle in Duisburg, Germany. The Swiss architects created the original gallery from a 19th-century grain mill – a project that ran in parallel to the Tate Modern and completed in 1999. The extension adds 2,500m² of white cube exhibition space. The sinuous stairwell acts as a deliberate contrast, and echoes the red-concrete stair tower created for the original museum.

Photo: Simon Menges