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CONCRETE QUARTERLY

WINTER 2019 | ISSUE NUMBER 270

WRINKLE TREATMENT
Steven Holl goes for the crumpled look at Washington DC's Kennedy Center for the Performing Arts

SOCIAL CLIMBER
How Camden's old council offices escaped demolition to become London's hottest new hotel

SECRETS OF A LONG LIFE
The new rules for durable structures and loose-fit design – the key to a low-carbon future

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On the cover:
The REACH, Kennedy Center for the Performing Arts, Washington DC, by Steven Holl Architects
Photo by Richard Barnes

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AGENDA

Guy Thompson
Head of architecture, housing and sustainability, The Concrete Centre

Second time around

Camden council's brutalist town hall annexe could so easily have been a goner. All but one of the proposals for its redevelopment involved demolition, even though the 45-year-old concrete structure was in good condition and the precast facade needed little more than a clean (see page 4).

It seems the tide is beginning to turn. Knocking down a building that could otherwise be repurposed is to waste our heritage, but more importantly, our precious energy and resources. Components such as servicing and finishes will need to be replaced over shorter cycles, but a building envelope that is well designed and properly looked after should last a great deal longer than the typical design life specified today. To achieve the circular economy to which we aspire, we need to minimise both carbon expenditure and material use, and maximise material efficiency. The goal is to consume less, and to make sure that the materials we do consume are used for as long as possible.

Ultimately we want to know that what we're building today is retrofittable and that it can also last as long as possible, so these revived structures offer useful lessons. For example, the waffle slabs that today's architects are uncovering and proudly displaying were originally specified by the engineers of the past to save materials. Now the technique is being reinterpreted in combination with new technologies, as for SOM's "stereoform" slab (see news, opposite).

ALL INVESTORS WILL BE LOOKING MORE CAREFULLY AT THE RESILIENCE OF THEIR ASSETS IN A CHANGING WORLD

The other consideration here is of course financial: waffle slabs went out to fit in more floors over the height of a building, and therefore more saleable space. But it may not take long for the equation to be skewed: there are already a growing number of green investors looking for sustainable places to put their money, and all investors will be looking more carefully at the resilience of their assets in a changing world.

Not every building needs to last forever. For those where any future usage may be uncertain or technology change threatens obsolescence, we should be prioritising reusability of the components. At this end of the continuum stands the logistics shed; at the other, we find the Oxford colleges that specify a 300 or even 500-year design life. There's no way to predict the future over that long a timeframe, so flexibility and robustness are essential. All we can do is look at today's refit projects, and try to avoid yesterday's short-termist mistakes as best we can.

EVENTS

INTRODUCING THE CQ AWARDS

For over 70 years, CQ has featured many of the UK's most inspirational buildings – but we don't have room to celebrate them all. So we are excited to launch the CQ Awards, to recognise the best of concrete architecture in the UK and beyond. All projects that appear in CQ will be automatically entered. As for the ones that got away, teams are invited to submit their projects to **info@concretecentre.com** by Friday 1 May 2020. The first award, in partnership with British Precast Architectural & Structural, will be for excellence in precast concrete, to be presented at the British Precast awards in June 2020. More categories will be announced soon. For more details, visit **www.concretecentre.com/cq**

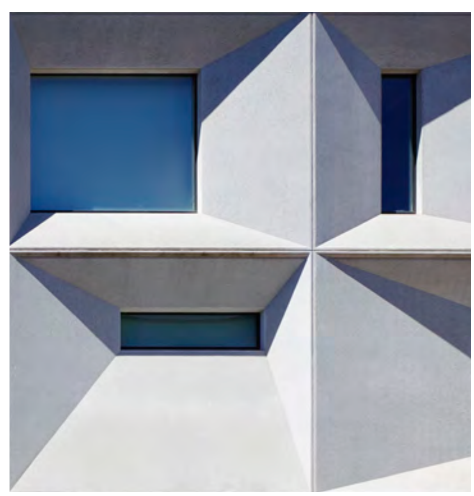


Photo: Timothy Soar

Photos: 1. Iwan Baan 2. LSE/Nigel Stead 3. Michael Molloy 4. Dave Burk/SOM

NEWS: PLENTY TO DANCE ABOUT

The 2020 RIBA Gold Medal has been awarded to Yvonne Farrell and Shelly McNamara of Grafton Architects, a practice that has created some of the 21st century's most celebrated concrete buildings. From the grand interior cityscape of Bocconi University in Milan to the cliff-like Utec campus ❶ in Lima and the Marshall Building ❷ at the London School of Economics, now under construction, their work shows how muscular masonry elements can be used to carve out compelling spaces. Meanwhile, Glenn Howells' latest completion reminds us of concrete's fleeter-footed side. Following Allies and Morrison's tardis-like HQ for the Rambert dance company on the South Bank (CQ 249), Howells has adopted a similar industrial aesthetic for English National Ballet's new base in east London ❸. The company's desire to open up its process to passers-by has prompted a factory-style look, with expanses of concrete revealed within its translucent skin. Finally, pirouetting from ballet to structural gymnastics, SOM has unveiled its stereoform slab ❹ at the Chicago Architecture Biennale, which it claims could cut the carbon footprint of high-rise structures by 20%. The practice is behind some of the world's most iconic tall buildings, including One World Trade Center and the Burj Khalifa, and says that the slab's curving form, created by a reusable, robotically crafted EPS mould, reduces the amount of structural material used by one-fifth.

INNOVATION: SELF-HEALING CONCRETE

"If it cracks, bacteria are released and form limestone to seal it"

Photo: Paul Burroughs

The extraordinary thing about the lump of concrete on Dr Kevin Paine's desk is that it looks entirely normal. But this concrete used to be cracked – and it has mended itself.

"I used to be able to see where the cracks had been," says Paine, reader at Bath University's civil engineering department and a leading researcher in the field of self-healing concrete. "But the fine white 'scars' have faded and now I can barely make them out."

So how is it done? Paine explains that the cracks have been filled with calcium carbonate precipitated by bacteria living in the concrete. "We add bacterial spores to the concrete mix along with food such as yeast extract. If the concrete cracks, the bacteria are released and exposed to oxygen and water. They feed on the yeast, they multiply, and as a result of metabolic actions, calcium carbonate – or limestone – forms to seal the crack before it has a chance to enlarge."

Paine's interest in self-healing concrete dates from a trip to Delft in Holland in 2011 where researchers were among the first to try the technique.

"To begin with it was a bit over my head," he admits. "I am a civil engineer and I didn't know much about bacteria. But I came back to Bath, talked to the microbiologists here and we agreed we could take it forward. Better still, researchers in other forms of self-healing concrete (vascular systems, for example) at Cardiff and Cambridge universities also took an interest and together we were able to secure grant funding to pursue our research."

Getting it to work well has not been straightforward: "The spores have to survive the mixing process," says Paine. "We can encapsulate them, but any coating has to be brittle enough to fracture and release the ingredients when the concrete cracks."

Trials are ongoing – as evidenced by the calcite-flecked Petri-dishes in the biology labs. "We have now got to the stage where we have mixes that work reliably," says Paine. "Small cracks will be repaired within about 14 days. Our problem now is that this works best at around 20°C or higher and in wet conditions. That might be OK for monsoon regions, but obviously we need to get it to work at much lower temperatures – hence the fridges in which we are testing our latest mixes."

This is truly groundbreaking stuff. "What we know about bacteria tends to come from medicine – so we know plenty about how bacteria behave at body temperature. How they operate at, say, 5°C we just have to find out for ourselves."

■ **Tony Whitehead**

GOING UP IN THE WORLD

Tony Whitehead finds out how skilful repair and renovation by Orms has given a tired council building on London's Euston Road new life as an ultra-stylish hang-out

The mid-seventies fashion for combining precast concrete with tinted glazing did not age well. Many examples were demolished as early as the 1990s and, by 2014, it seemed a bleak future loomed for one of the survivors: the eight-storey concrete annexe to Camden Town Hall.

Situated across the road from St Pancras Station, the annexe did not compare well with the restored masterpiece opposite. It was woefully inefficient, covered in grime, and boasted some 500 windows of a truly hideous tint. Unsurprisingly, all schemes submitted for the site's redevelopment proposed to flatten it.

All, that is, except the one devised by architect Orms with Crosstree Real Estate. "With all our projects we look to see what can be reused," explains Orms associate Simon Whittaker. "It's just a more sustainable approach. We saw past the grime. There was architectural merit in the building and its concrete frame was still in good condition."

Having looked at repurposing the building as offices or residential space, it became clear to Orms and Crosstree that the floorplan and location were ideal for a hotel. Whittaker believes the sustainability argument helped to swing Camden council behind the idea, "though they might also have been a little sentimental about their old HQ".

The building now houses a 266-room hotel, The Standard, the latest in a high-end, ultra-fashionable global chain designed to appeal to the well-heeled hip. So how to transform unloved council offices into a place where the beautiful people stay?

Most obviously, the building needed cleaning. "The facade is structural, and comprised glazed precast panels that were actually in pretty good condition," says Whittaker. "Just a few mastic joints needed reinstating and there was the odd small crack which was easily repaired. After cleaning with a mild abrasive system (see box, overleaf) it came up much brighter than we had hoped. The concrete has a large whitish aggregate in it, and with the dirt removed you can appreciate its true colour."

Needless to say, the single-glazed tinted windows have been replaced with double-glazed clear units with various coatings to improve efficiency and, on south-facing elevations, limit solar gain. Changing the glazing and cleaning the facade has effected a dramatic transformation from "tired" to "fresh". The building also benefits greatly from the removal of a stair core and roof-level plant room that ran up the right-hand side of the building and connected it, via a covered walkway, to the neo-classical town hall next door. With the core removed, the sculptural mass of the building is clearly expressed as a standalone structure for the first time. Its removal did have consequences, however. "It was a key contributor to lateral stability," Whittaker says. "Without it the building would sway from side to side. The solution was to introduce two new concrete stability cores."

One of these is a new lift shaft, constructed from in-situ concrete, which has been stitched into the original reinforced concrete structure and runs from basement to roof. The second is a C-shaped core, also in in-situ concrete, that rises from the basement to the fifth floor. This encloses a shaft for dumb waiters at basement level, but on the upper floors is simply a C-shaped shear wall enclosing bedrooms. The construction of both new cores was sequenced early in the programme to stabilise the building prior to the removal of the old stair core.

"The annexe has an interesting structure which made it amenable to reuse," adds Whittaker. "The concrete slabs span from four large 750mm^2 central columns out to the precast facade which is structural and supports the slabs at the perimeter. This gives spans of over 10m in all directions around the columns – so lots of clear space to reconfigure as we like."

Andrew Middlebrook, associate with structural engineers Heyne Tillett Steel (HTS), also sees merit in the structure. "Having a structural facade means you don't need columns near the perimeter and that produces a clearer floorplan. It also saves

WITH ALL OUR PROJECTS WE LOOK TO SEE WHAT CAN BE REUSED. IT'S JUST A MORE SUSTAINABLE APPROACH

Photo: Tim Soar

doubling up on structure and cladding. The floors are made from waffle slabs which have rather gone out of fashion today, but they can be a very efficient use of material." The waffle slabs at The Standard are just 106mm thick, but with 300mm downstands. The 406mm total allows long spans to be achieved with relatively little concrete. "An equivalent solid slab would have to be maybe 350mm thick, so the waffles have saved a lot of weight and material."

As well as boasting admirably reconfigurable floorplates, the existing concrete frame also proved robust enough to take three further storeys (see box, below). This added 1,914m² to the building's existing 15,360m² and was vital for the commercial viability of the scheme. To save weight, the rooftop extension was constructed largely from steel, with composite metal deck slabs with a 175mm depth of concrete. The 10th floor, featuring a restaurant and entertainment area, is acoustically separated from bedroom accommodation below by an extra 150mm slab above a 100mm air gap. "This is supported above the 175mm ceiling slab by sprung jacks to absorb noise and vibration," says Middlebrook.

The new floors are set back from the facade of the original building, as supporting their full weight off the facade was impracticable. Instead, HTS developed an ingenious solution which involved

The weight problem

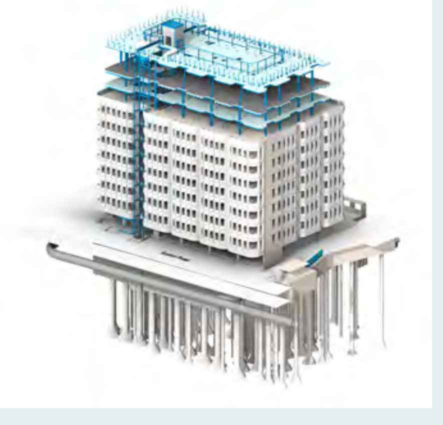
Adding three extra floors to the top of the existing annexe was always crucial to the future viability of the building. The question was: to what extent could the existing structure support the additional loading?

Structural engineer Heyne Tillett Steel's first move was to acquire a set of original drawings from the archives of Pell Frischmann, the engineer that designed the structure back in the early 1970s. HTS associate Andrew Middlebrook describes the existence of these as "an absolute lifesaver" as, without them, a number of "safety first" assumptions would have been made early in the design, with the risk of over-engineering the solution to the building's extra weight.

"As it was, we still had to carry out intrusive investigations on site to verify the drawings," says Middlebrook. "We dug trial pits to a depth of 4m around four of the piles that would experience the biggest increase in loads and confirmed the diameters shown in the original drawings."

He adds that the piles were under-reamed – designed with wider sections or "bulbs" at depth to help stability. "These needed checking too, so we dug bore holes all around the existing piles to establish the depth and width of the under-reams."

Once HTS had confidence in exactly what lay below ground, the true capacity of each retained pile was recalculated by geotechnical consultant RSK Group. "This is a useful calculation as, after 45 years, the foundations are unlikely to settle



any further," says Middlebrook. By comparing the existing versus proposed loads for each pile, HTS found that the increased loading produced by the weight of the extra floors was justified for all but two of the piles.

"These were strengthened by sinking smaller piles around them," explains Middlebrook. "We put three around one, in a triangle configuration, and five around the other. We didn't want to break out the basement slab so we piled right through it, sinking the new piles around the existing piles beneath. For each of the two original piles we then cast a very strong, 1m-thick pile cap to connect it to its new piles. This was an obtrusive structure, upstanding from the slab, but being in the basement it was buried in back-of-house space."

FAR LEFT The rhythmic precast-concrete facade is broken by a glass lift in Routemaster red

LEFT The waffle slabs have been exposed as a design feature in the new rooms

BELOW LEFT The hotel is directly opposite one of its more stately rivals: the St Pancras Renaissance

BELOW The original structure had an open floorplan with spans of 10m in all directions, making it ideal for reconfiguration

threading hollow steel section columns through the existing structure.

"These sections are 150mm by 250mm and are threaded through the waffle slabs down to the first floor," says Middlebrook. The first-floor slab is 1m thick and supported by columns set in from the facade above. "The slab is very strong and cantilevers out to support the facade at the perimeter and provide a covered area at pavement level. We positioned the steel columns to land on the slab directly above this inner set of concrete columns."

Middlebrook says that most of the steel columns missed the structurally important ribs of the waffle slabs, but even where ribs were pierced, the inherent strength of the concrete building came to the rescue: "Most of the pierced waffle slabs were strong enough to cope. We only had to mend and strengthen four of them."

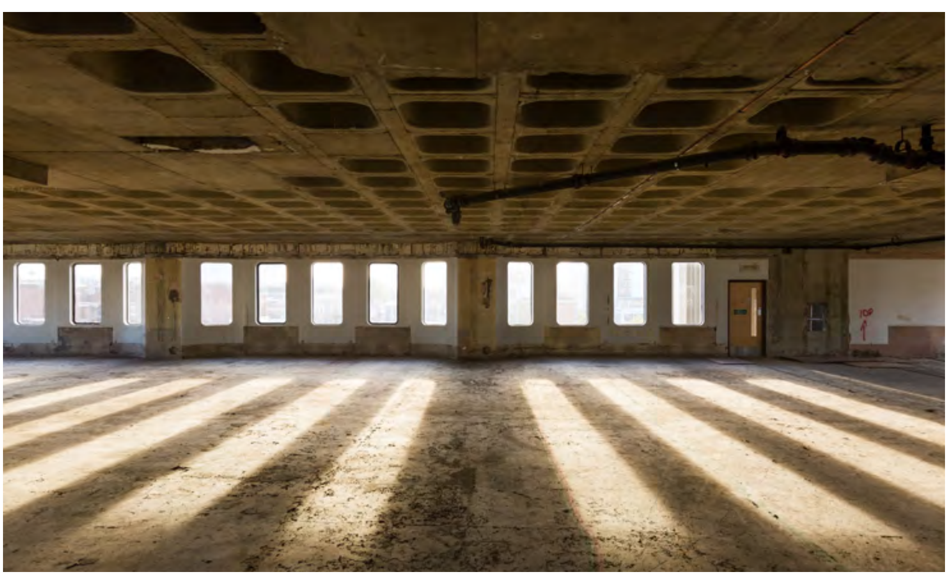
As the new steel columns are hidden within partitions, the hotel's glamorous interior betrays little of this structural ingenuity. Inside the bedrooms, the precast window panels have been insulated and replastered and the only concrete visible is the exposed waffle slab.

There is a pleasing irony here as, in 1974, the slab was covered with ceiling tiles. Now, The Standard's interiors specialists have made it integral to a stunning and up-to-the-minute design.

■ More on the reuse of concrete structures, page 12

PROJECT TEAM

Architect Orms
Structural engineer Heyne Tillett Steel
Main contractor McLaren
Concrete cleaning Restore London



Busting 45 years of grime

Over the years, Restore London has cleaned the brick and stone facades of some of the capital's most impressive classical buildings, including the Royal Academy in Piccadilly and the Royal Hospital Chelsea. Cleaning brutalist concrete, however, is becoming a more common occurrence. "It's coming back into fashion," says managing director John Rushworth. "But each job is different and we have to proceed carefully to ensure we clean thoroughly without doing any damage."

To deal with the precast-concrete facade of the former Camden town hall annexe, this involved trialling various methods to remove a film of dirt built up over 45 years of exposure to the pollution of the Euston Road. "We usually try a plain water-pressure wash first," says Rushworth, "or maybe heated water, and then move up through various levels of abrasive cleaning until we get the right result."

For The Standard, Restore London used a Jos (pronounced "Yoss") type system originally developed in Germany. This uses a selected abrasive particle carried by a flow of compressed air to a nozzle, at which point water is added. The mixture exits in a vortex and is then manually directed at the substrate to be cleaned. The process is akin to sand-blasting, but much gentler and more finely controlled.

"The trick is to use minimum force," says Rushworth. "For The Standard, we used a fine and relatively soft particle known as Olivine 80 [a magnesium/iron silicate]. We can then adjust the pressure of the jet, and the distance from the nozzle to the facade, to make sure we use just enough force to get it clean." Troughs are placed at each floor as cleaning progresses, and the water is collected and filtered to remove the particles before being either reused or drained away.

For one particular precast panel, extra care was required. "The building has a small Banksy original on it," explains Rushworth. "Obviously we had to be careful not to clean that away, so as a trial we did our own drawing on the facade – not quite as good – and practised cleaning right up close with an extra-fine pencil nozzle. Only when we were sure we could clean around a drawing accurately did we go anywhere near the original."

Photos: Tim Soar, Chris Mosier

VANISHING TRICKS

The utilitarian materials of Sophie Hicks' Earls Court house conceal a highly sophisticated machine, writes Nick Jones

Sophie Hicks Architects' 1a Earls Court Square is a house that revels in structural honesty, while also managing to conceal most of its working parts. It has been described by its architect as a "quiet machine", with heating and cooling systems, lighting and motorised blinds all discreetly hidden. Yet at the same time, it is a house with nowhere to hide, its walls, floors, ceilings, even some of its furniture, cast in concrete and left entirely exposed. This paradoxical approach required a single-mindedness on the part of the designers, Hicks and her colleague Tom Hope. "If you forget anything or you leave something till later, it will show in the finished building," says Hicks. "You have to design it all on day one – that's the challenge."

The sunken, two-level house, which has been shortlisted for the RIBA's Manser Medal, occupies a tiny 75m^2 plot between two Georgian houses. From the street, its upper, ground floor appears as a minimalist glass box barely rising above the neighbouring property's garden wall, but even this briefest of glimpses is enough to reveal the bold design approach. Set back 1m inside the glazed envelope is a muscular a 600mm-thick roof slab, which seems to hang beneath the glass. On such a tight site, this inset could be felt as an unnecessary encroachment, but the effect is just the opposite. Because the open-plan living space stretches out beyond the shadow of the roof slab, the room height suddenly rises from 3m to 3.6m and feels open to the sky. "You're drawn to the edge of the room because it leads the eye up, it expands upwards and outwards," says Hicks. "The space is not that big but it feels a lot bigger."

While the roof slab deflects the eye to the world outside, it also draws attention to itself: "It's like an artwork," says Hicks, "it's got nothing on it. If you look up, it's framed by sky." In this sense, it could be read as a celebration of unadorned structure – and yet, in a house crying out for hiding places, it's not as honest as it might seem. Rather than a 600mm slab, it's actually 200mm fronted by an upstand, which neatly hides a 200mm layer of insulation, as well as the connections to the glazing's steel frame and a shallow-pitched solar array – a lid for the quiet machine.

The concrete frame plays another important role. Because the house is half-basement and shielded on all sides by a 2m-high garden wall, it was always going to need huge amounts of glass at the top to suck in as much light as possible. This in turn meant that the rest of the structure would have to mitigate the potential for overheating and heat loss. Apart from a few areas of plasterboard in the basement, the concrete is exposed and boardmarked throughout. Hicks specified a "completely bog standard" mix from the nearest distribution centre on the basis that "there's a great pleasure in using what is normal".

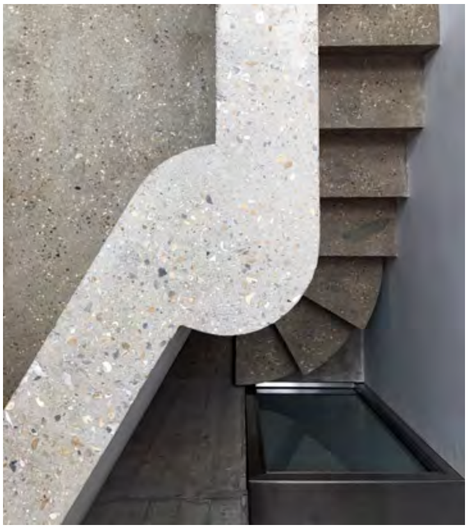
In an example of the all-on-day-one design approach, the finish informed the structure as much as vice versa. Hicks felt the building's four perimeter columns should be precisely two boards wide and worked backwards to make sure this was achievable. In search of an affordable, off-the shelf shuttering solution – in part to mitigate

Photos: Annabel Elston

the costs of bespoke basement construction in west London – she found herself on the phone to a fencing manufacturer in Yorkshire. "I asked for their standard board width, which was 100mm, and that's what we used. The whole thing was set out by the basic unseasoned fence board – that gave us the dimensions." This slightly unconventional approach to structural design gave Hicks 200mm-wide columns, which had to act as another hiding place, incorporating not only large amounts of rebar but also the cabling and 100mm-deep backboxes for the sleek stainless-steel electrical panels that are set into the front of the columns.

The rough-sawn pine fence panels define the finish of all the exposed walls and ceilings and are neatly aligned throughout. The junctions at the soffit appear seamless, as the columns were cast at the same time as the slab above. Hicks has noticed a couple of other benefits to her utilitarian shuttering method. "The concrete is full of little splinters that have come off the wood, which is absolutely beautiful," she says. "The other thing it does is leave tiny holes in the surface, which makes it acoustically absorbent, like a carpet or curtain. It is a very calming, acoustically softening space."

YOU CAN NEVER CHANGE YOUR MIND, BECAUSE EVERYTHING SHOWS IN A SMALL BUILDING ON A SMALL SITE



The floor has been polished throughout, with 10mm ground off the screed to reveal a consistent pattern of aggregate beneath. The screed is the same mix as the rest of the concrete so appears monolithic, but it actually sits on top of a network of heating and cooling pipes – another sleight of hand.

The polished finish continues onto the staircase, which was cast in timber formwork and turns down in a semi-circle to the basement level. Here, cocooned from street level, are the two en-suite bedrooms, both lit via glazed side walls that face onto a sunken, white-painted courtyard. The basement walls are protected by a cavity drain waterproofing membrane, while a mechanical ventilation with heat recovery system draws in fresh air from neighbouring gardens.

There is further evidence down here of design choices made on day one and stuck to: recessed shower heads cast into the bathroom soffits, and in-situ concrete bedside tables projecting from the perimeter columns, their surfaces polished to match the floors. "You can never change your mind," says Hicks, "because everything shows in a small building on a small site." She admits that they forgot one wire during construction – Hope spent a day recently routing it through one of the few plasterboard walls. Perhaps, after all, there is always one last hiding place.

PROJECT TEAM

Architect Sophie Hicks Architects
Structural engineer MLM Consulting Engineers
M&E engineer Libra Services
Concrete contractor GMP
Finishing contractor Advent Developments

CLOCKWISE FROM FAR LEFT

A sunken courtyard draws light into the basement bedrooms; upstairs, the concrete frame is set back from the glass envelope; the concrete upstand rises above the garden wall; the stair, balustrade and floor are all polished to expose a pattern of aggregate

WASHINGTON CONFIDENTIAL

How did Steven Holl create the dazzling "crinkled" concrete on its Kennedy Center extension? Pamela Buxton tries to crack the formula

The precise recipe for the distinctive crinkled concrete at the extension to the Kennedy Center for the Performing Arts in Washington DC is being kept a closely guarded secret. And after a lengthy research and development process involving countless iterations, you can hardly blame Steven Holl Architects for wanting to keep the exact details of the extraordinary concrete finish to itself.

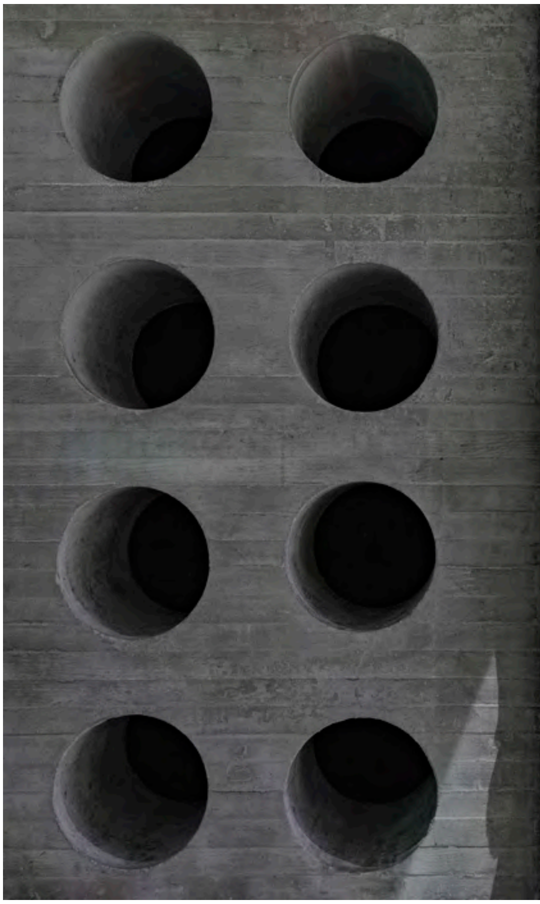
Known as The REACH, the project is an expansion of the centre built as a memorial to President John F Kennedy, and adds 72,000ft² of additional rehearsal, education and flexible space. The design is conceived as three pavilions that fuse with the landscape above ground with the help of green roofs, and are interconnected below ground.

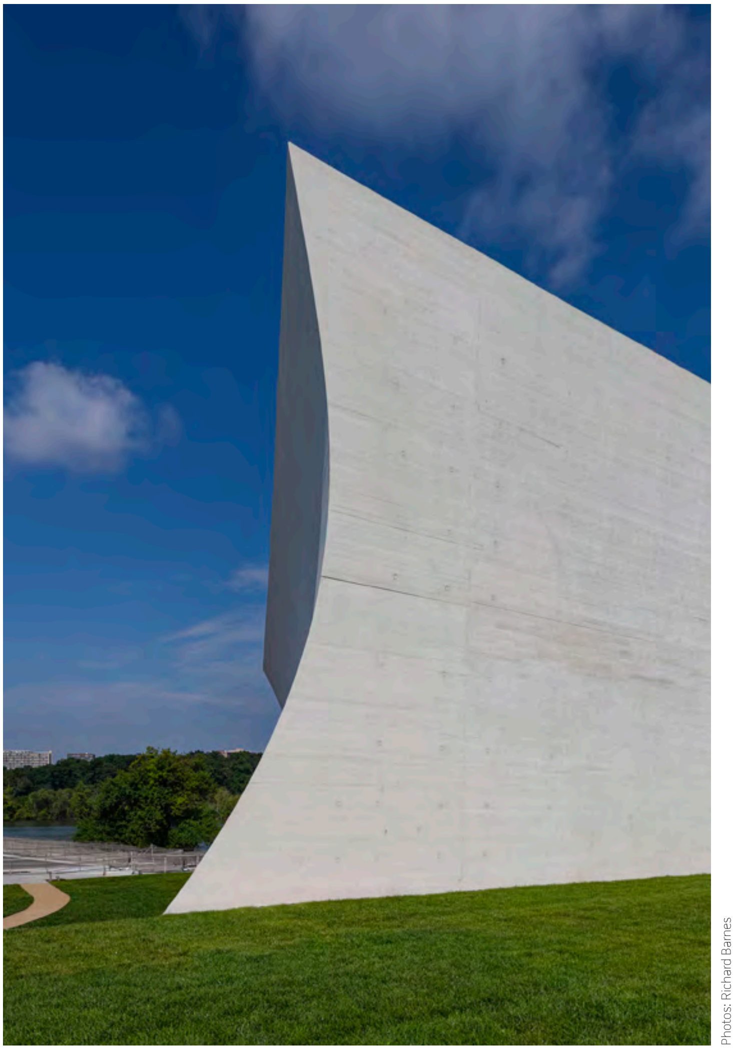
There are two notable uses of concrete. From the outside, the facades are white in-situ concrete, board-formed using 4-inch tongue-and-groove Douglas fir boards. According to project architect Garrick Ambrose, the idea was to reference the white Carrara marble of the original centre in an innovative way in order to get a whiter-than-white expression. After many mock-ups and experimentation with different concrete mixes and boards, this was achieved using white aggregate and then "super-charged" with titanium dioxide to enhance the whiteness. "It was an iterative process of testing different sands and different types of titanium pigment," says Ambrose. "It's like creating a recipe."

From a distance, the pavilions appear to be pristine white and seamless. "The tongue-and-groove boards mediated the geometry very well," he adds. "They were flexible and thin and naturally followed the formwork." Up close, however, the board-marking provides a very different experience – "of something tactile and hand-made".

But the real concrete showstopper is on the inside, in the shape of the innovative crinkled concrete for the 11,570ft² of in-situ walls that enclose the four rehearsal and performance spaces. This design was initially driven by acoustics, namely the requirement for a surface to diffuse the sound and mitigate echoes. The architects wanted to achieve this in a way that was integral to the structure rather than applied, and started experimenting with getting depth into the surface of the walls when they were cast. They came up with a method for hand-crinkling 10ft x 4ft aluminium sheeting so that it looks like crumpled paper, and "freezing" this in place by spraying foam insulation onto the back. From this, they created an elastomeric mould of the 3-inch pattern and used this to line the otherwise standard formwork for the reinforced concrete walls. "It's not only an aesthetic, it's performative and structural," says Ambrose.

The architects developed the idea through a number of mock-ups at different scales. Rather than creating many different crinkled sheets, they used just one type but rotated it so that the





Photos: Richard Barnes

CLOCKWISE FROM ABOVE
The pavilion facades are cast with titanium dioxide for added whiteness; the "crinkled" walls were cast against aluminium sheeting; the crinkled backdrop to the the 150-seat Justice Forum theatre; two of the pavilions are set around a reflecting pool

pattern of the repeat disappears. Visible joints are embraced as another wrinkle in the pattern, and a hint as to how it was made. In all, 50 reusable moulds were made and cast together in large sections of the walls, with the concrete pumped in from the bottom to reduce the risk of air bubbles.

Particular attention was paid to the interior corners, which were created using a strip of smooth concrete, and in the incorporation of electrical fittings. In the 150-seat Justice Forum theatre, the profile of the staircase was cut out of the mould so that the crinkled wall would accommodate the wooden staircase later.

Two types of finish were used. A white stain was applied in three layers in spaces where the architects wanted to bring in more light, while elsewhere the grey concrete is left raw with a matte sealant.

Ambrose says the crinkled concrete is the most expressive form of concrete the practice has done. "We knew what we were going to get because we did so many tests and mock-ups. But it's still amazing how it turned out … We may use it again, but I would be completely happy if its home was just at the Kennedy Center."

PROJECT TEAM
Design architect Steven Holl Architects
Associate architect BNIM
Structural engineer Silman
Concrete consultant Reg Hough Associates
Contractor Whiting-Turner

SECOND LIFE

Recent high-profile projects show the value of reusing existing concrete structures – and of designing reuse into new ones, writes Elaine Toogood

Photos: Alan Williams Photography

There is a growing awareness that our built environment could and should be valued as a resource for future development. This influences not only how we care for and refurbish existing structures but also how we design new buildings to facilitate adaptability and therefore longer lives.

A recent report by the Ellen MacArthur Foundation, Completing the Picture: How the Circular Economy Tackles Climate Change, identifies keeping products and materials in use as one of the three principles of circular thinking, making a clear link to a zero-carbon economy. For buildings and structures, this can be achieved through demountability and reuse elsewhere, or reuse of a structure in place – the latter being arguably a less energy-intensive activity. Both require some long-term thinking on the part of designers in the early decision stages.

Reuse of existing structures

Demountability for reassembly is largely reliant upon the junctions and jointing of the original structure being designed to facilitate disassembly, so that the forms retain their value without downcycling. It is also predicated on materials having durability beyond the life of the original building. This concept is most commonly associated with temporary buildings, but there is growing interest for more permanent structures. The precast concrete top tiers of the London 2012 Olympic stadium were designed to be fully demountable for reuse elsewhere though, for now, they remain in their original places. By contrast, there are many examples of existing concrete structures that have been appropriated or adapted for new uses, saving cost, carbon and materials in the process. Centrepoint (CQ 261) and Camden's town hall annexe (pages 4-7) were converted from offices to flats and a hotel respectively; while at Elizabeth II Court in Winchester (CQ 255) the thermal mass of previously covered concrete ceilings was key to a low-energy remodelling.

CONVERSIONS PROVIDE USEFUL LESSONS FOR EMBEDDING LONGEVITY IN THE BUILDINGS WE ARE DESIGNING TODAY

When planning to reuse an existing concrete frame, it is important to conduct a thorough survey, both to review the condition of the structure and also to understand the structural principles employed – such as which elements are integrated and loadbearing. Low floor-to-ceiling heights and close column layouts can pose challenges for spatial and servicing designs, requiring innovative solutions. The challenges of contemporary conversions provide useful lessons for embedding longevity in the buildings we are designing today.

Designing for a long life

Design for long life, loose fit and low energy is not a new concept – it is widely attributed to 1970s RIBA president Alex Gordon – but this mantra is even more relevant today, given the potential carbon savings associated with reusing existing structures. Flexible space planning, careful location of cores and generous floor-to-ceiling heights are all important considerations to allow for potential reuse with minimal adaptation. So too is the choice of structural frame. Long spans and regular arrangements are beneficial, as are design loads to suit a range of uses. At Glenn Howells' Selly Oak student housing development, for example, the precast-concrete floors provide a clear span between separating, structural walls, offering future flexibility of room layouts. A long-life loose-fit approach was also adopted by Lifschutz Davidson Sandilands for the Victory Plaza apartment towers (see overleaf).

Less well understood in the 1970s was the need to futureproof new developments against the effects of climate change, such as a greater risk of overheating, flooding and storm damage. The thermal mass of a concrete structure holds the potential for inbuilt passive cooling, for use now or in the future. With the transition to electric vehicles, there is a real and very appealing possibility that cities could become quieter and less polluted, allowing for greater use of natural ventilation and passively cooled buildings.

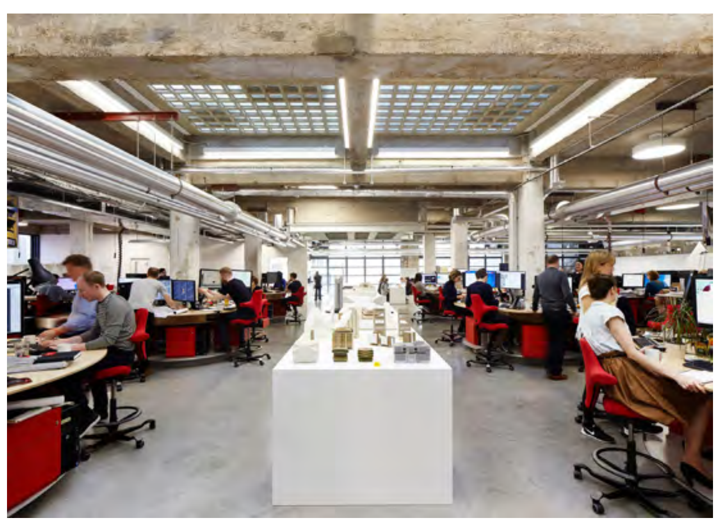
Another important factor is the durability and robustness of the structure itself. The predicted life of contemporary reinforced or prestressed concrete structural elements in an internal environment is 100 years, with no need to change the mix design and cover recommendations compared to the more typically requested 50 years (see British Standard BS 8500, Annex A, Table A.4 and A.5). Concrete is also fire and rot resistant, which means it needs little or no maintenance over a structure's lifespan.

In other exposure class situations, such as external parts of a frame, durability can be provided by increasing or changing the cementitious content and/or concrete cover to the reinforcing steel, or through the use of admixtures. Increased cover is a standard prerequisite for concrete design and workmanship, and is commonly provided using proprietary spacers. Covermeters can be used

LEFT David Attenborough Building, Cambridge. Nicholas Hare Architects has created a campus for sustainability research within the preserved structure of a brutalist icon by Arup Associates

ABOVE Grand Parc, Bordeaux by Lacaton & Vassal, Druot, Hutin. Three social housing blocks were transformed by adding a 3m-deep structural facade with winter gardens

RIGHT Make Architects' own high-spec office space in London was formerly a basement car park



Photos: Make; Philippe Ruault

to verify the cover achieved. In the event of any shortfall in cover, sealants are available for local application, reducing carbonation of the concrete and providing additional durability.

Health checks

Although concrete is typically very robust, occasions do arise where it needs some maintenance or repair. Techniques are well understood and can often extend the usable life of a structure by many decades. New techniques have been developed to monitor the health of our building stock, including use of drones, digital surveys and artificial intelligence. Retrospectively applied microamp circuits can detect problems with steel reinforcement early enough to limit further damage and enable targeted interventions.

In the future, adaptation, renovation and repair should be facilitated by more easily available data, the increased use of BIM and initiatives such as material passports and e-tagging of building elements. Certainly more value should be placed on communicating product information and service manuals. But fundamentally it is about valuing building structures themselves, making the most of them now and for the future.

LIFE AFTER LIFE: THE MANY USES OF RECYCLED CONCRETE

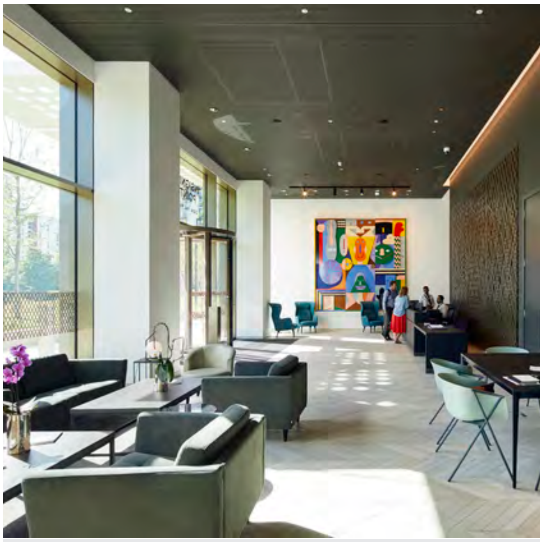
When a concrete structure finally reaches the end of its life, it provides a different resource for construction in the form of crushed concrete aggregate (CCA). Formerly known as recycled concrete aggregate, this material can be used in various ways in construction, including being recycled back into fresh concrete. British Standard BS 8500 permits CCA to comprise up to 20% of the coarse aggregate in most designated concrete, without declaration – in other words, unless the concrete is explicitly required to exclude it. According to the standard, it is possible to use higher percentages. In general concrete designated GEN 0 to GEN 3 – that is, non-reinforced concrete used for footings and floor slabs in domestic applications – up to 100% is allowable. Exposure class may be a limiting factor – in other applications, CCA is permitted provided it can be demonstrated to be suitable for the exposure class conditions. In practical terms, this would mean testing to meet quality protocols.

If concrete is not separated from other recycled construction materials, such as brickwork, the result is a more general recycled aggregate (RA). This has more limited uses within concrete itself, typically limited to mass concrete, but it plays a useful function in new construction by reducing the use of primary resources for hardcore, fill or landscaping and brown roofs.

Crushing concrete for reuse as aggregate substantially increases its surface area, allowing carbon dioxide to be more readily absorbed – a process called carbonation. Exposure to rain has been shown to significantly increase the rate of carbonation during this stage. Carbonation occurs during demolition and while the aggregate is stored on site, but continues during the concrete's secondary life if used in groundworks, hardcore and landscaping. The amount of CO_2 absorbed can be significant, reducing the initial cradle-to-gate embodied carbon of concrete by around a third.

ABOVE At Foster + Partners' Bloomberg London, winner of 2018's Stirling Prize and one of the world's highest-scoring BREEAM rated office buildings, the concrete in the piles contained 100% recycled granite aggregate. This is classified as a secondary aggregate and is a by-product of the china clay industry in Devon and Cornwall

Photo: Bloomberg

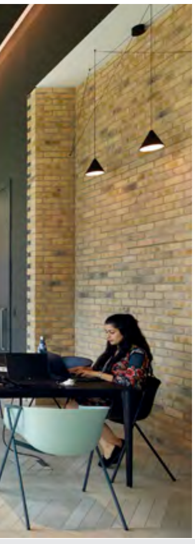


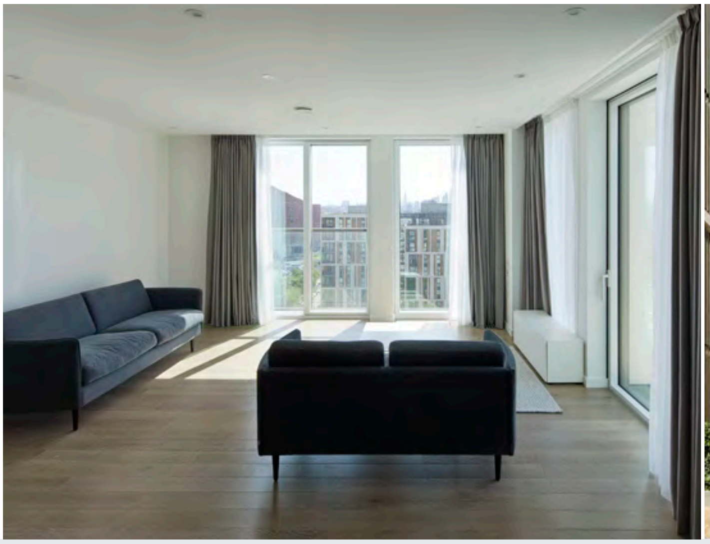
▲ Victory Plaza, London, 2019

The Olympic Park is a good place to go in search of lessons on the reuse of buildings. After all, its original purpose as a grand stage of sporting spectacle lasted little more than a few weeks. Lifschutz Davidson Sandilands was well placed to absorb, and indeed guide, best practice on the 2012 programme, working on everything from athletes' housing to drug-testing facilities before playing a major role in transforming the development into a long-term community. "The village was a good example of loose-fit architecture," says LDS director Alex Lifschutz. "The living spaces were wide enough to be used as two bedrooms in Games mode, then swapped into a living room with a kitchen post-Games."

LDS has now completed the first new homes on the East Village site since the Games and, appropriately, the two towers at Victory Plaza are also paragons of loose-fit, long-life design, where space is maximised so it can be adapted to future uses. This was partly driven by the fact that the towers – of 30 and 26 storeys respectively – were being built for an untested market. When Qatari Diar and Delancey Estates took over the Olympic Village in 2011, they planned to develop more than 2,000 homes for the private rental sector (PRS). "That was the novelty," says Lifschutz. "It wasn't just that things might change in the future. It was that nobody knew, for this scale of PRS, what the market was now. To give an example of how it foxed everybody, in the athletes' village we built duplexes around the perimeters of the blocks, and the assumption was that these would be let to families after the Games. But they weren't – I think well over 70% were let to sharers."

It therefore seemed all the more essential to build flexibility into the new towers at Victory Plaza. "At the design stage, the mix of flat sizes was constantly changing," says LDS director





Photos: Paul Riddle

Douglas Inglis. Their response was to open up the floorplan as much as possible. Working with a building footprint of 26m², LDS proposed a 7.5m-deep central core, built with twinwall structural panels. This would include four lifts and a stair, a corridor on two sides and a further core wall to provide stability. The floorplates would then span 7.5m on Omnia slabs to precast-concrete perimeter columns, which measured 600mm x 600mm on the lower floors, before narrowing further up. There were no structural party walls or blade columns, and all of the services risers hugged the core wall, which meant that any floor could house a moving number of flats – or theoretically be a single room.

It was still necessary to future-proof the design by making as much space on each floor as possible. "The first rule of loose fit is make it more generous volumetrically than it absolutely needs to be," says Lifschutz. "Any use other than a very low-density living space requires more air." With floor-to-floor heights of 3.3m, LDS was able to agree relatively high 2.6m ceilings with the PRS operator, Get Living. More innovatively, it managed to negotiate extra living space with Tower Hamlets council by designing out the balconies that would typically feature on an apartment tower of this type. "There's a huge westerly prevailing wind – it's very low-lying and there's basically nothing between the City and this part of the East Village," points out Inglis. "So instead of balconies, we put 2.6m-high sliding windows in every living room, and the corner flats had them on both sides. It means you can open up the space without feeling like you'll be blown away." On a 70m² two-bed flat this approach added another 7m², but the deal with the council was that this had to all be in the living space – they couldn't simply add an extra bedroom. "They were quite far-sighted," says Lifschutz. "They said, 'we get the point, as long as it's creating better living space'. And what's happened since is that many of the two-bed flats are shared – again something we would not have assumed – and that extra living space has become really important."

While Get Living has no grand ambitions to transform the use of its new towers any time soon, Lifschutz reckons its innovative "jump factory" method of precast manufacture and site assembly (see CQ 269) has also helped to make it more adaptable. 'If you wanted a co-working floor, you could do that," he says, pointing out that if the suspended ceilings were removed, an occupier could have a floor-to-ceiling height of 2.75m, which is 150mm better than the BCO standard. "The Omnia deck soffits are perfect, the precast columns are perfect. If you cleared it out and created a shell it would look pretty cool."

■ **Nick Jones**

ABOVE LEFT Communal spaces are an important part of the PRS offering

ABOVE CENTRE Corner flats have 2.6m-high sliding doors on two sides, which were felt to be more appropriate than balconies in such an exposed location

ABOVE RIGHT The striking facade of the towers – instead of balconies, substantially more living space was provided

BELOW Floor plans showing how the structural solution created 7.5m-deep spans between the core and perimeter, with no structural party walls. This means that the space is completely adaptable, and can be used for up to eight apartments, depending on what the PRS market demands.

FORM FOLLOWS FORMWORK

It may be temporary but formwork is at the heart of all concrete projects. Designers need to know how to get the best out of it, writes Jenny Burridge

Designers tend not to think about formwork. By its nature, it is "temporary works" and the permanent-works designers leave it to the contractor to sort out. It is, however, very useful for the permanent-works designers to have an appreciation of what is available, and to understand how their decisions affect the formwork and its design.

This article covers standard systems for falsework and the options available for formwork. Formwork is the part of the system against which the concrete is cast. Normally it is made of ply, steel or GRP, but other materials can be used. Falsework is the temporary scaffolding that holds the formwork in place. We normally call the system as a whole "formwork". Most falsework is prefabricated and modular, and normally hired from the formwork suppliers.

Together the formwork and falsework represent approximately half the cost of an in-situ concrete frame. This makes it more important, in terms of cost and programme, than either the type of concrete used or the quantity of reinforcement. For a reinforced-concrete bridge, formwork can represent up to 90% of the cost. Therefore, to achieve an economic solution for a concrete frame, the designers should think about the formwork required, and make it as simple and straightforward as possible.

All formwork should be designed to take the pressures from the wet concrete, no matter which type of finish is required. For basic and ordinary

ABOVE AND LEFT The formwork for Kengo Kuma's V&A Dundee comprised 1,200 unique CNC-cut shutters, created by Peri from plywood-faced timber with a controlled-permeability liner. These were supported on a vast system of steel falsework

finishes (see National Structural Concrete Specification v4) no further requirements need to be considered. For plain and special finishes, "good quality" formwork is specified and the arrangement of the panels and tie bolts should be in a regular pattern. The maximum step in the concrete between formwork panels is 3mm.

Design of the formwork system

The design for the formwork is normally done by the specialist temporary-works designer to British Standard BS 5975, "Code of practice for temporary works procedures and the permissible stress design of falsework". The formwork needs to take the full weight of the wet concrete before the concrete sets. Typically this is taken as 26kN/m^3.

Normally, walls are formed with two-sided formwork so that the pressure from the concrete can be taken by ties through the concrete wall. The pressures on the wall formwork are typically 60-80kN/m^2 and can easily exceed 100kN/m^2. If self-compacting concrete is used, the pressures tend to increase as the wet concrete is designed to flow, rather than just slump. The ties through the concrete wall can typically take 95kN at working loads so spacing of the ties is critical and usually set out by the formwork designer, or fixed in the type of formwork system employed. Ties should not be spaced too far apart or too far from the end of the formwork, or it will deflect too much under the weight of the wet concrete. For plain or special concrete finishes, the location of the ties in relation to the formwork panels should be considered, as it is always visible. Tie-bolt holes are frequently filled, but the outline is always evident.

Where the wall is one-sided – ie cast against another wall, such as a lining wall cast against a contiguous piled wall – then the pressures have to be taken by significantly more extensive falsework, typically in the form of A-frames. These need to be anchored into the permanent structure or into the ground to prevent movement.

FORMWORK INFLUENCES COST AND PROGRAMME MORE THAN THE CONCRETE OR REINFORCEMENT

Systems

Innovation in formwork has had a huge impact on the speed of construction of concrete-framed buildings and structures. Modern formwork systems have continued to evolve to improve health and safety on site as well as cost and programme benefits. The elements in the falsework used for the systems are reused many times in order to keep environmental impact to a minimum.

Table formwork is a large pre-assembled formwork and falsework unit, often forming a complete bay of suspended floor slab. It offers mobility and quick installation for construction projects with regular plan layouts or long, repetitive structures, so is highly suitable for flat slabs. In tableform systems, a series of individual falsework components, including primary beams and props, are connected to form a complete table, with plan area of up to about 100m^2. The formwork can be mounted on castor wheels or trolley units, allowing it to be moved horizontally. It relies on there being sufficient room for the tableform to swing out after the concrete has been struck, to be replaced on the slab above. The area below the tableform must be kept free of personnel during the lift, and these health and safety implications need to be taken into consideration when using tableforms.

Horizontal panel systems are now more common than tableform systems. These lightweight modular systems are engineered to be robust, easy to handle and capable of dealing with both regular and irregular formwork areas, with the number of different components minimised for quick installation. The system comprises props and panels, with the heaviest component capable of being handled by two operatives. This frees up the crane for other uses.

The column formwork systems now available are normally modular in nature and allow quick assembly and erection on-site while minimising labour and crane time. They are available in steel, aluminium and even cardboard (not reusable, but recycled) with a variety of internal face surfaces depending on the concrete finish required. Innovations have led to adjustable, reusable column forms that can be clamped on-site to give different column sizes.

Crane-lifted wall panel systems are commonly used on building sites to form vertical elements and usually consist of a steel frame with plywood, steel, plastic or composite facing material. The systems are normally modular in nature, and assembly times and labour costs are considerably lower than traditional formwork methods with far fewer components required. Panel systems are

Photos: Hunnebeck, Peri

ABOVE Hunnebeck's TOPEC modular slab formwork in use at Helical Bar's Fulham Wharf development in London extremely flexible and can be used for constructing standard concrete walls, perimeter basement walls and columns, and in conjunction with jumpform climbing systems.

Just as concrete can be moulded into any conceivable shape, formwork can also be provided in any shape. The one proviso is that the form has to be able to be demoulded. Intricate shapes can be made, but re-entrant corners and other difficult to demould shapes should be avoided. Formwork suppliers can supply 3D forms for non-standard cases to site which can then be bolted together. There are often a range of ways in which a particular shape can be created, depending on the balance of requirements for reusability, cost and finish. For formwork options for casting ribbed slabs, see CQ 268.

Formwork finishes

Where visual concrete is specified, the type of formwork facing material is critical to the appearance of the concrete. Generally, the less absorbent the formwork face, the shinier the finished surface of the concrete. So steel formwork will tend to give a shiny surface and MDO (medium density overlay) ply will give a matt finish. Table 1 summarises the finishes available from the different types of formwork. This is not an exhaustive list and other options are available.

Formwork linings, often using the materials mentioned, can also be used together with a proprietary falsework system to provide the desired surface finish. The choice of formwork depends on the finish required and the number of times the formwork can be reused. Steel formwork can be reused thousands of times if maintained and cleaned properly, but costs significantly more than the ply formworks available. Contractors will tend to choose formwork based on the required finish, programme, repeatability and cost to come up with the most appropriate and cost-effective solution.

Future formwork

Formwork design continues to evolve and to be an area of innovation, with suppliers starting to use 3D visualisation to check it on site and to ensure coordination between the formwork and any inserts or cast-in brackets, in collaboration with the BIM model.

One recent development has been Mace's jump factory (CQ 269), which allows hybrid – that is, precast combined with in-situ – concrete work to be carried out under factory conditions inside a movable enclosure. This is lifted up with the building as it progresses, and can allow the contractor to achieve speeds of one storey every 55 hours, which includes the installation of prefabricated pods.

Formwork is an important part of the design and construction of concrete, too frequently overlooked. But it is well worth developing an appreciation of the ways in which formwork can add to the design concept, and suppliers are very willing to explain the possibilities and provide advice to help designers get the best out of concrete.

ABOVE The in-situ slab at PAD Studio's Canoe Lake tennis pavilion in Portsmouth was poured in one go using phenolic-faced ply formwork

TABLE 1: TYPES OF FORMWORK FINISH

Formwork finish	Description
Softwood plywood	Plywood consists of a number of plies of timber laid orthogonally to the adjacent plies and glued together. WBP grade should be used for concrete work. Softwoods are not ideal because tannins can be released, staining the concrete, and they have a limited number of uses before the surface becomes unsuitable.
Natural birch plywood	Birch is a hardwood and ideal for forming visual concrete surfaces. Birch can be used throughout the plywood or as veneer to a softwood plywood. A high-quality face finish should be chosen for visual concrete. Waterproofing is required and an acrylic lacquer is recommended.
Phenolic film faced (PFF) plywood	Plywood can be faced with a phenolic film to maximise the number of reuses, hide the wood grain and defects, and prevent timber staining the concrete. Phenolin is a fully cured and impervious resin hot-pressed onto the face of the plywood to give a dark brown, waterproof finish. A shiny smooth concrete finish is obtained.
Medium density overlay (MDO)	An overlay of paper saturated in resin is used with plywood to minimise tannins released from the timber. MDO is less prone to temporary surface ripple than PFF. MDOs generally give a satin finish to the concrete, although some products do offer a matt finish.
High density overlay (HDO)	This has a higher resin content than MDO and thus gives a better surface finish, at a cost. Tannin migration is prevented, which makes it more suitable for situations in which the ply is in contact with the concrete for longer periods, for example slabs rather than walls. HDOs give a shiny finish to the concrete.
PFF orientated strand board (OSB)	An alternative to PFF plywood. OSB is an engineered timber product made from strips or strands of timber. It is orientated orthogonally and bonded with a resin.
Steel	Steel can be used to give a high-quality finish and is most cost-effective through multiple reuses. It is currently used for column shutters and tunnel-form construction. The face of the steel must be treated with care, as any marks and imperfections will be imprinted on the concrete surface. Sand-blasting must not be used to clean the shutter, as it will pit the surface.
Cardboard (EPS and plastic lined)	Impermeable cardboard is often used for circular column formwork. It can be used for visual concrete but tends to be difficult to strike and is disposed of after each use. However, the cardboard former can be used as temporary protection to the column.
Polypropylene, plastic composite	Alternative materials have been developed, avoiding the problems of swelling, staining and water damage associated with timber-based systems. Manufacturers claim long life and a high-quality finish can be achieved with the right workmanship. The provision of "seamless" formwork may be possible in some instances.

Note: This table is for guidance only. Further information can be provided by formwork suppliers.

Photo: Richard Chivers

LASTING IMPRESSION FERGUS FEILDEN

A CASTLE ON A HILL, A POOL ON THE ROCKS

I often try to visit buildings by foot or bicycle so I can understand the context. When I was at university I cycled up to Montjuïc in Barcelona to see the Joan Miró Foundation 1 by Josep Lluís Sert (1975). It made an immediate impression on me. It has this very heroic presence on the hill, with these clear Corbusian influences and primary geometries. From certain viewpoints, it is almost fortress-like. Yet it is an incredibly welcoming and humane place to visit. Single and double-height volumes intersperse with terraces, so you flow from inside to outside. It has an almost domestic quality – there's something about the balance of the concrete, terracotta tiles, timber furniture, and the artworks as well, that all feels extremely harmonious.

This was the second collaboration between Sert and Miró, following the artist's studio 2 in Palma, Mallorca (1956). You see a number of the same themes here: again, it has these heroic, primary forms, but when you're up close the concrete is very delicately boardmarked and handcrafted, and you suddenly relate to the building in a much more intimate way, understanding the endeavour that's gone into it. The expressive rooflights, which are subtly arced and almost scoop light into the gallery spaces, were a big influence when we were doing the Weston Visitor Centre (2018). With both of the Miró buildings, concrete brings a sense of personality but stays in the background so the artwork has its own presence.

Alvaro Siza's Leça swimming pool complex 3 (1966) is another building I cycled to, north from Porto along the progressively wild Atlantic coast. It could easily have felt like a brutal response to the coastline, but it's such a subtle project. Tonally the materials chime so strongly with the rock formations. I don't know how much was intentional, but the way that the concrete, copper and timber have all weathered, they don't try to compete – they are just in conversation with a stunning landscape.

Fergus Feilden is a director at Feilden Fowles Architects

Photos: 1. Nathaniel Noir 2. Naeblys 3. LusoArchitecture, all Alamy Stock Photo

FROM THE ARCHIVE: AUTUMN 1963

"A SHAFT OF WATER FROM A BAROQUE FOUNTAIN"

"New Zealand House, in the heart of London, will surely rank as one of the best British buildings of the 1960s," declared CQ in 1963. The 19-storey tower, designed by Robert Matthew, Johnson-Marshall & Partners, was the first tall building to be approved in central London, and CQ was in no doubt that this blast of modernity was precisely what its historic, not to say stuffy, setting needed. "Sited on the corner of Haymarket and Pall Mall, it is surrounded by buildings with stone ornament – the balustrades, pediments and porticos of clubs, banks and theatres. Above this elaborate display, the glass tower of New Zealand House rises as clearly as a shaft of water from a baroque fountain."

Fast-forward more than half a century, and RMJM's shaft of water appears poised for a sparkling future. Lifschutz Davidson Sandilands has lodged plans with Westminster council to comprehensively upgrade the tower, including replacing the glazing and reconfiguring the embassy space and office interiors. CQ's correspondent would be particularly pleased that the proposals include the refurbishment of the of the adjoining grade I-listed Royal Opera Arcade: "One view in particular lingers," he wrote. "A sudden glimpse down into the Royal Opera Arcade with its vaulted and old street lamps, framed in one large sheet of glass."

FINAL FRAME: APPLE AVENTURA STORE, MIAMI

Apple is a company usually associated with sleek lightweight minimalism, but for its new Foster + Partners-designed Miami store it has embraced the city's white art deco heritage – and concrete. The wavy, barrel-vaulted roof is formed of seven 6m-wide precast-concrete arches, supported on concrete beams that span 18.2m across the width of the interior. "We love the honesty and purity of the concrete," says Stefan Behling, Foster's head of studio, adding that it is the first Apple store to feature white precast concrete as the predominant structural system.

Photo: Nigel Young / Foster + Partners