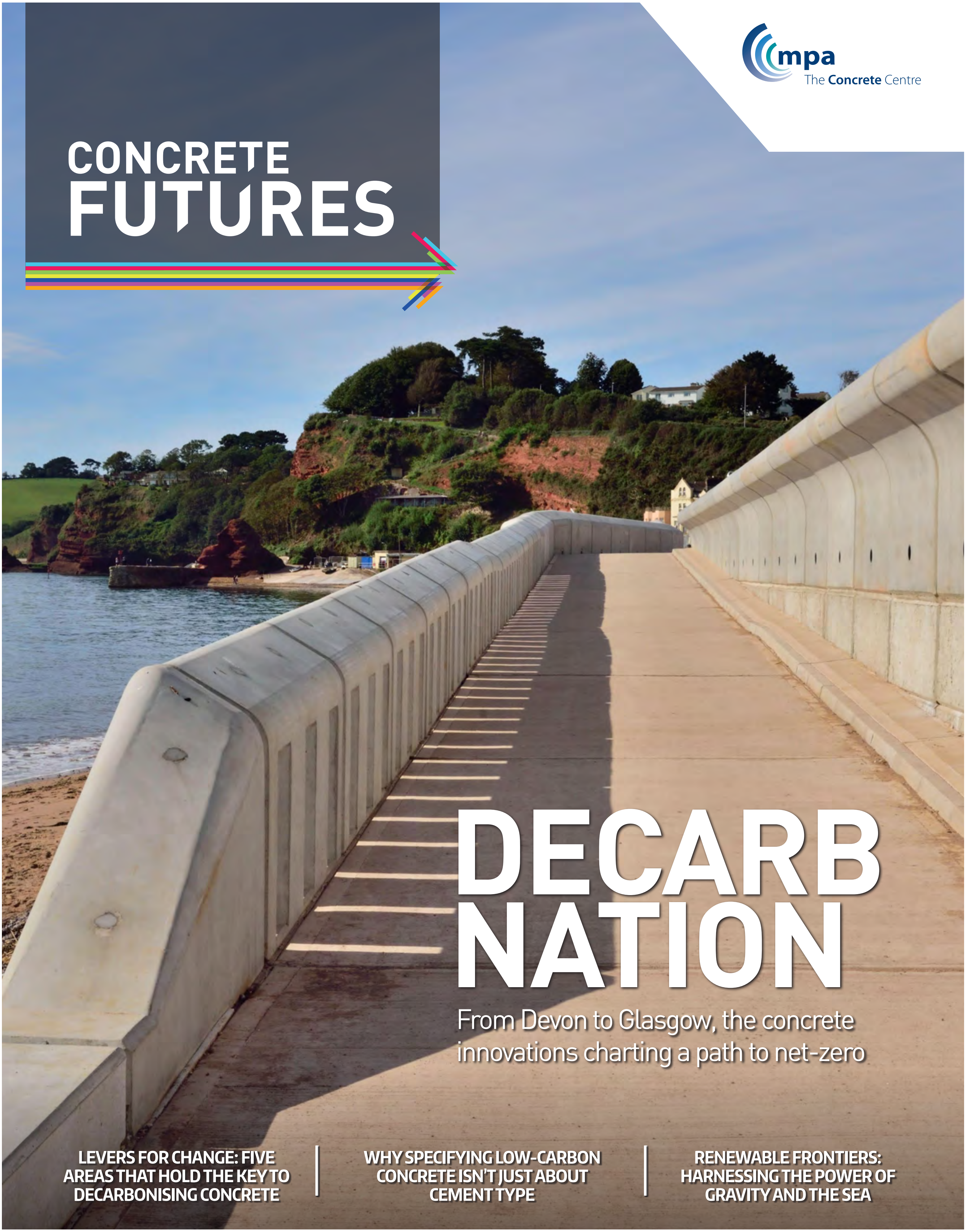
The Concrete Centre

CONCRETE FUTURES



DECARB NATION

From Devon to Glasgow, the concrete innovations charting a path to net-zero

LEVERS FOR CHANGE: FIVE AREAS THAT HOLD THE KEY TO DECARBONISING CONCRETE

WHY SPECIFYING LOW-CARBON CONCRETE ISN'T JUST ABOUT CEMENT TYPE

RENEWABLE FRONTIERS: HARNESSING THE POWER OF GRAVITY AND THE SEA

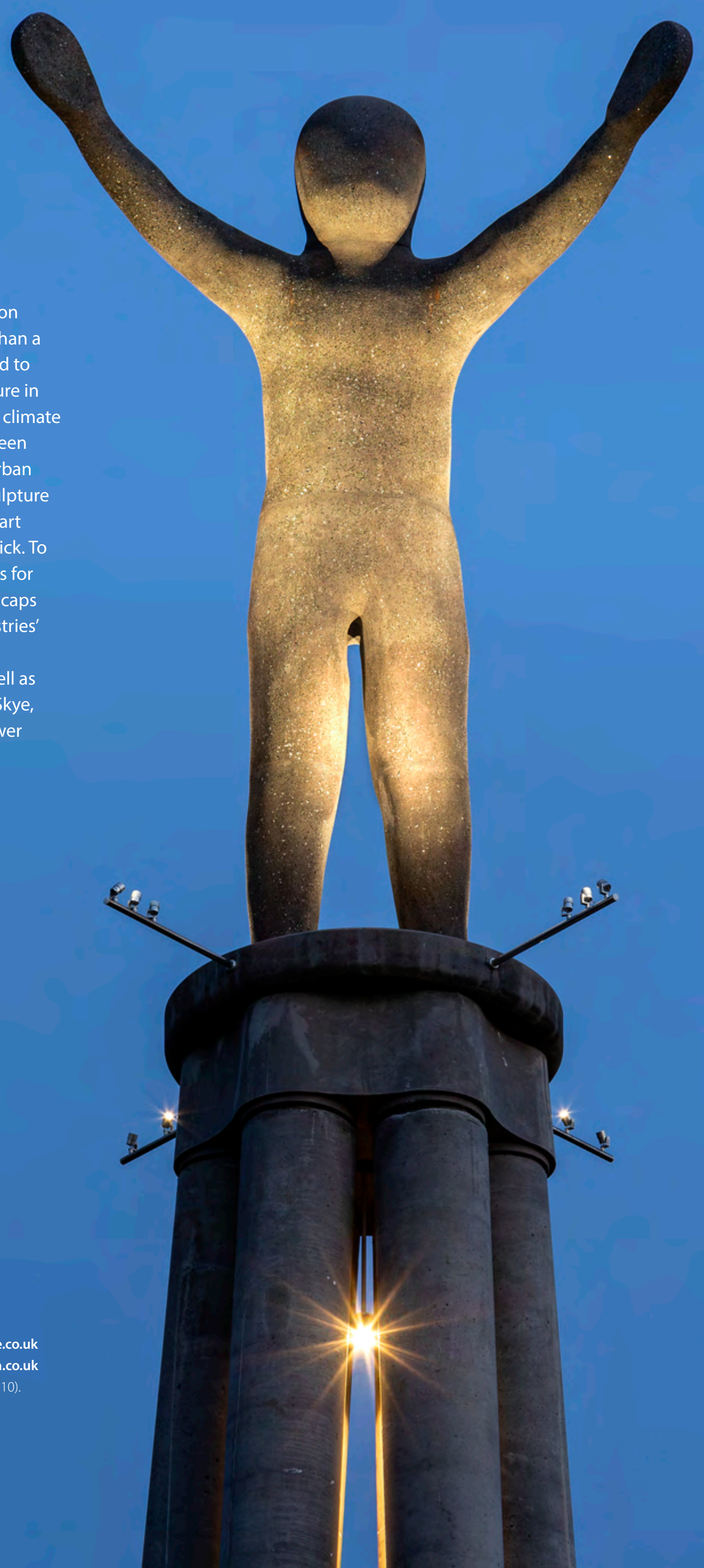


Photo: Keith Hunter Photography

High hopes

A low-carbon concrete, with carbon emissions more than 70% lower than a standard CEM I mix, has been used to create a dramatic 23m-tall sculpture in Glasgow, to tie in with the COP26 climate conference. A collaboration between Aggregate Industries, Ramboll, Urban Union and Keltbray, the Hope Sculpture is the centrepiece of three public art installations by artist Stuart Padwick. To meet the sustainability credentials for the project, the columns and pile caps were made from Aggregate Industries' ECOPact Max+. This bespoke mix included 20% recycled glass as well as a light-coloured aggregate from Skye, which were exposed through power washing to create a rustic finish.

Edited and produced by Wordmule **wordmule.co.uk**
Design by Nick Watts Design **nickwattsdesign.co.uk**
Cover: Dawlish sea defences, Devon (see page 10).
Photo by Chris Cole / Alamy Stock Photo

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The Concrete Centre provides design guidance, seminars, courses, online resources and industry research to the design community. Our aim is to enable all those involved in the design, use and performance of concrete to realise the potential of the material.

The Concrete Centre is supported by industry to inform, educate and inspire. Our members are: Aggregate Industries/Kendall, Allen Newport, Bathgate Silica Sand, Blue Phoenix, Breedon, Brett Group, Cemex, Colas, CPI Mortar, Day Group, Deme Building Materials, Eurovia Roadstone, F M Conway, Ferns Group, Gallagher Group, Glendinning, GRS Roadstone, Grundon Sand and Gravel, Hanson, Harleyford Aggregates, Harsco Metals Group, Hills Quarry Products, Hogan Group (Gwyndy Quarries), Ingrebourne Valley, J and J Franks Ltd, J Clubb Ltd, J Wainwright and Co Ltd, Johnston Quarry Group, JPE Holdings Ltd, Lhoist Western Europe, Lightwater Quarries, LKAB Minerals, Lochaline Quartz Sand, Mansfield Sand Group Ltd, Marshalls, Moorhouse Sand Pit, Moreton C Cullimore (Gravels) Ltd, Morris and Perry Ltd, Mortar and Screed, MPA Masonry, MPA Precast, Myers Group, NMSB (HH and DE Drew), Quattro UK, R Collard, Raymond Brown Quarry Products Ltd, Remix Dry Mortar Ltd, Rotherham Sand and Gravel Co Ltd, Salop Sand and Gravel Supply Co Ltd, Sea Aggregates Ltd, Sibelco, SigmaRoc Plc, Singleton Birch, Smith and Sons (Bletchington) Ltd, Springfield Farm Ltd, SRC Aggregates, Suttles, Tarmac, Tudor Griffiths Group, Volker Dredging.

The Concrete Centre is part of the Mineral Products Association, the trade association for the aggregates, asphalt, cement, concrete, dimension stone, lime, mortar and silica sand industries.
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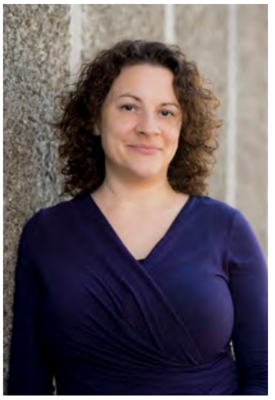
WELCOME



In the UK government's commitment to reaching net-zero emissions by the middle of this century, we have one overarching, unifying and undeniably ambitious target on our collective horizon. But it is our actions up to 2030 that will be crucial to whether or not we can meet our obligations in 2050: this is our decade to deliver.

The next few years will be a defining period of change for how building materials are produced and how they are procured and assembled. It will be during this decade that we start effecting the transition to a net-zero built environment, or put in place the foundations that will allow us to make critical changes later on. Achieving net-zero concrete is possible, but there's no magic solution – we will get there through a lot of small marginal gains, analysis and hard work.

Fortunately, there is widespread agreement on the technologies and product innovations that will be most important, the advances that are needed, and the ways that behaviour needs to change. The UK cement and concrete industry has produced a Roadmap to Beyond Net Zero, which identifies the levers by which we can fully decarbonise the world's most used building material (see page 4). The European and global industries have produced their own roadmaps and while there may be subtle differences in the percentage reduction attributed to each, it's notable that the levers themselves are exactly the same.

For these roadmaps to come to fruition, everyone in the industry, the wider supply chain and the client base has a part to play. This kind of cross-sector engagement is exactly why The Concrete Centre was established – to provide a link between many different stakeholders and a place to problem-solve and share information. We're excited about the journey ahead because, with all of our sights on net-zero, it's never been more important to collaborate.

Claire Ackerman, director, The Concrete Centre

IT IS OUR ACTIONS UP TO 2030 THAT WILL BE CRUCIAL TO WHETHER OR NOT WE CAN MEET OUR OBLIGATIONS IN 2050: THIS IS OUR DECADE TO DELIVER

LEVERS FOR CHANGE

The concrete industry has identified five areas of technology that hold the key to decarbonising by 2050. Tony Whitehead reports

Concrete is a vital and versatile component of the buildings and infrastructure that support our way of life. No other substance on Earth, with the exception of clean water, is made so widely or in such quantities. Yet it comes with a cost: in 2018 the cement and concrete industry in the UK produced 7.5 million tonnes of carbon dioxide or 1.5% of total UK emissions. Early and sustained action on CO_2 means that this is already 53% less than in 1990, but more needs to be done if the industry is to get to net-zero by 2050.

To address this, the industry has identified levers for change – the areas where improved efficiency, new technology, or just a completely different way of doing things, can eliminate the remaining carbon emissions – so that by 2050 all cement and concrete will be carbon-neutral, or even carbon-negative. Clean energy, decarbonised transport and low-carbon mixes, together with carbon capture and the utilisation of CO_2 within concrete products themselves or storage of the CO_2, can deliver zero-carbon concrete.

But it's a journey, says Elaine Toogood, head of architecture at The Concrete Centre. "There

Left and bottom right: The 13MW solar installation at Hanson's cement works in Ketton, Rutland. The 20ha ground-mount installation, jointly developed by Lark Energy and Armstrong Energy, includes 38,544 panels and provides around 13% of the plant's electricity requirements

are things we can do now, like using more low-carbon cements and concretes, that will make a difference, and we must look to every part of our industry to see where further immediate savings can be made. But advances in technology mean that the situation is evolving fast. For example, as the production of cement decarbonises through fuel efficiencies and carbon capture, the equation will change. What we do today to reduce emissions might not be what we are doing in 10 or 20 years' time."

Andy Spencer, Cemex EMEA's vice president in charge of sustainability, makes a similar point. "So far, much of our CO_2 savings have resulted from using less fossil fuel in our kilns, and using lower-carbon constituent materials," he says. "More recently, we have made rapid progress on new decarbonated raw materials for cement kilns that reduce process CO_2 emissions, along with groundbreaking waste-heat-recovery systems. While these technologies will be vital over the next few years, we cannot wait until 2030 to develop the innovation that will take us to neutrality."

For example, Cemex is involved in a number of carbon capture, utilisation and storage projects and is producing its own hydrogen in all kilns in Europe which it uses to improve efficiency and reduce CO_2. It's also one of several concrete producers that are investing in renewable energy generation, and working with governments and partners on a framework for a carbon capture infrastructure.

With the pace of change accelerating on all fronts, along with rapidly increasing stakeholder expectations, the concrete industry knows it cannot afford to be left behind, Spencer says. "We have to change to survive. Failure is not an option. But I am absolutely confident we can thrive in a green and circular economy."

Below, we explore five levers for change in more detail.

1 Energy

Operating at temperatures above 1,450°C, cement kilns account for the majority of the concrete industry's energy consumption. So as the sector looks to decarbonise, they are the subject of intense research: how can emissions be reduced?

"We have already succeeded in replacing around half of the fossil fuels that have been traditionally burnt in kilns," says Diana Casey, director of energy and climate change at the Mineral Products Association (MPA). "In fact, the UK now uses 11 alternative fuels, including waste biomass fuels such as meat and bone meal and sewage sludge pellets, refuse-derived fuel, paper and wood – even tyres." Because many of these fuels derive from organic sources, they are effectively carbon-neutral: "And their use has other benefits too – such as decreasing waste to landfill and reducing the amount of virgin raw materials required for cement production as the mineral content of the fuel is recycled into the cement."

But the search is now on to find ways of reducing fossil-fuel use even further. "Hydrogen is not yet available in sufficient quantities to completely replace the coal and pet-coke we still have to use," says Casey. "But it is being used in small quantities to help increase the proportion and efficiency of alternative fuels."

The industry is also striving to decarbonise energy consumption in other areas: "The UK cement industry uses some 1,000GWh annually. Quarrying, crushing, conveyor belts, the turning of cement kilns and the grinding of clinker all consume mainly electric power. That's why nearly all of the UK industry's power is now purchased from renewable sources."

As the UK grid decarbonises further, the carbon emissions associated with consumption of electricity will naturally fall. "But rather than just wait for that to happen," she says, "the concrete industry is starting to arrange its own green power, with solar farms and wind turbines at some quarries, cement and concrete plants across the country."

2 Transport

Moves to decarbonise the delivery of concrete and its constituent materials are now gathering pace, and companies are adopting a number of strategies to reduce their transport emissions.

As the carbon factor of the UK grid declines, switching to electric vehicles is an opportunity to reduce the CO_2 associated with petrol and diesel. "With cars, we're offering hybrid or pure electric options to our staff where appropriate," says Spencer. "But the bigger challenge comes from heavy deliveries. We have trialled a fully electric prototype truck mixer very successfully in some European markets. For the more challenging longer routes, such as aggregates and cement, we are trialling biofuels including biomethane and switching to lower-carbon transport such as rail and water.

Photos: Hanson

CASE STUDY: ENERGY

A world first at Ribblesdale

A breakthrough trial at a cement kiln in Lancashire has demonstrated for the first time that hydrogen can be used as a substantial part of a net-zero fuel mix. The gas was used at Hanson's Ribblesdale plant to supplement other carbon-neutral fuels including ground meat and bone meal (MBM), and glycerine – a world first for the industry.

Clinker used in cement manufacture is produced by heating limestone and other ingredients to around 1,450°C in rotating kilns – a temperature which has proved difficult to achieve without the use of fossil fuels such as coal or natural gas. However, the Ribblesdale plant ran for three hours on the innovative mix.

The plant would normally use a combination of powdered coal mixed with air, together with Cemfuel, a combustible liquid manufactured from waste products from the chemical processing industry, such as solvents. "Each would normally contribute some 50% to the heat of the flame," explains Iain Walpole, environmental sustainability manager at Hanson. "But for this trial we replaced the coal with hydrogen and MBM, a dry waste product from the meat processing industry. The Cemfuel was replaced with glycerine, a by-product of the bio-diesel industry."

The MBM contributed some 13% to the kiln energy requirements, and the glycerine a further 48%. "We then used the specially designed burner nozzle to supply the hydrogen, which provided the remaining 39% of the heat. Without the hydrogen, the flame would not have been hot enough to produce a high-quality clinker."

Since around 30% of cement's carbon footprint results from the fuel needed to heat cement kilns, a net-zero fuel mix has enormous potential to cut emissions. Hanson has calculated that, if fully implemented for the whole kiln system, it could save nearly 180,000 tonnes of CO_2 annually at its Ribblesdale plant alone.

"The beauty of the mix was that the MBM and the glycerine could use our existing delivery systems with very little adaptation," says Walpole. "Because of this, it was relatively simple and inexpensive to adapt the kiln. Procuring the hydrogen was actually more challenging. We are still analysing the trial, but early results suggest clinker quality was as good as ever."

They learned a lot about process safety beyond that normally implemented in the cement industry, he adds, especially how to handle the hydrogen gas. "For the trial, this was supplied by special high-pressure road tankers parked at the plant, but if we were to use hydrogen at this scale in the long term, we would need to arrange a permanent and substantial supply. Ideally, this would be green hydrogen produced via electrolysis from renewable energy."

The trial was made possible by Department for Business, Energy and Industrial Strategy funding provided through the Mineral Products Association (MPA).

Longer term, hydrogen offers potential, and vehicle suppliers are also moving fast to develop more CO_2-efficient technologies."

"When it comes to decarbonising transport, we are partly reliant on vehicle manufacturers," says Casey. "But there are other things we can and are doing – like delivering locally where possible and diverting road freight to rail."

Just how effective this can be was demonstrated when, in 2016, Tarmac reopened a rail facility at its Aberthaw Cement Plant in South Wales.

3

Decarbonising specification

Using less Portland cement (also known as CEM I) is currently one of the most effective ways to lower the carbon footprint of concrete. Reducing cement content by 50% typically results in a reduction of some 40% in its embodied carbon. Alternative cementitious materials, particularly ground granulated blast-furnace slag (GGBS) and fly ash have been used for decades, routinely representing 30-50% of the mix.

"For specifiers, these are a great way to start lowering the embodied carbon of their buildings and structures," says Toogood. "But new options and formulations are now becoming available which can also help reduce carbon, and eventually eliminate it altogether."

Above left: The hydrogen rig at the Ribblesdale demonstration project. Hydrogen provided 39% of the kiln's heat

Left: Hanson's Iain Walpole says that early results from the trial suggest that clinker quality was unaffected by the change of fuel to a hydrogen-based net-zero mix

CASE STUDY: TRANSPORT

Tarmac's electric vehicles

Tarmac has committed to upgrading its 2,000-strong fleet of corporate cars and vans to electric vehicles (EVs) by 2030 – a move supporting the company's ambition to be net-zero by 2050.

As a major supplier of construction materials, most people would associate the firm with larger vehicles like lorries, mixer trucks and shovels, says Lee Green, Tarmac's head of category management, who heads up the initiative. "But lowering the carbon footprint of our products involves tackling emissions wherever they occur in our business – and our substantial fleet of cars and vans is a very practical place to start."

Electric options for heavy payloads and long-range deliveries are currently limited, but thanks to rapid developments in the domestic car market, Tarmac is making effective changes straight away. "Accelerating our EV roll-out is an important element of what we're doing to achieve net-zero by 2050 and also reflects the commitments we've made in our 2030 sustainability strategy."

Tarmac has begun installing charging points at key office and industrial locations, including its headquarters in Solihull and its flagship Mountsorrel quarry in Leicestershire. Vehicles charged at these locations will have near-zero emissions thanks to a company-wide policy that allows all of its UK sites to use electricity supplied entirely from renewable sources. "The range and efficiency of EVs is improving rapidly, and we have better technology available than just a few years ago," Green says. "We now have good options to replace cars and smaller vans, with larger vans next on our list, as and when the technology is right."

Eventually Tarmac wants all its vehicles to make the switch away from fossil fuel, he adds. "We will trial our first all-electric concrete mini-mix truck this autumn. Non-road vehicles and machinery, such as the 60-tonne trucks used at our quarries, may offer additional challenges and considerations – so we are reviewing hybrid, hydrogen and biofuel options for those."

Photos: Hanson

Photo: Howard Harrison / Alamy Stock Photo

Left: Hanson's Regen GGBS cement was used on the four towers at Deansgate Square in Manchester. Mixes ranged from 40% GGBS in the main structural elements to 70% in the foundations and raft bases

Powdered limestone, for example, can be used in conjunction with GGBS and other existing alternatives to produce concrete with 65% less CEM I.

"Limestone formulations are now included in the British standard for concrete (BS 8500), making it easy for designers to specify with confidence," says Toogood. "Too often it is assumed that there is no alternative, so we must do all we can to inform clients and specifiers. Reliable, usable, low-carbon cements and concretes are available right now."

Other concretes, such as those using geopolymers, or alkali-activated cementitious materials, can reduce or totally replace the CEM I content. Breedon Group, for example, is trialling a geopolymer binder system which saves 75% in embodied carbon compared to standard concrete products.

Meanwhile, innovative materials that increase the strength of concrete by up to 30% mean that, as well as using less CEM I in the concrete, designers need less concrete to achieve their structural goals. "Mixes like these can be used now, though as they do not yet come under British standards they require performance testing," says Toogood. "Our challenge is to help standards and regulations keep pace with the huge amount of research and innovation under way."

Donna Hunt, head of sustainability at Breedon, agrees this will be key to the acceptance of new mix technology by the construction industry: "It's important we avoid greenwash and that we guide customers towards the products that will help them achieve the most sustainable outcomes, so we are working with the MPA and across industry to help ensure new products are fairly labelled. Carbon-reduction claims must be accurate and consistently calculated so that specifiers can confidently compare one concrete product with another, and also compare them with other construction materials at a project level."

4

Carbon capture and storage

There is no doubt that, in the drive to reach net-zero by 2050, carbon capture, utilisation and storage (CCUS) has some heavy lifting to do. Whether globally, or from a UK perspective, it represents by far the biggest contribution towards net-zero. CCUS will not just be essential for the decarbonisation of the construction sector, but for many other industries too. Simultaneously though, it also represents the biggest challenge: CCUS capacity is currently small, and the infrastructure to transport and store CO_2 almost non-existent.

"We don't expect it to really start to make a difference until about 2030," says Andrew Minson, director of concrete and sustainable construction at the Global Cement and Concrete Association. "It needs coordinated government help to create a market in captured CO_2. But there's good reason to be optimistic that the necessary support will be forthcoming."

Why? Because there's currently no other way to get all the way to zero, says Minson. "Governments are committed to net-zero, and they know that it's not going to happen without CCUS for several sectors. It will take time to organise, for example, the transport of CO_2 to places it can be permanently stored. But it will happen – because it has to."

The UK government has set targets to deploy CCUS in a minimum of two industrial clusters by the mid-2020s, to establish four low-carbon clusters by 2030 and one net-zero cluster by 2040. Hanson's Padeswood cement plant is part of the HyNet cluster, one of the first two set for delivery, so work is already under way on the UK's first cement CCUS project.

Because CCUS at scale is not yet available, it's even more vital that society makes full use of all the other levers that are, adds Minson. "But there is a recognition that whatever else we do, we can't get to zero without carbon capture at cement plants. There is just not the scope to use alternatives at the scale required."

The good news, he says, is that research is under way at sites across the globe. "We see a lot of activity across many different countries and companies and, excitingly, they are using several different technologies – from established post-combustion, amine-based solutions to calcium looping, direct separation, oxyfuel, even algae."

They are proven to work, says Minson: "So today's research is more about how can we refine processes to help make them commercially deployable."

There is also plenty of interest in CCUS from outside the materials sector: "Construction, finance, governments – they are all looking at this. We all now want the same thing, we all want to decarbonise. Policymakers are wondering how they are going to achieve the national targets they have set, so we say 'support us – we can help.'"

5

Carbon utilisation

All concrete slowly removes CO_2 from the air over time via the process of carbonation. The rate depends on the specification of the concrete and its exposure, and increases when concrete is crushed at the end of its life. Carbonation is typically controlled by design to protect steel reinforcement from corrosion. But there is an increasing number of concrete products coming to the market which have been expressly designed so that they absorb and store CO_2 during their manufacture.

"For concrete blocks and pavers and other precast concrete products, more CO_2 can be absorbed earlier into the concrete by making it part of the curing process," says Toogood. "Because the CO_2 becomes part of the concrete's chemical composition, it remains locked away even if the structure involved is demolished, so as a carbon store it has this advantage of permanence."

The use of carbon-negative aggregate, produced by combining waste products with captured CO_2, is another potential route for storing carbon in concrete. For example, UK company O.C.O Technology combines waste material arising from the treatment of flue gases with water and CO_2 to produce a manufactured limestone with a typical carbon value of -44kg per tonne. The firm now has three plants operating in the UK and has produced more than 1 million tonnes of aggregate. "Since around 80% of concrete is aggregate, there is great potential," says Toogood, "either used in in-situ mixes or in precast products."

Companies and researchers around the world are developing new ideas and techniques for locking CO_2 away in concrete, she adds. "It will be some years before the infrastructure exists to routinely store captured CO_2 in geological formations, but for these CO_2-absorbing concrete technologies, it is an exciting time. They could start to make a difference much sooner."

Download the UK Concrete and Cement Industry Roadmap to Beyond Net Zero at thisisukconcrete.co.uk

CASE STUDY: CARBON UTILISATION

CarbonBuilt: carbon-absorbing blocks

A new technology from US company CarbonBuilt is using CO_2 in the concrete curing process to help reduce emissions by 60-105% compared with standard concrete. The firm intends to begin commercial production of its concrete blocks in early 2023 after winning the prestigious NRG COSIA Carbon XPRIZE, a competition intended to spur development of new and emerging CO_2 conversion technologies to help solve climate change.

Developed by a team from the University of California, Los Angeles (UCLA), the CarbonBuilt blocks use a mix in which the majority of Portland cement (CEM I) is replaced with substitute cementitious materials, and hydrated lime, or portlandite, which helps the mix to absorb CO_2. The team then takes CO_2 directly from industrial flue gas, biomass waste, or direct air capture, for quick absorption by the portlandite as the concrete hardens.

CarbonBuilt is one of a growing number of companies discovering how to lower the carbon content of concrete by incorporating CO_2 into the manufacturing process. Its process differs from some in that it does not require the curing container to be pressurised. Instead, the CO_2 absorption rate is accelerated solely as a result of the changes to the mix, and by optimising temperature and humidity as the concrete hardens. CarbonBuilt says that its ability to use unpurified CO_2 also makes the system cheaper and more flexible.

While around 70% of the reduction in carbon is achieved via replacement of the CEM I, the rest results directly from absorbing CO_2. The company claims that each concrete block stores about 340g of CO_2.

LOW, LOWER, LOWEST

There are many ways to reduce the carbon emissions of concrete structures, from cement type to specifying slower strength gain. The key is to talk to concrete producers as early as possible

There are many different low-carbon concrete mixes, all with different characteristics in terms of performance and aesthetics. For specifiers, identifying the lowest carbon concrete with the characteristics required for each use is key - there is no single optimum solution for all uses.

There are many ways in which a specification will, often inadvertently, impact concrete mix design, and therefore embodied carbon. The optimum mix is unlikely to be something that a designer can establish on their own, unless they also happen to be a concrete technologist. Early engagement with concrete suppliers will enable designers to identify the right concrete for the right place, and select the lowest-carbon concretes to deliver the performance required.

This article aims to provide an overview of many of the factors to consider and provide links to new guidance from The Concrete Centre to help designers lower carbon.

Concrete mix design

There are a range of considerations that affect the embodied carbon of a concrete mix, many of which may not be obvious to the specifier. These include:

Cement content. This will be dictated by whichever of the following imposes the greatest requirement:

- the quantity required for target mean strength
- the specified minimum cement content
- the mass required to comply with the maximum water/cement ratio
- the minimum required for pumping.

BAM Nuttall has extended the sea wall at Marine Parade in Dawlish, Devon, using specialist concretes that have reduced the project's carbon emissions by 1,300 tonnes. The existing sea defence along this stretch of coast had been eroding to the point of failure, threatening the main railway route into south-west England, which runs directly behind. The new sea wall will protect the line and nearby houses, as well as improving safety for pedestrians by reworking the pathway and building a beach access ramp. The project used 8,500m^3 of Hanson Regen, a low-carbon concrete with a cement type containing 70% GGBS.

- **Aggregate size and type.** Aggregates are low in carbon, but their size and type can influence cement content. If you are developing a carbon benchmark for your project, be informed by potential regional variations.
- **Admixtures.** A water-reducing admixture can also reduce the amount of cementitious material required, providing an overall carbon saving.
- **Consistence.** Consideration should be given to the consistence of mixes and method of placement. Flowing concretes may have slightly greater embodied carbon but are easier and quicker to place, do not require mechanical compaction and can be poured directly from the truck in many instances of groundwork, removing the need for plant.
- **56-day strength.** For concrete with a high proportion of secondary cementitious materials, specifying concrete strength at 56 days after casting, rather than the usual 28 days, can reduce the cement content needed by 15-20kg/m^3. For these concretes, the use of 56-day strengths better accounts for the slower strength gain. British standard BS 8500 allows 56-day specification although discussion with the concrete supplier and contractor is recommended. For more information, refer to Using 56-day Concrete Strengths, published by The Concrete Centre.

Efficient design

There are various ways that designing for material efficiency can reduce the embodied carbon of a concrete-framed building – for example, by reconsidering the spans or loading, or changing the structural system.

Analysis carried out by The Concrete Centre, using Concept v4 (free to download at concretecentre.com/concept) shows that the most efficient concrete structure in terms of embodied carbon involves shorter spans with the lowest load.

For example, a flat slab for a 7m square grid for an imposed load of 5.0kN/m^2 has 9% more embodied carbon than that for an imposed load of 2.5kN/m^2. As the load increases so does the embodied carbon: with an imposed load of 10kN/m^2, it is 42% higher. The embodied carbon also increases with the span: a span of 10m and an imposed load of 2.5kN/m^2

SPECIFYING CONCRETE STRENGTH AT 56 DAYS CAN REDUCE CEMENT CONTENT BY 15-20KG/M^3

The Leeds headquarters of sustainable property company Citu includes over 70m^3 of a low-carbon concrete developed by Cemex. The Vertua Classic concrete offers a 30-50% reduction in carbon emissions versus a standard mix, and has been used for the foundations of the three-storey building, which will be known as The Place. The building is part of the latest phase of the Climate Innovation District, which is at the heart of Leeds' South Bank Regeneration scheme and a key driver for Leeds to become a zero-carbon city.

Images:: Peter Titmuss / Alamy Stock Photo; Citu

Left: A demonstration precast project by the MPA, trialling the use of limestone powder in multi-component cements

Know your low-carbon concrete

Low carbon concretes in BS 8500
All concretes to BS 8500 are based on Portland cement, or CEM I, but most contain additions, or other cementitious materials. These include: ground granulated blast-furnace slag (GGBS), fly ash, silica fume, limestone powder and Pozzalana. Table 9 in Specifying Sustainable Concrete, published by The Concrete Centre, provides indicative embodied carbon of typical UK cements.

Multi-component cements in BS 8500
Combinations such as CEM I-GGBS-limestone, CEM I-fly ash-limestone and CEM I-calcined clay-limestone have the potential to lower carbon and increase availability. Evidence from MPA research on developing new low-carbon multi-component cements for UK concrete applications has been presented to the BS 8500 standards committee to support their standardisation in the forthcoming revision to BS 8500.

Low-carbon concretes using AACMs
The use of alkali-activated cementitious materials (AACMs) is not included in BS 8500. For guidance on the use of AACMs refer to PAS 8820. The Concrete Centre agrees with the Green Construction Board's Low Carbon Concrete Group in advocating for an update to PAS 8820 or a new British standard for AACM and geopolymer cements and activators. Achieving standardisation will enable them to become a more mainstream solution.

Fly ash and GGBS
Fly ash and GGBS have been used as cementitious materials for decades. The materials have a positive influence on the durability and aesthetic of concrete, and they are also currently the most common means of lowering its embodied carbon. Fly ash and GGBS are by-products of industrial processes that are in decline in the UK, and this trend may eventually be seen globally. Consequently, while these materials provide a solution for saving carbon now, they are unlikely to remain the dominant solution in the coming decades. Research is under way to test the potential of recovered or previously stockpiled fly ash, and the global GGBS supply is forecast to continue to increase until 2025. Therefore fly ash and GGBS are still viable, proven cementitious materials for the UK.

Limestone and calcined clay cements
Limestone and calcined clays are already used as cementitious materials globally, and work is under way to make their use more common in the UK. MPA research has already demonstrated the performance of limestone cements. A new MPA project, funded by the Transforming Foundation Industries Programme, has been announced to test the performance of UK clay, with the aim of increasing the role it can play. These materials have the potential to replace and/or work in combination with existing cementitious materials.

contains 83% more embodied carbon than a 5m span with the same imposed load. This shows the significant savings that reductions to span and loading can make when considering the embodied carbon of the structure.

The Concrete Centre has also produced a guidance document, Comparison of Embodied Carbon in Concrete Structural Systems, which compares 10 systems commonly used in UK construction, assuming the same concrete mix each time. The conclusion is that profiled slab solutions – such as waffle slabs – offer considerable material efficiency benefits.

Eurocode 2 sets out partial factors for the concrete and reinforcing steel used in the design of reinforced concrete structures. In the UK, CARES data has shown that it is possible to reduce the partial factor for reinforcing steel, which can lead to reductions in the quantity of reinforcement, potentially reducing cost and embodied carbon. The Concrete Centre publication, Reducing Carbon and Cost of Reinforcement, provides more information.

Construction decisions will also have an impact on embodied carbon. The use of BIM and standard details have the potential to improve material efficiency and accuracy, reducing over-ordering and waste. Designers should also consider the formwork system and the potential for reuse.

Whole-life carbon

There are many areas in which taking a holistic view of a project over its entire lifespan can reduce its embodied carbon.

A recent life cycle carbon analysis (LCA) of a residential building, commissioned by The Concrete

Photo: Mineral Products Association

Centre, showed the significance of carbon emissions from building services and refrigerant leakage, accounting for over a quarter of the building's whole-life impact. The LCA also demonstrated that adopting the more passive approach of heating and cooling the building by using the concrete's thermal mass in combination with night-time ventilation requires less M&E equipment, saving carbon.

In the study, using the thermal mass in this way resulted in whole-life carbon savings in several areas:

- avoiding the need for mechanical cooling plant
- limiting cooling energy demand at the point when some mechanical cooling is required
- reducing the peak heating and cooling loads, allowing the heat pump to be smaller than in an equivalent CLT design.

For more detailed analysis of this study, read Life Cycle Carbon Analysis of a Six-Storey Residential Building, published by The Concrete Centre.

Concrete can also fulfil more than one function, reducing the need for other materials now and in the future. For example, its inherent fire performance minimises the need for additional fire protection. If concrete is used as finish, this avoids the upfront embodied carbon of separate finishes, and also their maintenance and replacement over the life of the building.

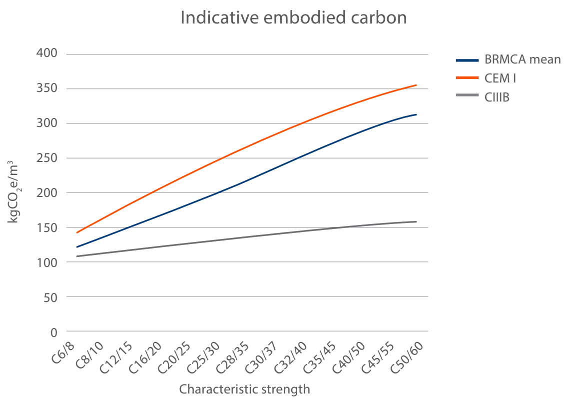
Measuring accurately

Carbon should be measured to recognised international standards, such as EN 15804 for environmental product declarations (EPDs) and EN 15978 for the sustainability of construction works. As there is a wide range of concretes, based on strength, application and cement types, it is recommended that designers use the most appropriate data for specific elements. For example, it is likely that the foundations and superstructure will use different concretes, as they present different performance requirements, so the embodied carbon of the concrete will differ.

Specifiers should be aware that some generic carbon databases use an international figure for reinforcement steel. In the UK, this is produced from recycled sources – sourcing an EPD will provide a more accurate (and considerably lower) embodied carbon value.

If embodied carbon is measured this should be across the whole life of the building, asset or system. The design-life and end-of-life scenarios should not be ignored, as decisions made now can save carbon in the future. The robustness and durability of concrete means that structures can remain useful over a long period and be reused and adapted. When they eventually come to the end of their lives, concrete is 100% recyclable.

For more information on all Concrete Centre publications, go to concretecentre.com/publications



Benchmarking the embodied carbon of UK ready-mixed concrete

The Concrete Centre and colleagues in the MPA are active members of the Green Construction Board (GCB) Low Carbon Concrete Group, which is working to define what "low" carbon means. The GCB group guidance, due for publication in April, recommends a benchmarking approach, which allows project mixes to be compared with industry performance.

The British Ready Mixed Concrete Association (BRMCA) has been supporting the benchmarking discussion by providing an indicative embodied carbon for UK ready-mixed concrete. In the graph above, the mean line represents indicative carbon for all UK ready-mixed concrete production in 2021. The upper line provides an indication of concrete mixes with a CEM I cement type. The lower line indicates the embodied carbon of a concrete with 70% GGBS (or CEM III/B or CIIIB).

BRMCA, MPA Masonry and MPA Precast are also developing generic EPDs for a range of products. These can be used by designers as an indicative carbon value at early stages of design, and early engagement with concrete producers is recommended to get the lowest-carbon concrete and product-specific environmental data.

▲ National Highways' £282m improvement scheme at Junction 6 of the M42 is trialling a low-carbon, reinforced concrete solution. Tarmac has provided two types of concrete for the trial: a mix comprising conventional blended cementitious material and a low-carbon alternative incorporating an AACM. Tests are also exploring the use of basalt fibre rather than steel reinforcement. Contractor Skanska says that the combination of the AACM concrete and lightweight reinforcement reduces the road's carbon footprint by more than 50%.

Photo: Commission Air / Alamy Stock Photo

PEAK PERFORMER

Transitioning the UK to renewable energy means being smarter about managing peaks and troughs. "Active buildings" are the next frontier of demand-side technology, and thermal mass can play a vitally important role. By Tom De Saulles

The UK's energy supply is undergoing a visible transformation as more and more wind and solar farms are connected to the grid. Less apparent is what's happening further downstream: a quiet revolution is just beginning in the way buildings regulate their energy use to cut carbon and save money. This centres on the introduction of active buildings, capable of electrical and/or thermal storage, a technological development that will be included in the next major SAP update (SAP11). Active buildings represent an important step towards meeting our carbon targets, and materials with high thermal mass such as concrete can play a part in maximising their effectiveness.

How do active buildings work?

An active building supports the energy network by intelligently controlling the way power is used. Central to this is the use of smart controls and some form of energy storage system, whether electrical, thermal or both. For example, dwellings can provide thermal storage using their domestic hot water cylinder and/or the thermal mass of the building fabric, while electric cars can provide power storage via the home charging system. Smart control of these and other technologies enables the electrical load for heating, hot water and power to be shifted, creating a much flatter demand profile that helps support the UK's already stretched supply network. The net result is less reliance on fossil fuel power generation to cope with peak demand, and greater use of renewable energy at times when it might otherwise be wasted. Carbon savings are a key driver for active buildings, along with reduced operating

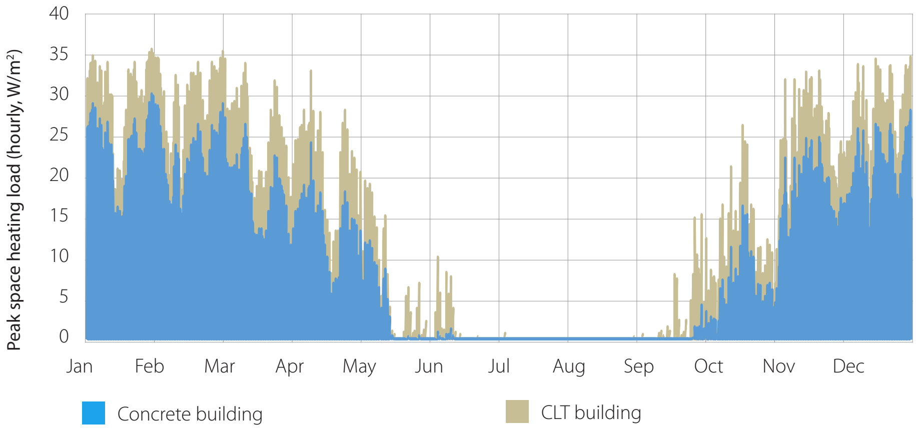
THERMAL STORAGE USING THE BUILDING FABRIC IS MADE POSSIBLE BY MODERN DOMESTIC HEATING CONTROLS

STRUCTURAL COMPARISON

Heat pumps, thermal mass and flattening the load

With the shift away from gas heating towards heat-pump technology, loads on the national grid may be more affected by weather conditions during the heating season. However, medium and heavyweight buildings can reduce stress on the supply network at times of high demand by using their thermal mass to help flatten the space-heating load profile. This can be seen in the graph below, produced as part of a recent study of the comparative life-cycle performance of two six-storey apartment blocks, one with a concrete structure and one made from cross-laminated timber (CLT). The modelling shows that the average daily peak space-heating load of the concrete building is 25% lower than that of the equivalent CLT building, both of which used a heat-pump system. The study was carried out by environmental engineering consultancy Max Fordham, commissioned by The Concrete Centre. Download the full report from **concretecentre.com/publications**

Predicted peak space heating demand (2020- 2040 time period, intermittent occupancy)



costs resulting from the ability to capitalise on time-of-use (TOU) tariffs. These have now been extended to the domestic sector, allowing a much broader market for the purchase of energy when it's cheap, avoiding high-demand periods. For example, one currently available tariff allows users to coordinate energy consumption with half-hourly prices, updated daily based on wholesale costs.

Thermal storage using the building fabric is becoming a practical option, made possible by modern domestic heating controls that can adjust the temperature in individual rooms using remotely controlled valves. These respond to timing and temperature commands from a central controller, a system recognised in the current version of SAP. This technology is now being developed to include load shifting and TOU tariffs, with the potential for additional enhancements such as the ability to take account of weather forecasts and occupancy patterns based on self-learning. In response to new technologies such as these, a SAP industry forum was established to consider priorities for inclusion in SAP 11, and to provide a route for industry and government to discuss views and policy. In April 2020, the forum published a report detailing the likely mainstream technologies that SAP 11 may need to cover when launched in the mid-2020s, of which active buildings and their systems are a major part.

Left: Agar Grove in north London by Hawkins\Brown and Mæ Architects. Set to become the largest Passivhaus development in the UK, it aims to reduce heating bills by around 90% compared with conventional homes. The highly insulated concrete structure is designed to retain heat in summer and coolth in summer. This retention capacity will play an even more important role in the next generation of "active buildings"

Photo: Jim Stephenson

How do active buildings use thermal mass?

Active buildings provide a new perspective on the role of thermal mass, which is arguably more relevant today than ever. This ancient and widely understood technology continues to provide an effective means of reducing the problem of overheating, and its use is now growing to address the challenge of low-carbon design. Active buildings will harness the ability of heavyweight materials such as concrete and masonry to store and release significant amounts of heat. For example, a heat pump supplying underfloor heating to a concrete floor can be operated with a smart controller monitoring air/fabric temperature and half-hourly electricity prices from a smart meter. When power is cheap, the controller is able to charge the slab with heat, while ensuring both the floor and living space remain within comfort limits. Heat is then slowly released over several hours, limiting the need to operate the heat pump at times of high grid demand and prices.

WHEN POWER IS CHEAP, THE CONTROLLER CAN CHARGE THE SLAB WITH HEAT, WHILE ENSURING THE LIVING SPACE REMAINS WITHIN COMFORT LIMITS

As this form of thermal storage uses the building fabric, it is a simple, low-cost option. The control technique also works with traditional space-heating systems, where heat from radiators is indirectly absorbed and released from heavyweight walls and floors in the usual way, albeit with slightly less control and efficiency.

Even a modest change to the temperature of heavyweight floors and walls requires a relatively large amount of heat to be absorbed. The effect on occupant comfort remains small since the surface temperature is changed neither significantly nor quickly, a useful property of thermal mass.

This method of controlling space heating does, however, incur a small rise in energy use, because the slightly higher average temperature results in increased storage losses from the building fabric. The increase in energy use has been shown to be around 3.5% for dwellings with underfloor heating supplied by a heat pump.

However, this loss only occurs at the building level; at grid level, much larger savings are realised as renewable energy from the supply network can be used for longer periods. For example, when underfloor heating is controlled in response to grid demand, curtailment – or reduction of output – of renewable energy sources has been shown to lessen by around 30-45%. This type of saving is expected to be included in the SAP 11 results, which won't be limited to evaluating carbon emissions at the building level, as is currently the case.

Curtailment can be significant at times of low demand – in China around 7% of wind power was wasted in 2018, and Ontario, Canada lost about 25% of all renewable generation in 2017. The UK is not immune to this problem, particularly as the renewable capacity grows, making periods

Above and right: Powerhouse Telemark, an "energy positive" office in Norway, features a heating and cooling system that supplies pipes embedded in the concrete slab. Here the source is geothermal, but when combined with smart controls, such embedded systems will be a particularly effective way for heavyweight buildings that are reliant on grid energy to maximise renewable sources, by storing heat and coolth and therefore spreading out demand

Above left: As seen on Grand Designs, Concrete House by Raw Architecture is constructed entirely from exposed, in-situ concrete. Its thermal mass, coupled with a high level of insulation, retains heat so well that owner Adrian Corrigall has only had to switch on the underfloor heating once in two years

of excess more of an issue than shortfalls. So, alongside battery storage to help balance supply and demand, thermal storage has an important role to play, especially during winter when heat demand is what peaks most.

Cooling in active buildings

The application of thermal mass is equally relevant to active buildings with mechanical cooling and air conditioning, which can be controlled to pre-cool heavyweight floors and walls when grid demand and TOU tariffs are favourable. The fabric can then slowly absorb internal heat gains while providing passive radiant cooling to the occupants. This works particularly well with water-cooled concrete floors supplied by a heat pump, which also delivers warm water in the heating season for year-round smart control of the floor slabs.

The benefits to the grid of active cooling control depend on many variables, but research into the use of thermal mass in a nearly zero-energy office building found that peak power demand can be decreased by around 55% during the occupied period. It is estimated that every 1°C of pre-cooling gives two hours of storage. So if the comfort limit is set to 4°C below the maximum temperature of, say, 22-24°C, the pre-cooling duration is limited to a maximum of eight hours. The subsequent period of heat absorption varies with the characteristics of the building, but to maintain comfort, the indoor temperature should not rise by more than 2.1°C per hour, according to US building services organisation ASHRAE.

With institutional investors already focusing on low-energy design as a way to future-proof property assets, it seems highly likely that this will broaden to include active buildings. A good example of the cost saving this technology can provide is at the Bullring shopping centre in Birmingham, a leader in the use of this technology. Owner Hammerson worked with Aston University spin-out Grid Edge to optimise energy demand for heating and cooling on a day-ahead basis while allowing for changes in footfall and weather. Grid Edge's control technology uses AI learning to predict the energy profile. This enables the heat flow to and from the building's thermal mass to be managed so that HVAC loads are shifted in response to the cost and carbon volatility of the grid, while internal conditions always remain within desired comfort limits. Over a six-week test period, the system delivered £23,000 in energy savings.

The use of energy storage and smart controls in active buildings shifts them from being passive, standalone energy consumers to become active participants in a much wider system that optimises energy use and carbon emissions – potentially a new energy asset class for investors. High thermal mass construction now has smart thermal storage to add to its other future-proofing attributes.

Tom De Saulles is building physics advisor at The Concrete Centre

Photos: Ivar Kvaal; Tarry + Perry

HIDDEN POWERS

Switching to a completely renewable power grid presents engineers with many fascinating challenges. Tony Whitehead gets to grips with two developing solutions for capturing and storing energy from nature

As we look towards a future in which energy is generated almost entirely from renewable sources, an awkward question remains to be answered: what do you do when the wind isn't blowing and the sun isn't shining?

When renewables were only part of an energy supply mix that included fossil fuels, the solution was simple: simply turn up the gas to compensate until day dawned or the breeze got turbines moving again. But the closer we get to the world's declared target of net-zero carbon by 2050, the less this answer will do. We have to find ways to store energy for when nature is failing to provide.

Some technologies already exist, of course, perhaps the most effective being pumped hydro. At Ffestiniog in Wales, for example, spare power from times of low demand, particularly night-time, is used to pump water up to a reservoir in the hills. This can then be released to flow down through turbines to generate electricity in time to power the nation's kettles as the populace wakes in the morning.

Pumped hydro has been a useful moderator of electricity supply and demand in the UK since the 1960s, but more recently giant batteries have also begun to feature. Since 2017, what was then the world's largest battery, a 100 megawatt lithium-ion device made by Tesla, has been helping to even out power supply from a neighbouring wind farm in South Australia. An even bigger battery is planned to do the same for a solar power station in New South Wales.

But even between them, these methods of storing power do not entirely solve the problem. Pumped hydro relies heavily on having the topography to create a high-level reservoir – not an option in drier, flatter parts of the world. And though batteries are becoming much more efficient, there are valid concerns about sourcing the rare-earth metals to make them and the environmental cost of their manufacture.

More solutions are needed, and one of them has just completed a demonstrator project at Ticino in southern Switzerland. Like pumped hydro, Energy Vault uses gravity to release stored energy, but instead of falling water, it uses falling blocks of concrete.

Energy Vault's commercial demonstration unit (CDU) is 80m high and features six crane-style jibs, each of which can lift or lower a "reservoir" of 35-tonne concrete blocks, measuring 4.2m by 2.8m by 1.4m. When there is a plentiful supply of power, the CDU lifts blocks and stacks them. Then when power is scarce, or demand is high, it lowers the blocks, the suspending cable driving dynamos to generate electricity.

The blocks are lowered at about 3m/second and each generates around 1MW as it falls, explains Davide Zampini, head of global research and development at Cemex, which developed and manufactured the specially designed blocks. "To see this thing working is amazing," he says. "The blocks go up and down surprisingly fast but then, like a high-speed lift, they slow at the last moment so they are stacked gently. The software controlling the shape of the stack, and so optimising the storage of potential energy, is also impressive – as is the level of control the cranes have. They are able to place blocks precisely, even in high winds."

The principle at work in Energy Vault is hardly new. A 14th-century clock in Salisbury cathedral, one of the world's oldest, is similarly powered by suspended weights falling (slowly this time) from a great height. Traditional cuckoo clocks work the same way.

The ironic thing, Zampini notes, is that some of the most advanced technology in this project is in the blocks themselves. "Energy Vault wants to provide stored energy at a similar price to pumped hydro, so we have minimised the cost of the blocks by using an innovative, soil-based concrete."

The result is that almost 80% of each block is made from soil, and at Ticino, much of it came from the ground that was excavated to construct the foundations for the CDU's tower. This is achieved using soil-solidifying admixtures, which Cemex originally designed to create rural roads in developing countries quickly and cheaply. "But in fact, they have many uses, including cost-effective, soil-based concrete," says Zampini. "You can use a wide variety of soils because once you have analysed the content, you can adjust what else you put in the mix. The remaining 20% will comprise cement, the admixture, and perhaps a little sand or aggregate depending on what the soil is already giving us."

This mixture, drier than most concrete mixes, is then compressed to form a very strong and durable block. "The industrially produced blocks at the CDU site yielded compressive strength of 10MPa, double the targeted design strength of 5MPa. But it can be 20-30% cheaper than conventional concrete, especially important when blocks are produced in large numbers."

Several other advantages flow from the use of soil-based concrete. Because local soil can make up most of the mix, transport is minimised, and there is less need for the conventional resources of sand, aggregate and cement. The lower cement content and reduced transportation together lower the embodied carbon of each block. "And the polymers we use are biodegradable," adds Zampini. "So if for any reason you don't want your soil-based concrete any more, it can be crushed and returned to the ground as soil."

At Ticino, the CDU uses just 100 blocks, but Zampini says the concept is scalable to a 100m-high tower using up to 8,000 blocks. As these are stacked in concentric circular walls, they would create towers, with the blocks at the top storing a full 100m-drop's worth of potential energy.

Above: The crane stands 80m over a valley in Ticino. The concept is scalable to a 100m-high tower using up to 8,000 blocks

Of course, if you are going to be constantly building and unbuilding high towers out of giant concrete blocks, there are structural issues to consider, he points out. For this reason, it was essential that the blocks had both very precise dimensions and very square ends, so that each sits perfectly straight on top of the one below. To ensure this, Cemex deployed more patent technology, casting on to the end of each block a layer of a proprietary concrete mix, Resilia HP.

"This is a very ductile material, eight times stronger than conventional concrete, and it can be cast with precision. You could have steel plates at each end of the blocks, but we have this instead. The 150mm-thick fibre reinforced plates are cast separately with connecting hooks, and then placed at each end of the moulds into which the soil-concrete mix is poured. The plates are strong enough to withstand the compression which is then applied to the mix."

As well as providing a lasting precision join between each block, the fibres add to their durability. "The soil concrete is strong, water-impermeable stuff – but

Photos: Energy Vault

AN ENERGY VAULT USING THOUSANDS OF BLOCKS WOULD BE A SPECTACULAR SIGHT

this is much stronger still. The fibre mix enhances the flexural and energy absorption performance of the blocks, promoting a resilient material response, and thereby making the blocks extremely durable. And they need to be, as they are continually being placed one on top of another and will be subject to wear and tear."

Once a block has been placed by the crane, it is locked into position by stops which slide automatically into place. Nevertheless, much of the tower's stability comes simply from the heavy blocks being accurately stacked. Would a 100m-high tower of such blocks really be safe?

"Energy Vault had the structures analysed by the University of California, Berkeley and they are more stable than you might think," says Zampini. "As well as wind loading, they looked at how they might react to seismic events. The modelling shows that while the blocks would slide a little in relation to each other, this action absorbs a great deal of energy, helping to keep the tower stable."

Should the vision of an Energy Vault using thousands of blocks be realised, it would be a spectacular sight. In a desert it might provide a welcome point of interest, though a little creativity might be needed in more sensitive locations. Energy Vault points out that its falling blocks can be made in any colour – brown, say, or green – to help a tower blend into its surroundings. It may even be possible to use different coloured blocks like pixels to create pictures or logos.

"Once you start playing with this idea, the possibilities are endless," says Zampini. "With our admixture technology we could incorporate local waste streams like glass or plastic into the blocks as well as soil, so we would be contributing to the circular economy by using the mass of the waste to store green energy in concrete. A pleasing solution, I think."

Above: As the jib lowers the blocks, the suspending cable drives dynamos to generate electricity. The blocks drop at about 3m/second and each generates around 1MW as it falls

WAVE ENERGY CONVERTERS

Turning the tide

Everyone knows what a wind turbine looks like, and what a solar panel looks like. But what about a wave energy converter? How does it work? And what is it made of?

"In the renewable energy sector, wave energy is not as mature as, say, wind power," says Karoline Lende, an engineer in Arup's advanced digital engineering group. "The technology has not converged on one predominant design, nor is there yet agreement on the best materials to use for the designs that do exist."

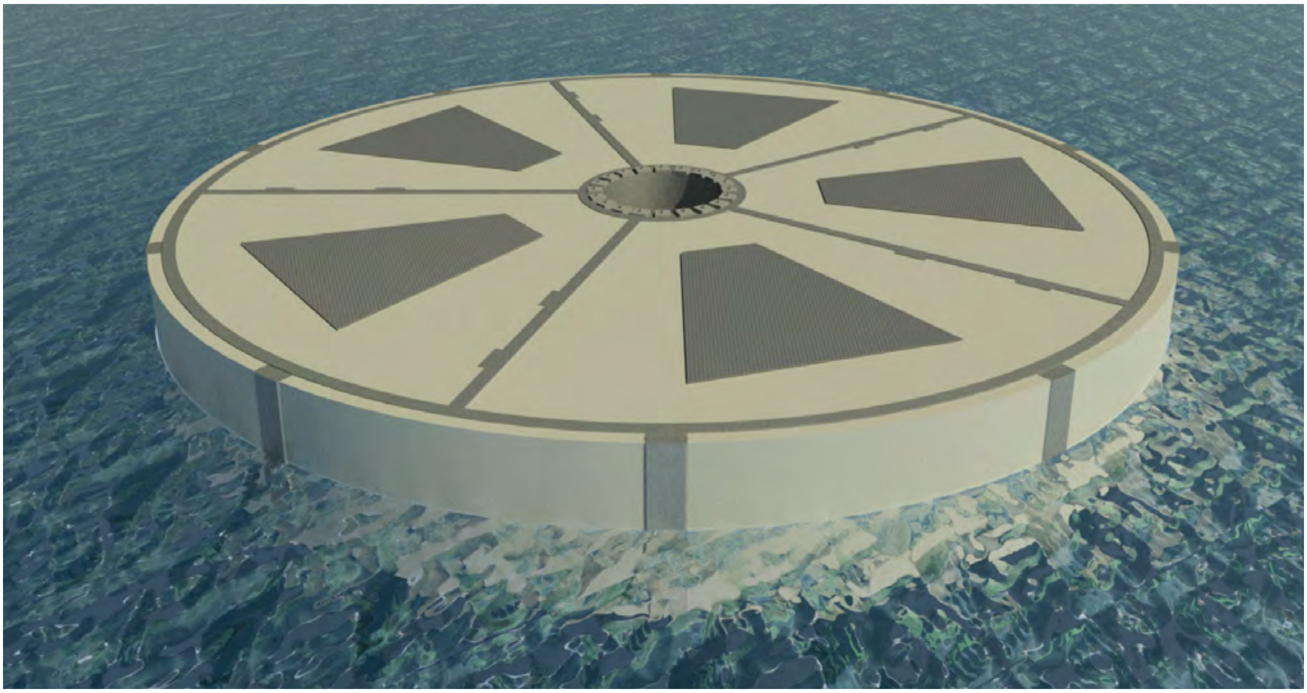
Lende has been working on a project sponsored by Wave Energy Scotland to test the suitability of concrete as a key material in wave energy converters (WEC). Arup looked at two designs: the Archimedes Wave Swing, developed by AWS Ocean Energy; and CETO from Australian firm, Carnegie Clean Energy. The Wave Swing features a large buoy, or floater, which moves up and down with the waves and effectively drives a large piston within a non-moving base tethered to the sea bed. A hydraulic motor converts this linear motion to rotary motion and this, in turn, drives a generator. CETO – named after the Greek goddess of sea monsters – is a 20m-diameter disc shape arranged to float beneath the surface where it can capture the orbital motion of waves and power hydraulic pumps which generate electricity onshore.

"Although these devices have different ways of capturing wave energy, they are both quite large, weighing hundreds of tonnes, and both operate below the surface of the waves," says Lende. "Both need a large moving component and a stationary component, and both need to have a certain mass and buoyancy to be efficient."

So what to make them from? The default material has tended to be steel – partly because it is relatively easy to fabricate experimental shapes and construct one-off prototypes. But because the buoyancy of the devices is key, they have often had to be weighed down with ballast to work properly.

Lende explains that even though the devices are located metres beneath the surface of the sea – a location that reduces wear from storms – they have to "want" to float if they are to capture wave movement. "But if they are too buoyant, they will exert too much pull on their tethers or the stationary part of the device. Hence the need for ballast."

Arup found that making the CETO buoy, and the Wave Swing's (stationary) silo, from concrete instead of steel, obviated the need for ballast and delivered a number of other advantages: "There is a well-developed precast concrete industry in Scotland which would be able to easily supply these components in the large numbers that might be required," says Lende. "We worked with contractor BAM to investigate the cost and practicality of creating these components from concrete and found that it could deliver savings of around 12%, assuming a 25-year device life. However, if you take advantage of the enhanced durability of concrete and



assume a 50-year device life, then we achieve a cost reduction of 20% compared to steel."

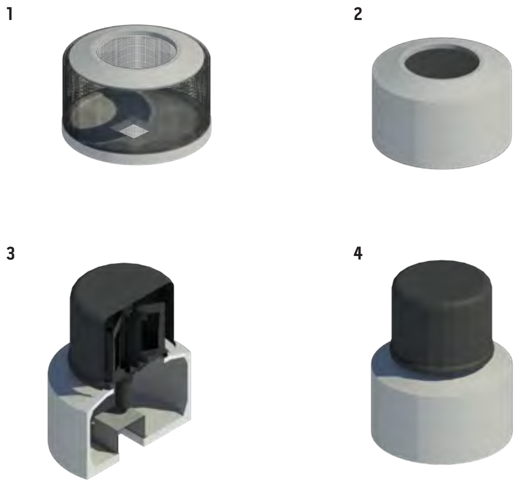
Much of the saving, she says, flows from reduced capex: "Especially when you make large numbers of either devices. But as concrete needs less maintenance than steel, there is also an opex saving that would apply to an all-concrete CETO device."

Arup has made its findings available to anyone interested in WEC design, along with a tool that helps designers calculate the buoyancy ratio of devices made from concrete.

"We also have information available on the embodied carbon values that designers can expect from concrete-based designs," says Lende. "Often there is little difference between concrete and steel, or concrete WECs can actually have lower embodied carbon than steel equivalents."

She adds that much of Arup's research in this area is applicable to other renewables technology, particularly "floating wind" – offshore turbines which, instead of having seabed foundations, stand on large hollow platforms made from concrete. Being hollow allows them to float, but being heavy and semi-submersed endows them with surprising stability. They can also be cheaper, involve less embodied carbon, and cause less disruption to local ecology than traditional foundations.

"These floating structures are much bigger than the WECs we have been looking at," says Lende. "But the benefits of local concrete supply chains, scalability, low maintenance and longer design lives all apply to floating wind platforms too. There's also scope for manufacturers of WECs and floating wind structures to share coastal manufacturing facilities such as concrete batching plant."



Top: CETO's precast concrete buoy is a 20m-diameter disc that floats beneath the surface, capturing the orbital motion of waves and powering hydraulic pumps
Above: The construction sequence for the Wave Swing's precast concrete silo

Both the Wave Swing and CETO are still prototypes, and have not been fully deployed at scale. But to have a mature and broad-based renewable energy sector, the immense power of the sea will need to be harnessed. And it's clear that it will take a material as durable, scalable and stable as precast concrete to catch those waves.

THE **CRUNCH**

The concrete industry was ahead of the curve on measuring and reporting sustainability performance. Now, the data collected and the lessons learned from it are informing the next phase of transition. Claire Ackerman of The Concrete Centre explains

In 2022, the concrete industry will publish its 14th annual sustainability performance report, containing the latest data for 2020. Since the Concrete Industry Sustainable Construction Strategy was launched in 2008, many parts of the industry have come together as part of, or affiliated to, the Mineral Products Association (MPA). In 2020, MPA UK Concrete was formed and the strategy will now be published as the UK Concrete Sustainable Construction Strategy, aligned with the MPA's Vision Zero strategy on health and safety and its biodiversity strategy.

One success of the strategy to date is that it has brought together producers of different types of concrete – ready-mixed, precast and concrete masonry – and all its constituents – admixtures, aggregates, cement, fly ash, GGBS, lime, reinforcement – to measure against a common framework of indicators. This maturity of reporting enables the industry to focus on environmental impacts at a sector level and to come together and share best practice.

The achievement of annual data collection and reporting should not be underestimated. Only recently has government procurement for large projects required the public disclosure of carbon data at a company level. This is possible for all those who already contribute to the strategy, but is still not the case for all construction products.

We are now looking forward to 2030 and work is under way to develop new milestones for the next phase of the transition. Clearly, some of the metrics that we've been reporting on since 2008 will become less meaningful as our society changes to address climate change. Energy consumption is one example. As the grid decarbonises and industry switches over to electricity and deploys new technologies such as plasma energy and carbon capture, total consumption will increase but carbon emissions will be lower.

It is essential that we continue to measure the carbon emissions associated with production. But we have learned that the amount of carbon per tonne of concrete is influenced by specification as well as sector decarbonisation. Going forward we will look to provide data

Above right: A bittern in flight at Shorncote Nature Reserve, Gloucestershire. MPA members have a long legacy of high-quality quarry restoration, creating over 8,000ha of priority habitat. The UK mineral product industry is uniquely placed to deliver biodiversity net gain, with MPA members managing or controlling an area of land totalling over 247 square miles on concrete production by strength class so that the changes in relative carbon emissions due to market demand and sector decarbonisation are more transparent.

A roadmap to 2050

It is the actions that we all take today that will determine whether or not we meet the goal of net-zero carbon emissions by 2050. The UK Concrete and Cement Industry Roadmap to Beyond Net Zero was published in 2020, building on and replacing the UK Cement Industry 2050 Greenhouse Gas Strategy that was originally launched in 2013.

The roadmap presents the technology levers that hold the potential for net-zero concrete and cement in the UK, and also discusses the government policy enablers, and the technology and infrastructure accelerators that can make this a reality. Measuring the progress of these levers and the decarbonisation of UK concrete will be a key commitment of the updated strategy.

Working towards a circular economy will be another major focus, with a specialist taskforce now working on new targets in this area. A sustainable system must value its inputs, and aiming for a circular economy reduces waste and encourages the reuse of materials. The concrete industry is a net consumer of waste, using 314 times more waste and by-products from other industries than it produces.

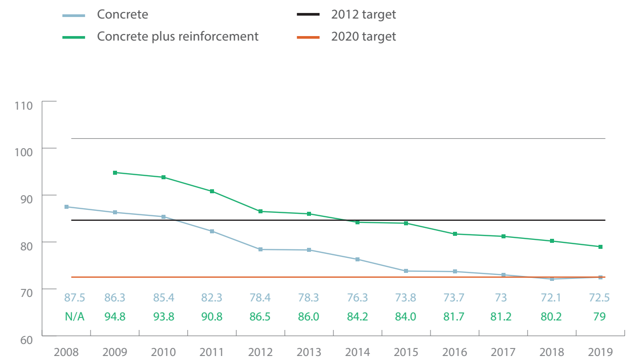
Using materials more efficiently also reduces the embodied carbon of the built environment. The concrete industry, through The Concrete Centre, will continue to develop guidance on the efficient design of concrete construction, and on reusing and extending the life of existing structures.

For more information on the UK Concrete Sustainable Construction Strategy, visit www.sustainableconcrete.org.uk

PROVEN PERFORMANCE: MILESTONES FROM 12 YEARS OF DATA

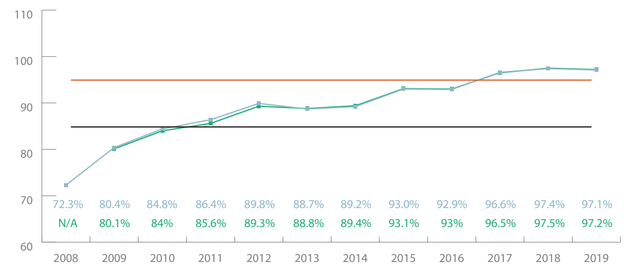
Carbon emissions per tonne

The baseline mix indicator for carbon emissions from production strips out the influence of specification and measures the decarbonisation performance of the industry. The indicator shows that carbon emissions have reduced to 72.5kg per tonne, a fall of 29.3% from the 1990 baseline against the 2020 target of 30%.



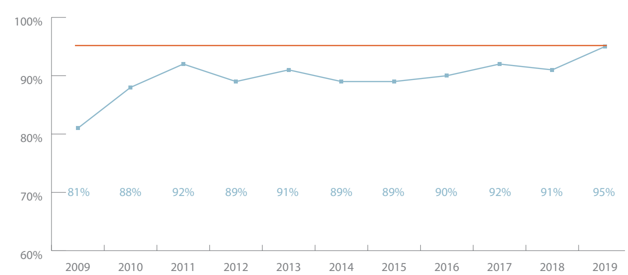
Environmental management

The best practice approaches represented by ISO 14001 underpin the UK Concrete Sustainable Construction Strategy. The 2019 data shows that 97% of sites are certified to ISO 14001, surpassing the target of 95% for 2020.



Responsible sourcing

Concrete and its constituent materials are produced by a UK supply chain providing ethically and responsibly sourced materials certified to BRE BES 6001. The latest data shows that 95% of production is certified to a recognised responsible sourcing scheme, meeting the target of 95% for 2020.



Reducing waste to landfill

The industry has reduced its waste to landfill as a proportion of production output (kg/tonne) to 0.4, a reduction of 92%, exceeding the 2020 target of 90% from the 2008 baseline.

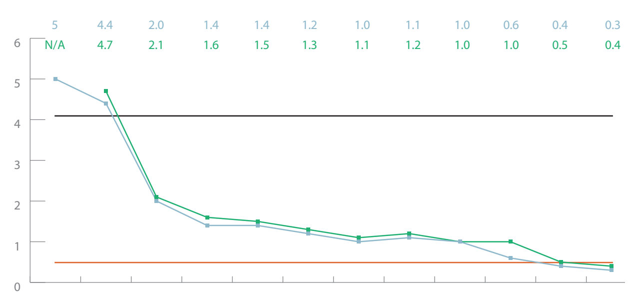


Photo: Dave Soons

TEXTBOOK SOLUTION

Town House, the 2021 Stirling Prize-winning building for Kingston University by Grafton Architects, is a showcase of innovative, efficient concrete design. The hybrid structure is made of precast, prestressed beams and slabs, reducing the amount of material needed. The slabs are topped with a structural in-situ screed with integral cooling pipes, supercharging the effect of the concrete's thermal mass. This "kit of parts", which was delivered by PCE, included concrete containing 40% GGBS – helping the building to achieve a BREEAM Excellent rating.

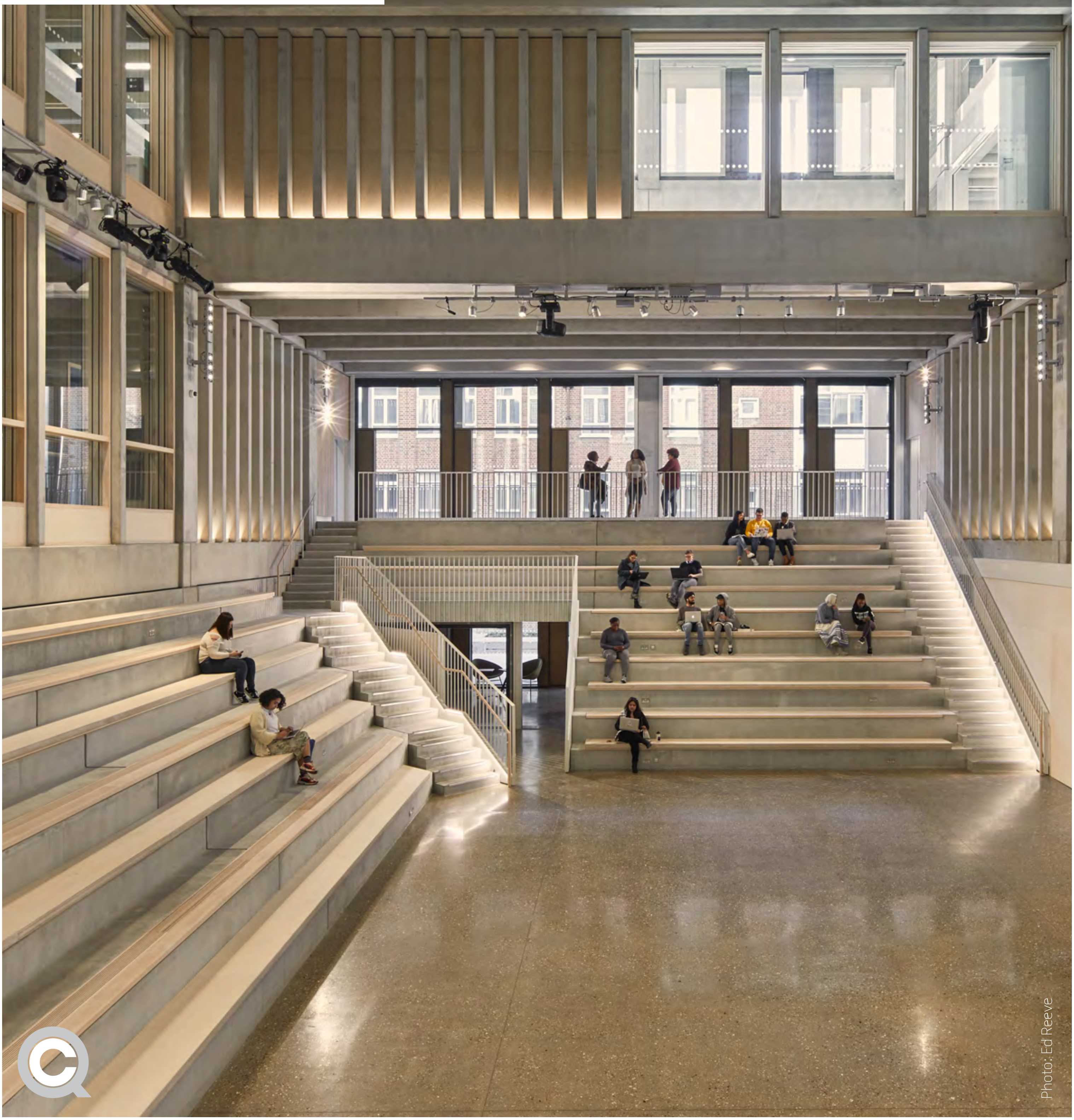


Photo: Ed Reeve