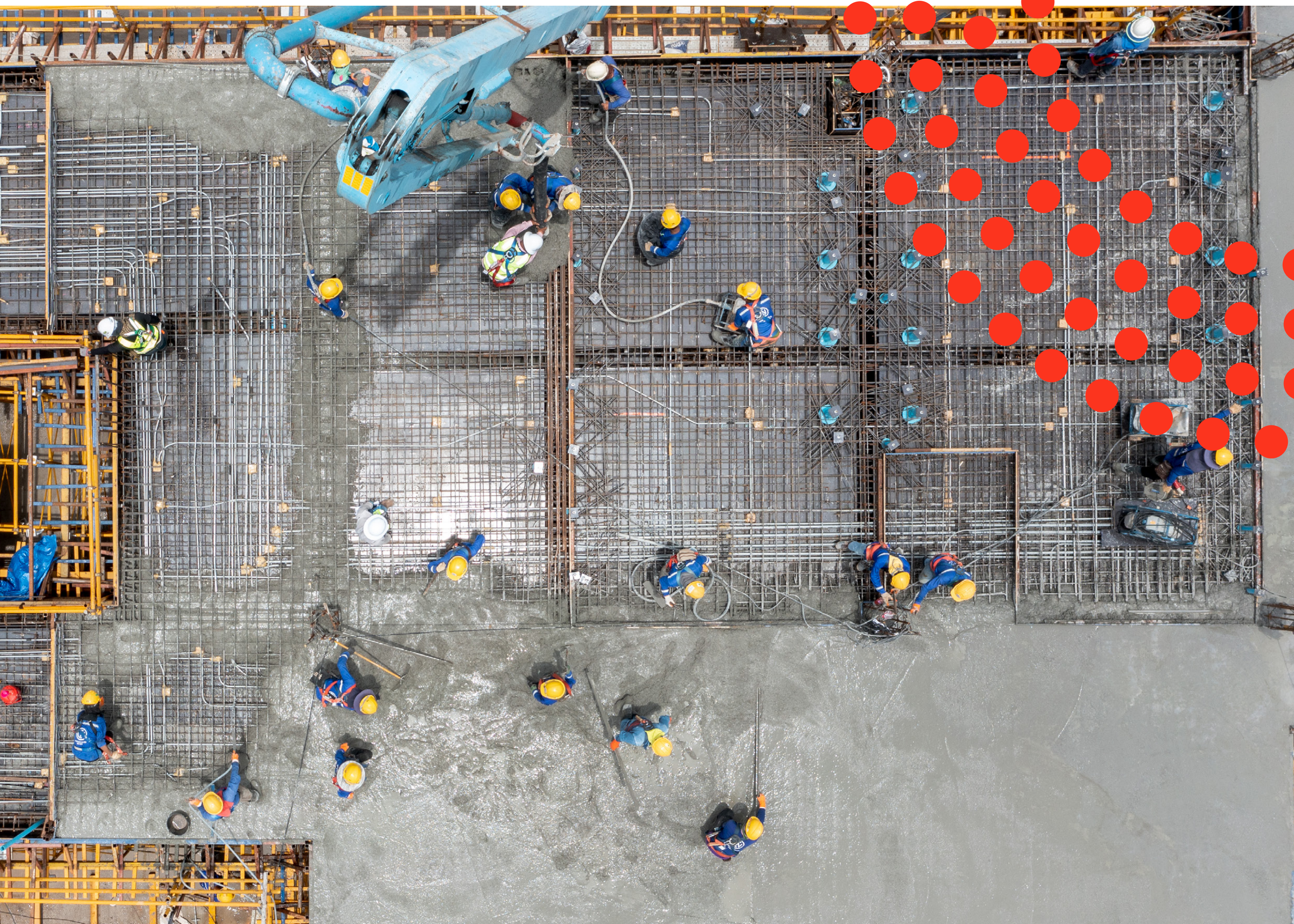
CLIMATE GROUP

CONCRETE ZERO

ConcreteZero specification guidance

How the specification process can drive down emissions associated with concrete

April 2025



Executive Summary

ConcreteZero's members have set ambitious decarbonisation targets which require new ways of working and the use of lower carbon and net zero carbon concrete materials to turn ambition into practice.

The concrete specification process presents an opportunity in every construction project for developers, engineers, contractors and suppliers to work together to make both incremental and step-change reductions in embodied carbon. This document sets out how the process of specifying concrete can be harnessed to drive down the embodied carbon of projects and, through sharing learnings and data, help accelerate the sector's overall decarbonisation.

This guidance document is intended as a practical resource for those directly or indirectly involved with the concrete specification process. The guidance unpacks some of the technical nuances and management processes involved in preparing a successful lower carbon concrete specification, to enable all contributing parties to positively influence the process.

Building on previous work (notably Figure 3.1 of the Low Carbon Concrete Routemap (1)) this document sets out to:

- Map out and sequence the flows of information and feedback mechanisms needed to successfully specify and use lower carbon concretes.
- Provide clarity on the contributions of the various project stakeholders.
- Offer practical advice for those involved in the specification process, including the provision of guiding parameters to inform embodied carbon targets in concrete specifications.
- Illustrate the specification process through ConcreteZero member case studies.
- Foster more informed and coherent collaboration across the value chain in addressing concrete's embodied carbon.

This guidance document is a first attempt to distil and share best practice advice on how to integrate embodied carbon considerations into the specification process for concrete. It was developed by UK practitioners, for the UK market, though many of the underlying principles are expected to be relevant across other markets.

The real-world case studies featured are intended to empower those involved in the concrete specification process to introduce elements from this guidance into their own practice to accelerate the successful specification and, in turn, the production of ever-lower carbon concrete.

Figure 1: Summary of the main actions needed to realise the specification of lower carbon concrete that different roles within the project team can take at each stage of the project. More detail on specific underlying actions can be found in **Figure 5.**

Summary project lifecycle

RIBA Plan of Work	Strategic Definition 0	Preparation and Brief 1	Concept Design 2	Spatial Coordination 3	Technical Design 4	Manufacturing and Construction 5	Handover 6
PAS 2080: 2023	Need	Optioneering		Design		Delivery	Operation
Client Asset Owner/Manager	Establish project sustainability aspirations	Set specific carbon targets & Appoint consultants who can deliver against those targets	Invite design team to challenge the brief & Initiate early supply chain engagement	Develop contractual incentives around achieving lower carbon concrete	Commit to using concrete that meets specified carbon criteria	Allow for use of lower carbon concrete in construction programme	Confirm concrete mix information is available to support industry decarbonisation
Project Manager Cost Consultant Architect	Explain cost/programme implications of sustainability aspirations & Advise of the need for early engineer/ contractor engagement	Ensure the consulting team have the skills and scope to deliver lower carbon concrete	Enable liaison through the supply chain to ensure optimum lower carbon concrete solutions are developed Support challenge to the brief & Assist with early supply chain engagement	Support and monitor the design development, procurement approaches and construction proposals against low carbon concrete ambitions			
Designer Structural Engineer (Permanent Condition Specifier)		Explain sustainability and lower carbon concrete possibilities to client	Challenge Brief Set structural and concrete carbon targets Take part in early supply chain engagement	Develop structural arrangements to minimise material use Collaborate with contractors and suppliers around lower carbon concrete possibilities	Optimise structural elements Finalise concrete specification with carbon targets	Review and challenge supplier mix designs	Hold lessons learnt session with contractor, subcontractor and supplier to seek to improve for next project
Constructor (Construction Requirement Specifier)			Support project team to assess construction impacts as part of early supply chain engagement	Support the development of the design with specialist construction knowledge to enable lower carbon concrete use	Develop construction methodology which enables use of lower carbon concrete	Ensure the concrete used on site meets carbon expectations Minimise waste of concrete	
Concrete Supplier Concrete Mix Designer				Support concrete carbon ambitions with specialist concrete knowledge	Provide initial mix designs to de-risk unexpected carbon increases during construction phase	Supply lower carbon concrete and provide verified embodied carbon information	

Note: "Enable liaison through the supply chain…" spans stages 2–5; "Support and monitor the design development…" spans stages 3–4.

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Authors and acknowledgements

Authors

Ben Azoula-Victory, Love Concrete

Daniel Cowan, WSP

Tim Hoyland, Related Argent

Mike Sefton, Expedition Engineering

Nia Bell, ConcreteZero

Reviewers

Natalie Bird, Independent

Ian Fiebelkorn, Buro Happold

Liam Forde and Gareth Wake, Mineral Products Association

Anh Nguyen, Holcim UK

Keith O'Flynne and colleagues, John Sisk & Son

Laura Stefanini, Byrne Bros

Case studies

Jimmy Barratt-Thorne, WSP

Joe Gartlan, John Sisk & Son

Rob Hutchison, Byrne Bros

Tim Lohmann, Keltbray

Anh Nguyen, James Coveney and Sam Oscroft, Holcim UK

Athina Papakosta and Apostolos Tsoumelekas, SCS Railways

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Contact

Please direct any questions or feedback related to this guidance to nbell@climategroup.com.

List of Abbreviations

AACM	Alkali-Activated Cementitious Materials
ABS	Alternative Binder System
CEM I	Ordinary Portland Cement
CPC	Combined Performance Category
DAbT	Design Assisted by Testing
EPD	Environmental Product Declaration
FA	Fly Ash
GGBS	Ground Granulated Blast-Furnace Slag
GCCA	Global Cement and Concrete Association
LCCG	Lower Carbon Concrete Group
SCM	Supplementary Cementitious Material
WBR	Water Binder Ratio

1.0

Introduction

Emissions of greenhouse gases associated with the lifecycle of concrete represent 8% of global emissions (2). In the case of the UK, as addressed in the 2024 Gap Analysis report (3), these emissions are failing to reduce in line with nationally determined decarbonisation trajectories.

Significantly reducing concrete-related emissions represents a whole-system challenge, stretching from the production of the constituent materials to the end-of-life management of concrete when buildings and infrastructure are demolished. **This guidance targets one discrete but pivotal stage in concrete's lifecycle – the step where the type of concrete for a certain application is specified.**

Where concrete is selected as the most suitable material following the application of the hierarchy of net zero design (4,5), the specification process presents the biggest opportunity to reduce the material's climate impact, and in many cases, the climate impact of the overall project.

1.1 About this guidance

The purpose of this document is to enable project teams to understand and effectively deliver their responsibilities as part of the process of specifying and using lower carbon concretes.

Developed by UK practitioners, for UK practitioners, this guidance shares core principles and insights intended to be of interest to a wider audience.

This document highlights the management processes, technical nuances, and potential pitfalls in the preparation of a 'successful lower carbon concrete specification'; thereby supporting stakeholders to positively influence the process.

This document advocates for a collaborative approach to enable appropriate limiting values to be derived to suit project-specific variables. To support this approach the document includes principles and guiding parameters for the translation of carbon targets into concrete specifications.

1.1.1 About the development of this document

This specification guidance has been developed to support ConcreteZero members to translate their commitment to specify and procure 50% of their concrete below the ConcreteZero Low Carbon Concrete threshold by 2030, and 100% net zero concrete by 2050, into action. It has been written by the volunteer specification working group formed by ConcreteZero members and collaborators, supported by the ConcreteZero project team.

This document has been peer-reviewed by a cross-industry group including clients, structural and civil engineers ('engineers'), principal contractors, contractors, cost consultants, project managers, suppliers, and industry bodies.

While shaped by the needs of the ConcreteZero membership, this guidance is relevant to all those directly or indirectly involved in the development or use of concrete specifications, as well as those interested in this important process for unlocking further decarbonisation of concrete. It sets out both an idealised approach to the process of specifying concrete, as well as illustrating some of the core principles in a series of case studies.

This guidance document is intended to inspire and enable specifiers of concrete, and their value chain partners and collaborators, to work towards lowering the embodied carbon of concrete used in projects. Clients, designers, concrete suppliers, principal contractors and contractors can all gain from a better understanding of how each can influence concrete specifications to meet their collective decarbonisation targets and obligations.

1.1.2 How to use this document

Reading the full document offers a holistic view of the specification process and the variables relevant to the various stakeholders, while some readers may choose to focus on sections particularly relevant to them as set out below.

The remainder of **Section 1** provides additional context on the climate impact of concrete and general approaches to mitigating this. Read if new to the subject or if looking for a refresher.

Section 2 defines the **roles** that project team members and suppliers need to play to facilitate the effective specification of lower carbon concrete. This section is recommended reading for all, as it includes a summary diagram as well as a diagram setting out the specification-related activities arranged by the typical phases of a construction project.

Section 3 describes the **key processes** that support the specification of lower carbon concrete. While aimed at clients and project managers, other value chain participants may find it valuable reading.

Section 4, aimed at engineers and specifiers, provides an overview of the main **methods for specifying concrete.**

Section 5 sets out the **technical** factors to consider when including embodied carbon requirements into concrete specifications. This section is most relevant to architects, engineers, contractors and concrete suppliers, whose specific responsibilities in the technical specification of concrete are presented.

Section 6 provides guidance on collecting and managing **embodied carbon data** for use in reporting and tracking progress against decarbonisation targets and is relevant to all.

Note that where the terms 'lower carbon' and 'carbon emissions' are used, the authors are referring to carbon dioxide equivalent emissions. The term 'lower carbon concrete' in this guidance loosely relates to the ConcreteZero Low Embodied Carbon Threshold, but can also be read as lower, relative to standard practice, for the particular concrete application being specified.

Additionally, the document covers both standardised cementitious materials and their equivalent combinations, as well as alternative binder systems (ABS). The term 'binder' is used throughout to reflect all cementitious materials. Where 'cement' is used (e.g. "cement replacement") the term refers to CEM I only.

1.2 Concrete's embodied carbon emissions

For the purposes of this document the term 'embodied carbon emissions' means carbon dioxide equivalent emissions arising from Life Cycle Assessment stages A1 to A3 i.e. 'product stage emissions', the carbon emissions associated with the raw materials supply, transport and manufacture of the concrete product.

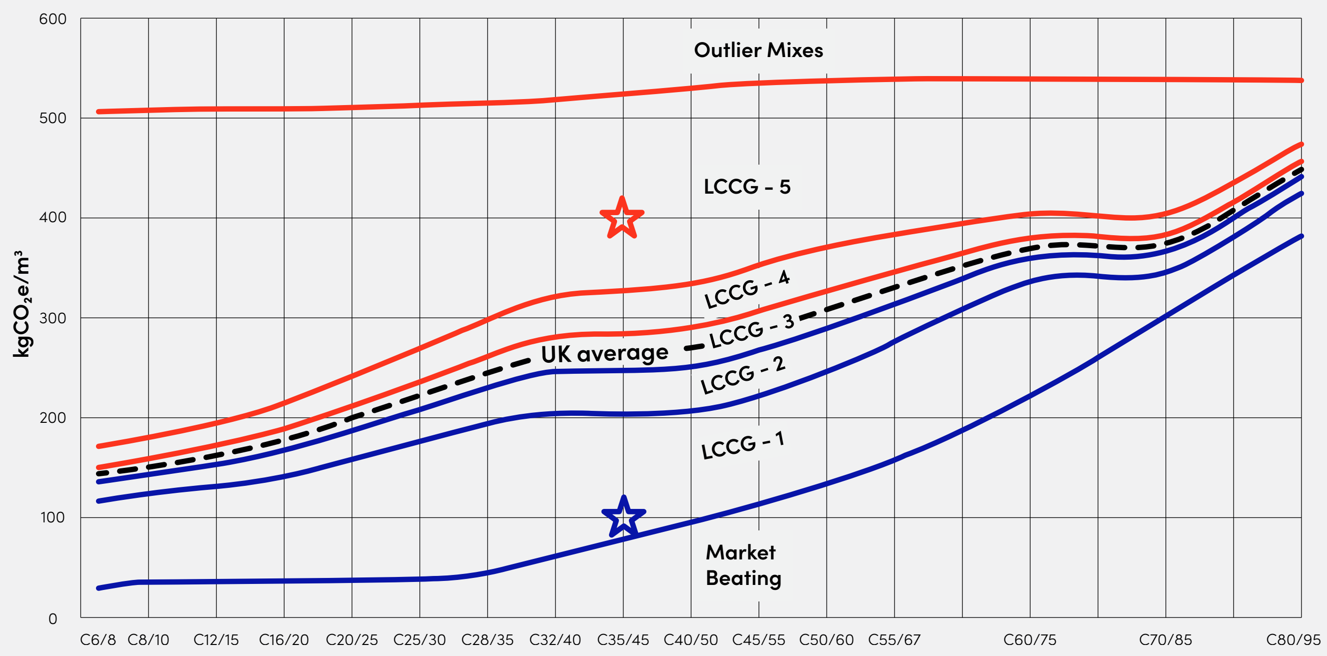
The emissions associated with the production of constituent materials, particularly the clinker used in Portland cement, account for most of the embodied carbon emissions of concrete. The proportions of concrete's main constituents: (i.e. aggregates, sand, water, binders and admixtures) can vary significantly depending on the application and the design choices of the specifier. This adaptability allows concrete to deliver a range of strengths, remain durable in different conditions, and be used on site in different ways, amongst other beneficial properties.

This variation in constituent materials leads to significant differences in the embodied carbon (per unit volume) of different concrete mixes. This holds true even for concretes that provide the same strength and meet the same durability requirements (see **Figure 2**). Concrete poured in summer, for example, can achieve lower embodied carbon emissions than concrete being poured on the same site, for the same element, in winter, because the required early strength gain can be achieved with a lower binder content or a higher proportion of cement replacement.

For reference, guidance regarding other environmental impacts of using concrete can be found in the following reports: *The Embodied Biodiversity Impacts of Construction Materials* (6) and *Specifying Sustainable Concrete* guide (7).

1 Brought together by the Green Construction Board in its role as the sustainability workstream of the Construction Leadership Council, the Lower Carbon Concrete Group (LCCG) has been working together since January 2020 with a bias towards action. The LCCG is formed of professionals from the concrete and cement industry, academia, engineers and clients.

Figure 2: The 2024 LCCG Market Benchmark highlighting two C35/45 concrete mixes with a four-fold difference in emissions. LCCG-5 represents a mix with an embodied carbon in the highest 20% of that on the market (red star) and LCCG-1 an embodied carbon in the lowest 20% (blue star).



Note the importance of avoiding assumptions regarding the equivalence of concretes being benchmarked. Source: 2024 LCCG Market Benchmark (8)

Market Benchmarks and Classification Systems for Concrete Embodied Carbon

The industry has introduced market benchmarks and classification systems to aid understanding and comparability of the embodied carbon of concrete.

In the UK, the Lower Carbon Concrete Group (LCCG)[1] Market Benchmark is based on data from concrete produced during the previous year (8). The bands represent the distribution of embodied carbon emissions per strength class of concrete and, when updated each year, the bands shift.

The LCCG Market Benchmark is an effective and popular tool in the UK for targeting relative gains in embodied carbon relative to industry peers, taking into account market conditions. Also, being well-established, its use can streamline conversations related to the specification of lower carbon concrete within the project team. That said, its dynamic nature is not conducive to setting longer-term targets, such as those needed on multi-year projects or corporate policy setting.

For longer-term target setting and tracking of absolute changes in the embodied carbon of concrete, static classification systems, such as the Universal EC Classification System and the GCCA Global Banding, are better suited (9,10,11). The benefits and drawbacks of referring to the LCCG Market Benchmark, for tracking performance relative to the market, and/or static classification systems, for tracking absolute performance, should be considered before being applied consistently in a project.

For more information on market benchmarks and classification systems for concrete embodied carbon see the overview published by ConcreteZero in 2024 (12).

1.3 How to reduce concrete's embodied emissions

Most of the embodied carbon emissions from traditional concrete are associated with the production of clinker used in CEM I (Ordinary Portland Cement). Even though binders typically contribute only ~10% of the concrete volume, CEM I can account for up to 87% of the associated carbon emissions (see **Figure 3**). Clinker is produced by heating a mixture of clay and limestone (as well as minor additional materials) to approximately 1450°C. Around 60% of the CO_2 from clinker production is due to the chemical reaction which occurs when the limestone (calcium carbonate) is heated and is therefore unavoidable, while burning fossil fuels to achieve these high temperatures generates additional emissions (~40%) that cannot easily be abated through electrification or other means.

Current strategies for reducing concrete's embodied carbon emissions generally involve minimising the clinker content of concrete, while still meeting the performance requirements for its intended application.

As binders are a small fraction of the combined material and construction cost of concrete elements, using higher amounts than required for a particular application can be a low-cost approach to providing additional certainty over factors such as minimum strength attainment. This guidance document intends to safely reduce the excess use of binders on projects (particularly clinker-based compositions) through the careful design and specification of concrete, in conjunction with enhanced supply chain collaboration.

It is also possible to reduce the amount of CEM I by replacing part of the total binder content with lower carbon supplementary cementitious materials (SCMs)[2]. Using SCMs is an established practice, with SCMs providing performance benefits as well as carbon reductions (i.e. ground granulated blast furnace slag (GGBS) can have durability benefits for concrete used in chloride-rich environments such as experienced by marine structures). The carbon intensity of cementitious materials (and other concrete constituents) used can vary depending on the source of the data, but critically, it is widely accepted that the emissions associated with SCMs are significantly lower than those of CEM I[3]. Refer to Section 6.2 for more information on carbon reporting.

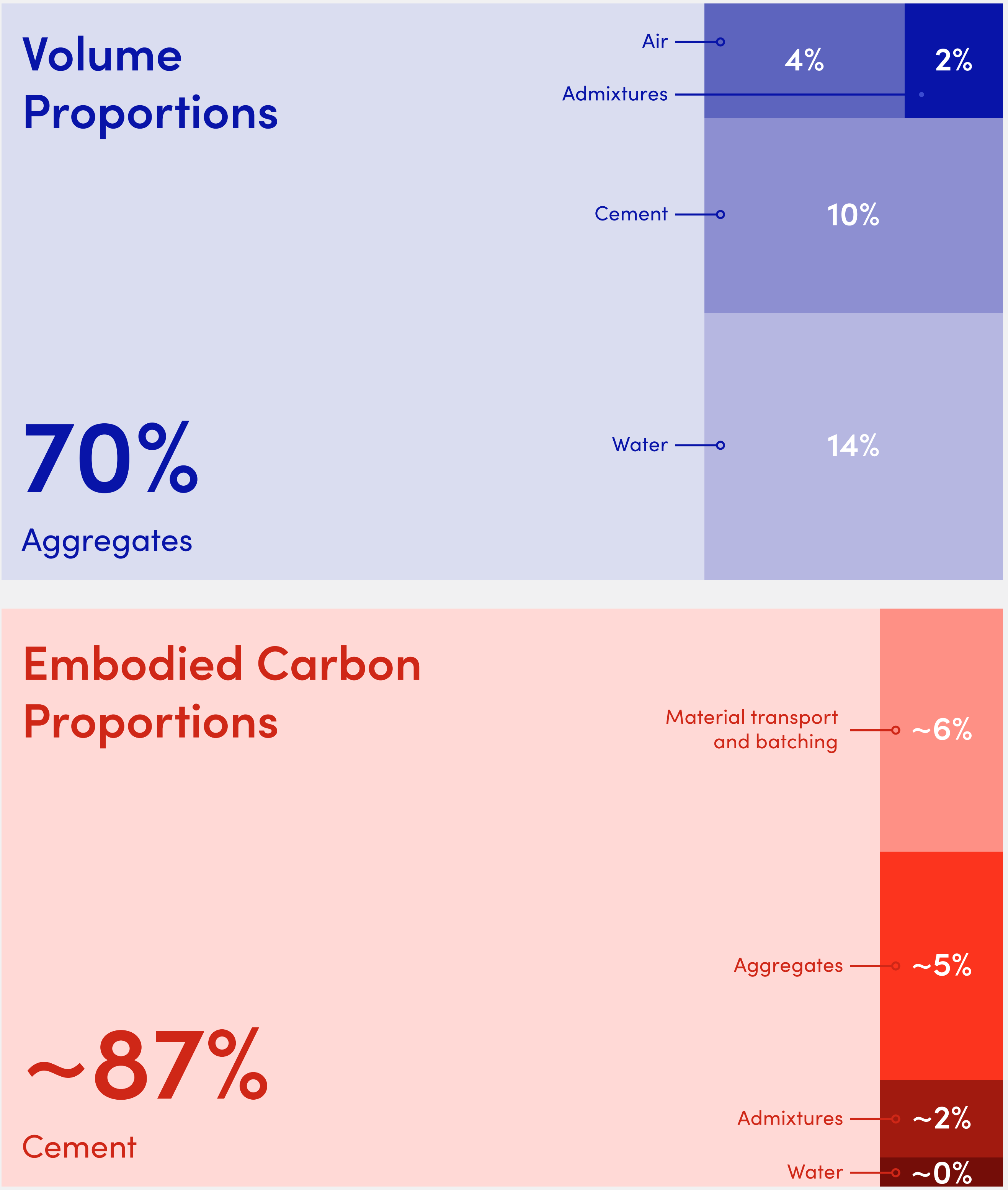
At the time of publication, the most used SCM in the UK currently is GGBS, which is a by-product of blast furnace steelmaking. While GGBS has a continuing role to play in lowering emissions associated with concrete, it is a finite resource unable to meet the demand for cementitious materials in the UK and globally (13). Other SCMs include fly ash (a by-product of coal-fired power stations), limestone fines and silica fume, although the latter is rarely used outside of high-strength and specialist applications. In the UK, the industry is also working to bring to market other SCMs such as calcined clay and advancing various other lower carbon concrete technologies at different levels of technological and commercial readiness. It must be noted, however, that the availability and use of SCMs varies significantly by region and market.

Further information on developments in lower carbon concrete technologies can be found in the IStructE's technology tracker (14) and the ConcreteZero (member only) Innovation Hub.

2 Note that an SCM is called a 'constituent' when used as part of a binder, or an 'addition' when used as part of a combination i.e. added by the cement manufacturer or the batcher, respectively.

3 For representative emission factors for concrete constituents see **Table 6.**

Figure 3: Illustrative diagram comparing, for 1m³ traditional concrete, the proportion of constituents by volume (top) and the allocation of embodied carbon to those constituents, as well as the transportation and batching of the material (bottom).



Source: The LCCG Low Carbon Concrete Routemap (1)

Case Study

John Sisk & Son

Using a portfolio of mixes to respond to site conditions and ambient temperatures

John Sisk & Son, principal contractor on the 2022 Fibonacci Square project in central Dublin, were asked to mitigate as much embodied carbon involved in the construction of a seven-storey office development over a 10,000 m^2 double basement as practically possible. This was in accordance with the client Ronan Group's goal of achieving LEED Platinum certification.

The challenge was to optimise the use of GGBS in the 40,000 m^3 of concrete poured for this project without causing programme delays, despite higher GGBS use correlating to slower early strength gain, especially in low air temperatures. By developing over 35 mix designs, the John Sisk & Sons site team, along with specialist frame contractor RDL, managed the concrete ordering and placing process to

maximise GGBS use, while accounting for the design requirements, site conditions, ambient temperatures, and site schedule.

The 35 concrete mixes provided by the supplier Kilsaran had to be approved by the structural engineer CSC in advance of implementing. The relevant mixes also had to be approved for post-tension slabs by the post-tension specialist designer Cleartech.

The result of the optimisation was an estimated 900 tCO_2e reduction in the overall embodied carbon of the concrete used on the project, representing a 9% saving.[4] The biggest savings were realised in the 600mm deep basement foundation slab which, due to ambient temperatures at the time of the pour, allowed the GGBS content to be increased from 20% to 50%, representing an embodied carbon saving of 490 tCO_2e. As a result, LEED Platinum certification was subsequently achieved at project completion.

Note from the authors: While industry's understanding of GGBS's finite nature has developed since this project was built (13) the approach set out above to develop a mix-portfolio optimising SCM content to reduce reliance on clinker-based cement is still recommended.

4 Based on emission factors of 42 $kgCO_2e/t$ for GGBS vs 700 $kgCO_2e/t$ for normal Portland cement

Holcim UK

Supplier-initiated switch to lower carbon concrete mid-project

What concrete is specified at the start of the project does not always, as demonstrated in this example, preclude the switch to lower carbon materials that become available at a later date.

On the Thornwood housing development in Essex, UK, developer and builder GS8 was committed to minimising the carbon impact of its operations and recognised the opportunity for carbon reduction associated with sourcing lower carbon concrete, particularly for use in foundations.

The concrete mix agreed at the start of the project, FND2 C IIIA, was selected by Holcim UK in collaboration with sustainability consultant KLH Sustainability and approved by structural engineers BW Murray.

During the project, Holcim UK introduced a new product, ECOPact CEM VI, as an option to GS8 for consideration, understanding their appetite for addressing carbon emissions and for innovation. This mix design, which uses ground limestone fines as a cement type in accordance with BS8500:2023, reduces reliance on GGBS and has a 27% lower carbon footprint than the CIIIA mix, and 48% lower than CEM I. Third-party verified carbon data and EPDs were used to transparently demonstrate the carbon benefits of the proposed switch.

While limestone fines are cost-competitive with GGBS, the mix was not available in the plant local to the project site. However, the project team's interest in using limestone fines supported the commercial decision by Holcim UK to allocate silo space so it could be supplied for subsequent concrete pours, the first of which took place in January 2025.

2.0

Roles in the concrete specification process

Concrete specifications define the core material properties required from the concrete for a particular element/application. The concrete specification is often considered the responsibility of the structural engineer, with some input from the architect regarding finishes and other project considerations.

The concrete specification defines detailed requirements for fresh and hardened concrete properties, as developed by the engineer (hardened concrete properties) during the design stage of a project, and the concrete contractor (fresh and early-age concrete properties) usually at or just before the start of the construction phase.

The engineers' requirements cover material properties such as strength, durability, curing time, conformance with technical standards, depth of cover to reinforcement, the environmental exposure conditions of each element and potentially limits on embodied carbon. The concrete contractor or 'user' requirements are focused on attributes that affect the method of placement and compaction, formwork striking times and weather conditions. In the UK, most specifications for concrete follow the methods and guidance for specifications provided in BS 8500-1 (15).

The concrete specification is normally regarded as the document which defines the project requirements from the design team perspective which the contractor is required to meet[5]. However, in practice, there are many more influences on the concrete specification. Furthermore, the specification document only partially defines the requirements determining which concrete mixes are poured on site or used in the pre-cast factory.

This section introduces the roles which impact on the final specification of the concrete used on site including, but not limited to, the specification document requirements. It also sets out specific actions during the lifecycle of a project that enable the use of lower carbon concrete.

5 An example of a concrete specifications template, in this instance used predominantly for buildings, is the National Structural Concrete Specification (NSCS)

2.1 Roles

The traditional process for defining the concrete mixes to be used on a construction project, somewhat simplified and generalised to cover a wide range of project types and locations, is:

1. **Engineer:** Specifies the hardened concrete performance requirements for each element or group of elements.
2. **Concrete contractor:** Adds fresh and early-age requirements.
3. **Concrete producer:** Designs mixes to meet the engineers and contractor requirements.
4. **Engineer:** Reviews and approves mix designs.

This established linear process enables the efficient specification and procurement of concrete and is largely based on repeated delivery of what has been previously done. Given the industry's urgent need to shift to lower carbon concretes, it is necessary to rapidly move beyond conventional past practices. This requires activating additional members of the project team and ensuring they apply their expertise to supporting the shift to lower carbon outcomes. Recognising that introducing any new process relies on behavioural as well as organisational change, best outcomes can be expected with a collaborative project team, tethered to a common purpose.

2.1.1 Proposed approach

This section sets out best practice recommendations for managing the design and construction process with the aim of maximising the use of lower carbon concretes. The recommendations align with a typical design and construction process.

Central to this approach is the definition of a clear brief and the implementation of a collaborative approach throughout the design, procurement and construction phases. Only by working with all stakeholders can the variables affecting the use of lower carbon concretes be holistically evaluated to enable informed decision-making and reduced risk. This approach requires all parties to engage at an earlier stage, including with stakeholders they may not traditionally work closely with, and relies on open discussion and the alignment of project objectives.

Figure 4 shows a more connected approach to concrete specification. It demonstrates the client, project managers and other design team consultants' impact on the concrete to be used by driving the brief and enabling the project environment in which the concrete experts can deliver the lowest carbon concrete. It also shows a collaborative and iterative design approach where structural engineers, constructors and concrete suppliers engage to find an over-arching solution where design and construction requirements are developed to support the use of lowest carbon concrete.

This moves the real mix design of the concrete which will be supplied to site (and therefore the actual embodied carbon emissions) from an outcome of previous decisions to something which is a key consideration in those decisions. It therefore makes lower carbon concrete use much more likely and of lower impact on cost and programme as it is embedded into the process at all stages.

Figure 5 takes this high-level collaborative intent and breaks it down into specific actions which should be taken by different roles within the project team at each stage of a project. These actions are intended to demonstrate how the collaborative approach can be practically implemented. Many, but not all, of these actions are referenced within this guidance. Where not included here, they have also been drawn from other industry guidance and carbon reduction best practice, including:

- Low Carbon Concrete Routemap (1)
- LETI Client Guide for Net Zero Carbon Buildings (16)
- PAS 2080: 2023 Carbon management in buildings and infrastructure (5)

It is recommended that reference is made to these documents to strengthen understanding of the opportunities of all project team members to deliver lower carbon concrete.

Figure 4: Overview of a connected concrete specification approach including a collaborative and iterative design loop supportive of the use of the lowest carbon concrete.

Connected concrete specification approach

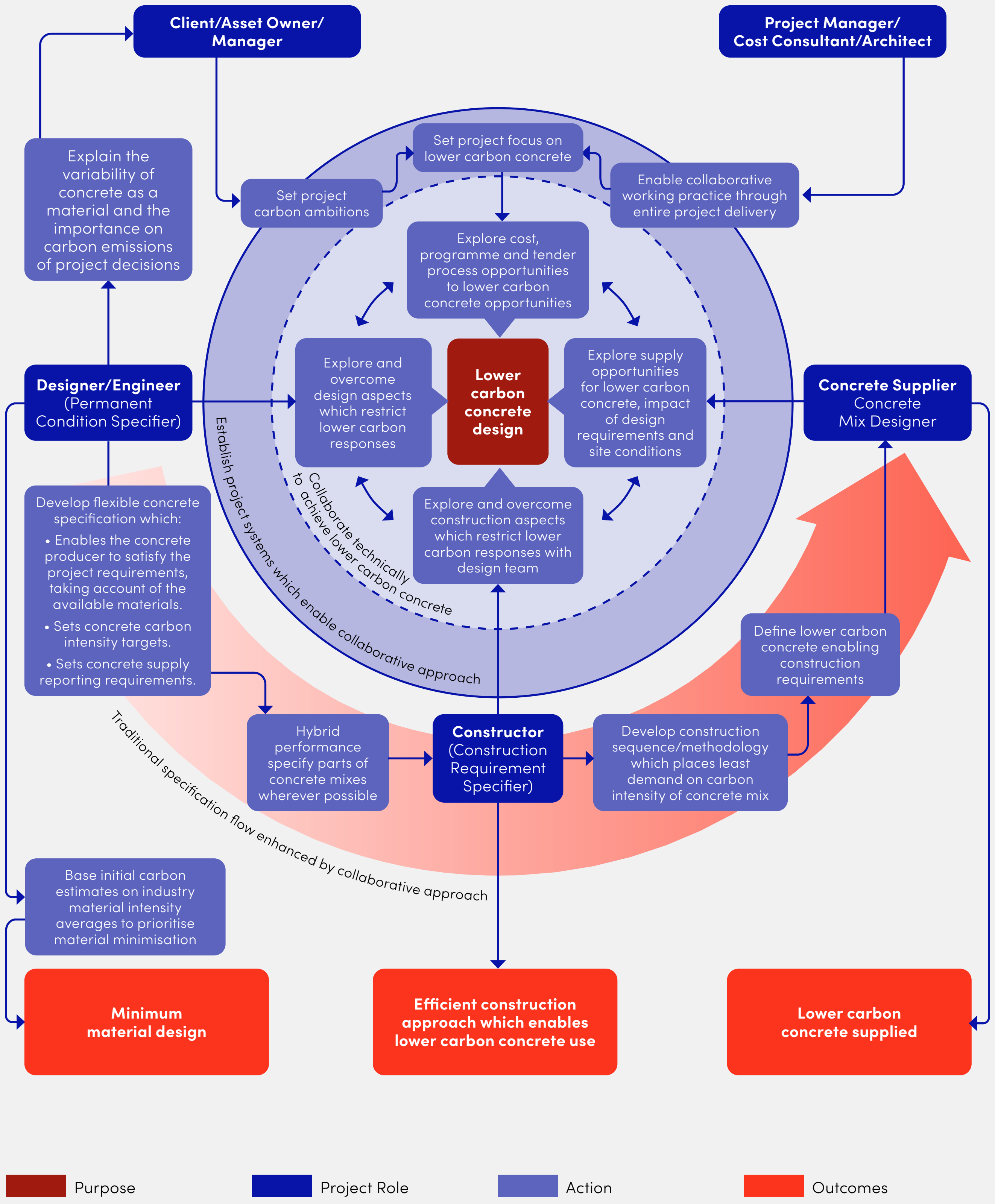


Figure 5: Breakdown of the high-level collaborative intent into specific actions that can be taken by different roles within the project team at each stage of the project.

Key

Primary themes for workstage	Lower carbon concrete best practice	General lower carbon project approaches with influence on concrete outcome	Developing a lower carbon concrete future

Project lifecycle lower carbon concrete enabling actions

RIBA Plan of Work	Strategic Definition 0	Preparation and Brief 1	Concept Design 2	Spatial Coordination 3	Technical Design 4	Manufacturing and Construction 5	Handover 6
PAS 2080: 2023	Need	Optioneering		Design		Delivery	Operation
Client Asset Owner/ Manager	Establish project sustainability aspirations Establish the sustainability aspirations of the project and understand the implications of the intentions	Set specific carbon targets & Appoint consultants who can deliver against those targets Within the project brief, set: - Project embodied carbon targets - SCORS targets for the structure - Instructions to apply the Hierarchy of Net Zero Design Set lower carbon concrete intention Encourage the setting of concrete carbon intensity specifications as part of overall project carbon targets Include requirement in brief to test assumptions with relevant specialist contractors and local concrete batching plants Appoint consultants who can deliver lower carbon concrete Ensure demolition/enabling works contractors receive early stage tender documents that include project carbon targets	Invite design team to challenge the brief & Initiate early supply chain engagement Encourage challenge from the the design team to evolve the brief in order to achieve lower carbon outcomes Ensure designers are given the fee and scope to develop lower carbon concrete options (as opposed to defaulting to tried-and-tested) – consider allocating time for Design Assisted by Testing (DAbT) Enable early engagement with contractor and supply chain knowledge Consider contractual incentives around achieving lower carbon concrete Encourage and enable pilots of novel lower carbon concretes to support the development of future industry solutions	Develop contractual incentives around achieving lower carbon concrete Support the development of incentives to support the use of lower carbon concrete.	Commit to using concrete that meets specified carbon criteria Support defining concrete carbon benchmark rating criteria Commit to buying concretes that meet carbon criteria	Allow for use of lower carbon concrete in construction programme Allow time and fees for review of alternative lower carbon concretes proposed by the contractor against technical and performance standards Review monthly concrete mix tracker with actual embodied carbon results against targets and actively support development through construction programme where needed	Confirm concrete mix information is available to support industry decarbonisation Ensure final concrete mix tracker data is submitted to ConcreteZero and other relevant industry bodies to support industry wide decarbonisation efforts, ensuring the data are shared with the project team
Project Manager Cost Consultant Architect	Explain cost/programme implications of sustainability aspirations & Advise of the need for early engineer/contractor engagement Support client in setting lower carbon overarching ambitions for the project Explain to client the benefits of early engagement with the structural engineer, contractor and concrete specialists/suppliers to achieve lower carbon outcomes Ensure that the cost forecasts account for the sustainability aspirations of the project	Ensure the consulting team have the skills and scope to deliver lower carbon concrete Ensure the project team is appropriately skilled and resourced to enable lower carbon concrete outcomes Ensure engineers scope enables full engagement with whole lifecycle carbon ambitions and focus on lower carbon concrete delivery	Enable liaison through the supply chain to ensure optimum lower carbon concrete solutions are developed Support challenge to the brief & Assist with early supply chain engagement Support the design team to challenge and develop the brief in order to achieve lower carbon outcomes Engage concrete contractor and concrete supplier to gauge a more rounded project understanding of possibilities and limitations for lower carbon options, to overcome any obstructions prior to contract award Cost consultant to ensure financial implications of lower carbon concretes are quantified in cost plan	Support and monitor the design development, procurement approaches and construction proposals against low carbon concrete ambitions Ensure the Tender Requirements clearly define the client's requirements for the use and reporting of lower carbon concrete Consider the use of a Pre-Construction Services Agreement to enable better collective evaluation of lower carbon concrete Provide feedback to design team on cost and programme impacts of lower carbon concrete decisions	Ensure sufficient focus is given to the specification and supply of lower carbon concrete and review decisions relating to the supply chain During the tender process, require the Principal Contractor to provide options for baseline, stretch and challenge concrete mixes Establish cost impact of baseline, stretch and challenge concrete mixes	Review monthly concrete mix tracker with actual embodied carbon results against targets and actively support development through construction programme where needed Identify a site based lower carbon concrete manager and ensure everyone understands the lower carbon concrete strategy Ensure the impact of 'value engineering' considers carbon emissions alongside cost and programme	
Designer Structural Engineer (Permanent Condition Specifier)		Explain sustainability and lower carbon concrete possibilities to client Support the development of a project brief which enables lower carbon outcomes Support setting lower carbon ambitions for concrete in the project brief Explain variability of concrete as a material and impact on carbon emissions of project decisions	Challenge brief Set structural and concrete carbon targets Take part in early supply chain engagement Challenge the project brief to continue enabling lower carbon outcomes Establish targets for the carbon intensity of the concrete (on an element type basis) using appropriate classification system Establish position on the use of GGBS and alternative SCMs as lower carbon cement replacements Define and promote opportunities for use of novel concretes which require 'Design Assisted by Testing' for suitable aspects of the project	Develop structural arrangements to minimise material use Collaborate with contractors and suppliers around lower carbon concrete possibilities Adopt best practice in structural arrangements to reduce structural demand Engage and collaborate with local concrete suppliers, concrete contractors and concrete technologists to establish optimum concrete and the minimum associated in-service strength of the concrete and the maximum age at which this strength must be attained Become familiar with concrete options available to the project and cement types available to local batching plants	Optimise structural elements Finalise concrete specification with carbon targets Optimise structural elements for embodied carbon Be flexible and develop design through collaboration with contractors and suppliers Design using the actual strength of concrete that will be used in construction Include requirements for embodied carbon assessment of mix designs, set targets and require reporting of as-batched concrete kg CO_2e/m^3 in specifications Specify with flexibility to enable the concrete producer to satisfy the project requirements, taking account of the available materials	Review and challenge supplier mix designs Review proposed concrete mixes and support ongoing development of lower carbon options Define the sampling and testing required to demonstrate conformity/identity of novel concretes against intended performance characteristics, in consultation with project stakeholders, especially the contractor and supplier	Hold lessons learnt session with contractor, subcontractor and supplier Share learnings with others in the industry through ConcreteZero or relevant industry bodies.
Constructor (Construction Requirement Specifier)			Support project team to assess construction impacts as part of early supply chain engagement Specialist concrete contractor to review the engineer's high-level specification for appropriateness and that proposals are viable with the preferred construction methodology Provide input on atypical approaches to construction to enable lower carbon concrete use	Support the development of the design with specialist construction knowledge to enable lower carbon concrete use Provide feedback to design team on cost and programme impacts of lower carbon concrete (including material costs and impact on construction)	Develop construction methodology which enables use of lower carbon concrete Input to the design team with a collaborative ethos to enable use of lower carbon concrete Programme site works to accommodate slower rate of strength gain where beneficial for lower carbon concrete Devise a strategy for working with baseline, stretch and challenge concrete mixes Explore offsite manufacture where this can enable lower carbon concrete use Early workshop to minimise carbon emissions of temporary works requirements Propose novel lower carbon concretes/mixes including as pilots	Ensure the concrete used on site meets carbon expectations Minimise waste of concrete Manage concrete mixes using baseline, stretch and challenge mixes Appoint a concrete technologist to advise changes to the mix to meet site requirements without further increasing carbon Adopt working methods that reduce the requirements for early strength gain and required consistence (slump/flow) of concrete. Use digital sensors employing the maturity method to optimise strength attainment. Provide a monthly concrete mix tracker including actual embodied carbon results compared with targets Implement a quality control plan to ensure delivered concrete is as per the optimised mix Enhance site supervision and quality inspection where it can support successful use of an unfamiliar lower carbon concrete	
Concrete Supplier Concrete Mix Designer			Potential novel concrete suppliers to engage and explore areas of project which might be suitable for application Respond to questions about local materials availability	Support concrete carbon ambitions with specialist concrete knowledge Advise on the impact of design and construction choices on the carbon intensity of resulting concrete mixes Liaise with designer to provide concrete options available to the project and cement types available to local batching plants and provide EPDs where available Support contractor with cost and programme advice with supply information	Provide initial mix designs to de-risk unexpected carbon increases during construction phase Identify suitable baseline, stretch and challenge concrete mixes which meet project performance requirements Increase use of ternary (three-part) and quaternary (four-part) multi-component cements already in current standards (BS EN 197) Propose alternative lower carbon concretes/mixes to clients, including as pilots	Supply lower carbon concrete and provide verified embodied carbon information Provide embodied carbon information from identified and auditable sources for the project mixes using calculation of as-built CO_2e based on as-batched ingredients and volumes mixed or dispatched to site	

3.0

Overview of the concrete specification process

The concrete specification process is, when done right, an iterative, collaborative endeavour bringing in the knowledge and skills of the project team and supply chain to optimise the concrete mix and its embodied carbon. The stages set out in more detail in this section represent key opportunities in the process to positively influence the carbon intensity of the specified concrete.

This section supplements the process presented within **Figures 4** and **5.**

3.1 Strategic Definition

During this strategic phase:

- The client should determine the embodied carbon objectives for the project and develop a strategy for achieving them. This may require specialist advice and should align with industry standards.
- The implications of achieving these objectives should be evaluated at a strategic level, i.e. is the client willing and able to incur potential additional costs and risks in the pursuit of achieving their objectives?
- The use of lower carbon concrete is likely to introduce a manageable risk to the project and should be monitored throughout the project's duration (with input from relevant specialist disciplines) to ensure that committed cost and risk remain at an acceptable level.

3.2 Briefing

During briefing it is essential that the client prepares a clear brief for the engineer during RIBA Stage 1 (or equivalent).
As a minimum the brief should include:

- Overall project, upfront and whole lifecycle, embodied carbon maximum and target performance. For example, for building projects an upfront embodied carbon limit may comprise a limit on $kgCO_2e/m^2$GIA (lifecycle modules A1-A5); whereas infrastructure projects may find a weighted mean per unit volume more appropriate, such as $kgCO_2e/m^3$, lifecycle modules A1-A5 (17).
- SCORS minimum and target ratings for the structure (18).
- Instruction to apply the principles of the IStructE's Hierarchy of Net Zero Design and/or PAS 2080's carbon reduction hierarchy (4,5).

The engineer's scope should align with the project brief, and it is recommended to include the following, as a minimum:

- Embodied carbon/capital carbon calculation and reporting requirements.
- Participation in wider project embodied carbon workshops.
- Contribution to relevant aspects of the whole lifecycle carbon assessment.
- Allowance for an iterative approach to enable rationalisation and optimisation exercises.
- Requirement to test assumptions with relevant specialist contractors and local concrete batching plants.

It is recommended that during briefing sessions the following items are clarified between the client and wider design team:

- Appetite to use less commonly used or new concrete materials, infrequently used structural framing systems and construction techniques, and for the associated implications.
- Appetite for exposed concrete finishes or the use of architectural concrete.
- Position on the use of GGBS as an addition/constituent of concrete for embodied carbon reduction purposes and the appropriate carbon emission factors (13,17).
- Appetite to use novel concretes which require 'Design Assisted by Testing' and the associated implications.
- Appetite to use lower carbon concretes and the associated implications.
- Appetite to set embodied carbon targets for concrete within the specification.
- Appetite for early engagement with contractors and concrete suppliers.
- Potential amendments to traditional change control procedures to enable the technical approver to quickly respond to contractors' proposals.
- Agree the carbon emission factors to be used on the project (refer to **Table 6** of this document for an example).

The design team should be afforded the opportunity to challenge the brief and advise the client of the implications of delivering upon the brief with respect to the other constraints on the project. The client should be receptive to comments throughout the specification process.

3.3 Early supply chain engagement

During RIBA Stage 2 optioneering and coordination exercises, the engineer and cost consultant should engage with concrete suppliers and local batching plant(s) to obtain a suite of realistic concrete mix designs for the project, accounting for the options under consideration, e.g. post-tensioned versus traditional reinforced concrete, quickest programme etc. The architect should also engage with concrete suppliers to understand the embodied carbon implications of using any exposed or architectural concrete. For example, the selection of a particular-coloured concrete may necessitate the use of white cement, pigments or specific aggregate. This is essential to test the assumptions made by the design team and allows the concrete supplier to impart expert advice and comment on existing proposals.

Where relationships exist, the client should engage with a specialist concrete contractor during RIBA Stage 2 to ensure the engineer's high-level specification/intent is appropriate and that proposals are viable with the preferred construction methodology. The outcome of this exercise should inform the selection of the most suitable structural option and concrete mix designs for the project.

This is typically the opportune moment to begin the process of engagement required to use novel concretes.[6] It is also an opportunity to discuss and evaluate atypical ways of achieving lower carbon concretes such as the use of warm and cold weather mixes, additional back propping to offset slower strength gain, 24 hour slip forming to minimise the use of a fast setting but high carbon intensity mix each morning, use of frost blankets, use of 56-day strengths, use of insulated formwork, and the use of varied strengths within the core etc.

It is recommended that engagement continues throughout RIBA Stages 3 and 4 to ensure that the Employer's/Contract Requirements (see Section 3.5) are not conflicted, and the associated risks and implications of using lower carbon concretes are understood.

This process of engagement is equally, if not more crucial, when using pre-cast concrete, where factory throughput, architectural finish and the number of binders stocked by the factory are critical considerations for the embodied carbon intensity of concrete compositions that can be used. It is recommended that engagement with preferred pre-cast concrete suppliers begins during RIBA Stage 2. This is likely to avoid unexpected costs during tender.

In circumstances where the client is directly appointing a 'contractor' to complete demolition or enabling works, these conversations will happen earlier in the development process. Pre-demolition collaboration with the 'contractor' can be used to identify opportunities for the on- or off-site use of recycled concrete, whether it be as aggregate or a form of reactivated binder.

Note that in circumstances where a specialist 'contractor' has control over the construction works the 'contractor' is likely to be legally required to fulfil the role of 'principal contractor'.

3.4 Tender considerations

As this document is describing a process that is different to business as usual, it is advisable to discuss the procurement of lower carbon concrete with the principal contractor and ensure that the requirements are explicitly recorded within the invitation to tender.

It is recommended that the principal contractor is required to present the upfront carbon, cost, programme, technical, placement and finishing implications of the options under consideration during the tender process. One approach is to require the principal contractor to tender against the following system for lower carbon concrete mixes:

- Baseline - concrete mixes which comply with the specification
- Stretch - concrete mixes which comply with the specification but have the lowest possible embodied CO_2ekg/m^3
- Challenge - concrete mixes which meet the performance requirements but may require changes to the specification [in agreement with the client and engineer] to achieve a lower carbon outcome

This process can be used in circumstances where the client is directly appointing a 'contractor' for demolition and enabling works which require the temporary and/or permanent use of concrete.

By fixing costs for baseline, stretch and challenge concrete mixes during tender, a greater degree of cost-certainty is secured,

6 See Figure 2.4 of the Low Carbon Concrete Routemap (1)

thereby allowing the concrete contractor to strategise for their use. If rates for a range of mixes are not secured at this stage, new mixes procured during the construction phase are likely to incur a cost premium.

It is recommended that the agreed change control process accommodates the iterative and collaborative nature of specifying, procuring and using lower carbon concretes. This may require basic changes such as ensuring that the format of technical submission templates are agreed; or perhaps more fundamental changes that enable faster decision-making, i.e. a derogation from the employer's/contract requirements. Such changes should be made with the intent of improving the efficiency of change control to enable the technical approver to more quickly approve beneficial changes before the opportunity has passed.

The principal contractor should likewise agree commensurate amendments to their contractor processes.

For this to be a worthwhile exercise the client team should take a collaborative approach to suggestions and be willing to heed the advice of the principal contractor, specialist concrete contractor and concrete supplier. The advice of a concrete technologist or admixture manufacturer may also be required to optimise mix designs and reduce risk.

The use of a Pre-Construction Services Agreement is likely to result in a better outcome for all parties due to the ability of the principal contractor, contractor, engineer and client to evaluate opportunities for low carbon concrete holistically and collectively (19).

The impact of 'value engineering' proposals upon upfront carbon emissions should be evaluated alongside cost and programme benefits (20).

In instances where projects are tendered where a portion of design development remains incomplete, it is critical that clear objectives are communicated, and baseline assumptions are agreed to ensure the tendering organisations provide comparable tender returns.

3.5 Employer's/Contract Requirements

The Employer's or Contract Requirements should clearly define the client's requirements for the use and reporting of lower carbon concrete. More specifically, the following requirements should be included:

- Where the use of baseline, stretch and challenge mixes has been adopted (see Section 3.4) the contractor can be required to use the maturity method (BS EN 13670) to manage the use of mixes relative to programme requirements. For example, the use of maturity method for a slab may reveal that the baseline mix is gaining strength far more quickly than is required to meet programme requirements (i.e. maybe there is too much CEM I or total binder); whereas traditionally this may lead to programme betterment, from an embodied carbon perspective, once evaluated, it may be an opportunity to adopt the stretch mix.
- The use of a concrete mix tracker to actively manage the programme implications of using the baseline, stretch and challenge mixes relative to embodied carbon targets. The ConcreteZero reporting framework can be used to track overall performance; however, equivalent in-house systems can be used to capture the same minimum data requirements. This represents a proven approach to lowering the embodied carbon of concrete.
- Requirement for the principal contractor to obtain embodied carbon values in accordance with Section 6 of this guidance, which should be read in conjunction with *Figure 6* of the *UK Net Zero Carbon Buildings Standard* (21) and/or PAS 2080 *Carbon management in buildings and infrastructure* (5).
- Requirement for the Whole Lifecycle Carbon Assessment (WLCA) to align with the methodology described within the *UK Net Zero Carbon Buildings Standard.*

Note that the employer's/contract requirements will also contain the concrete specification, the requirements of which should reflect Section 5 of this document.

3.6 Construction programme and methodology

As described above, the programme and technical implications of using alternative mixes should be transparently highlighted to the client management team during tender to ensure alignment of understanding and optimal outcomes.

Where the principal contractor proposes the use of a particular construction method or system, e.g. a post-tensioned system or composite slab, the implications for the choice of concrete mixes and the associated embodied carbon impact should be made clear.

All 'Change Requests' proposed by the principal contractor during construction which relate to the use of concrete, should be required to present the embodied carbon impact to the client's management team along with the supporting calculations.

It is highly recommended that the contractor establishes a logical naming convention for the concrete mixes they use. This is invaluable when trying to extract concrete use data from internal accounting software and aligning it with the corresponding concrete mix design certificate for reporting purposes.

3.7 Construction stage monitoring and management

The principal contractor should provide a monthly concrete mix tracker to the client management team, including actual embodied carbon results compared with the target in both tabular and chart format (using the emission factors agreed for the project). In addition, a monthly supporting narrative should be provided to explain any peaks or troughs in performance.

By procuring baseline, stretch and challenge mix designs the specialist concrete contractor should be able to manage the common trade-off between programme and lower carbon concrete. The intent being that rather than jumping from a mix with higher levels of replacement straight to a high clinker-based mix; the contractor can manage the mixes in a more sophisticated manner. Specifying a range of compositions at tender stage will allow the contractor to better understand the cost implications of changing between mix designs during the contract.

The monthly concrete mix tracker should be made available to the client, engineer, principal contractor, contractor, concrete supplier and supporting specialists (concrete technologists etc.) to enable learning to be shared. A practice of publishing monthly concrete carbon data on site is encouraged to support engagement.

3.8 Reporting and learning

Each 'Stage Report' and Whole Lifecycle Carbon Assessment is an opportunity to formally review performance and evaluate compliance with the project brief.

Upon completion of a project it is recommended that a 'lessons learnt' session is held to understand the successes and challenges of the concrete specification, to support all parties to take forward these learnings into future projects.

The final concrete mix tracker should be reported to ConcreteZero by one of the entities involved. Where novel techniques were used or industry leading performance is achieved, the project team is encouraged to submit a case study to ConcreteZero to ensure learning can be shared and used to update guidance documents as required.

Case Study

SCS Railways

Concrete mix optimisation for a tunnel invert through facilitated expert project team engagement

The invert is the lowest part of a tunnel's section that forms the 'floor' at the bottom of a tunnel. For the SCS Northolt Tunnels East (NTE) twin bore TBM tunnels, approx. 20,000 m^3 of concrete are required for the invert.

The SCS concrete optimisation process, which considers both long-term concrete performance such as specified strength and durability, as well as fresh concrete properties such as early strength and workability, was followed.

All relevant requirements for the invert concrete were captured in a designated data collection template ('SCS sustainable concrete specification form') ahead of the beginning of construction works. The information was provided by the members of the SCS team responsible for the invert structure: construction managers/site engineers, with input from designers - if needed, and materials engineers, facilitated by the environmental sustainability team. The full set of requirements, both long- and short-term, was carefully reviewed by the appropriate team representatives, as per above, and discussed in the context of construction sequencing and programme to clarify as needed and identify any potential opportunities for efficiencies.

Throughout this process, it has emerged that the early-stage concrete performance needed for the selected construction method could be achieved with a 'lighter' mix compared to the default one, that had been used for a similar structure elsewhere on the project.

The final, optimised concrete mix contains 300-320 kg/m^3 of total cementitious material vs. 440 kg/m^3 in the original one, leading to savings of approx. 2,200 tonnes of CEM I & 100 tonnes of GGBS that in turn reduced embodied carbon by over 2,000 tonnes CO_2e for its use across NTE tunnels, alongside significant cost savings[7].

Members of the SCS team key to materialising this efficiency: Alexander Zhamgotsev from the Materials Engineering team and Matt Cook, Arun Rajta and Brad Dragun from the NTE tunnelling team.

7 Based on emission factors of 80 kgCO_2e/t for GGBS (EPD for Regen (reference number 000245)) vs 840 kgCO_2e/t for normal CEM I (UK average sector EPD (reference number S-P-05824))

WSP

Using specification clauses to drive embodied carbon improvements

WSP were looking to drive adoption of lower carbon concrete in line with internal and external carbon targets. They did this by focusing on assessing the relationship between specification content and concrete decarbonisation respectively.

They developed and subsequently rolled out a set of additional National Building Specification (NBS) clauses within their Office Master Specifications to introduce requirements for concrete frame contractors and ready-mix producers to supply lower carbon concretes on their projects. These clauses are shown below.

Table 1: Template for developing specification clauses developed by WSP

Mixing/casing/curing in situ concrete

Embodied carbon of mixes	**1.** The contractor shall state the A1 to A3 (cradle to gate) embodied carbon of all concrete mixes (excluding reinforcement) in line with BS EN 15978 (22).
Overall embodied carbon ceiling	**1.** The overall average embodied carbon ceiling for the project is: XXX kg/m³. **2.** The embodied carbon ceilings for each mix are given below. **3.** However, the individual mix carbon ceilings are flexible provided that the contractor proposes an acceptable alternative means of meeting the overall average embodied carbon target and any mix requirements for minimum cement replacement (durability, shrinkage etc) are also met. **4.** Within 1 month of the main concrete operations being complete the contractor shall provide data on the volumes and carbon intensity of all mixes used on the project.
Cement replacement	**1.** All concrete shall contain reasonably practicable amounts of GGBS, FA, limestone, calcined clay and/or other by-product cement replacements to minimise the concrete's embodied carbon. **2.** GGBS should not be used in proportions greater than the national consumption average (25% in the UK) if the only reason for its use is carbon reductions. Where there are other performance requirements that indicate the use of GGBS over other SCMs, these should be demonstrated. **3.** Limiting GGBS contents does not mean limiting SCMs generally. Efforts should be made to use other available cement replacements/lower carbon mixes. **4.** The cement replacement mix design shall not increase the total binder content by more than 10% above that required with no cement replacement. **5.** The contractor is to note that strength gain for high cement-replacement mixes will be slower than for a low- or zero-replacement mix, and appropriate allowance should be made in the construction programme.
Mix options	**1.** The contractor shall submit three outline mix designs at tender stage for at least 80% of the concrete mixes by volume. These three mixes should be: **1.1.** Baseline Mix: A 'business as usual' mix. **1.2.** Target Mix: A mix with the lowest embodied carbon which meets the specification. **1.3.** Stretch Mix: A mix that meets the necessary performance requirement, but may require changes to the specification, extend the concrete programme or involve a novel concrete.
ConcreteZero data	**1.** The contractor shall submit data to the engineer on poured concrete volume poured, mixes, embodied carbon etc. using the latest version of the ConcreteZero tool. **2.** Frequency: Monthly & within 4 weeks of the last concrete pour.

The work presented in this case study was led by Daniel Cowan and Marika Gabbanelli.

4.0

Current specification methods for concrete

In the UK there are five methods by which concrete can be specified as set out in BS 8500-1, the complementary British Standard to BS EN 206 which covers specification methods and guidance for specifiers (15, 23).

While designated and designed concretes are currently the most widely used methods for specifying concrete this section also covers prescriptive and performance-based approaches, as summarised here.

Additionally, BSI Flex 350 v2.0 (24) provides for performance specification of 'alternative binder systems' not covered by BS EN 206, BS 8500-1 or BS EN 197 (when building to BS EN 1992 Eurocodes). This specification method supports innovative, lower carbon concrete technologies for use in unique concrete structures and components.

Table 2: Overview of the pros and cons of BS 8500-1 specification approaches, related to embodied carbon minimisation

Specification method	Pros	Cons
Designated concretes	Simplest and quickest specification process	Not suitable for all applications and less scope to optimise to the application, hence typically leads to higher than necessary embodied carbon
Designed concretes	Suited to wider range of applications and supports optimisation, including of embodied carbon Offers strong opportunities for carbon reduction	More complex, and requires better specifier understanding (than designated concretes)
Prescribed concretes	Full concrete mix provided by specifier; performance tested and assured by specifier or technologist	Rarely used approach, producer bears no responsibility for performance
Standardized prescribed concretes	Can be used when third-party certified concrete supply is not available	Typically have higher embodied carbon values than achieved through other specification approaches
Proprietary concretes	Producer guarantees performance requirements will be achieved	Concrete producer does not declare composition or changes, limiting validation and reliability of carbon or other environmental claims

Table 3: Overview of the pros and cons of the BSI Flex 350 specification approach, as related to embodied carbon minimisation

Specification method	Pros	Cons
Performance specified concrete	Enables greater degree of innovation and flexibility Offers greatest opportunity for carbon reduction	Greater time and resource commitment by all parties Insurance and risk allocation to be developed

4.1 Designated concretes

For common applications and smaller scale projects, designated concretes have historically been the simplest route to specifying concrete. However, because designated concretes are intended to cover a wide range of applications, the limiting values of composition are less transparent and may be conservative, resulting in higher embodied carbon compared to concretes specified through designed concrete approaches.

The five types of designated concrete are:

- **GEN:** GEN0, GEN1, GEN2 or GEN3; unreinforced concrete (blinding, mass fill etc.).
- **FND:** Foundation concrete, (e.g. FND2, FND 4Z etc. with the number representing the Design Chemical (DC) class).
- **PAV:** PAV1 or PAV2; paving and road base concretes such as for domestic parking.
- **RC:** Reinforced concrete; with numbers representing compressive strength requirements for cylinders/cubes (e.g. RC32/40).
- **CB:** Cement bound material concrete, generally for reinstatement works; the numbers represent compressive strength requirements for cylinders/ cubes (e.g. CB20/25).

Specifying designated concretes is not permitted for some concrete materials (i.e. lightweight or heavyweight aggregates), and not suitable for applications that involve:

- Chloride exposure (except PAV2 which can be used in reinforced concrete paving applications exposed to de-icing salts).
- Foundations stronger than C25/30 in aggressive ground.
- Requirements for particular binder combinations (e.g., deep rafts and water-retaining structures).

Also, where the limits of minimum binder content or maximum water/binder ratio determine the binder proportion, reference should be made to BS 8500 parts 1 and 2 (15,25) to understand whether the designated concretes approach is permitted.

It is always important to consider that without an understanding of the limiting values of composition for the concrete (for instance BS 8500-1:2023 Table A.15), it can be difficult to estimate the embodied carbon of the concrete being specified and used.

4.2 Designed concretes

Designed concretes may be specified in a wider range of uses than designated concretes and are tailored to a specific application. This allows the designer greater flexibility over the concrete specification. However, with optimisation comes more complexity, requiring better understanding by the specifier of durability and environmental exposure conditions.

Limiting values of concrete composition are established within the various tables of BS 8500-1, subject to the intended working life (either 50 or 100 years) and environmental conditions the concrete element is expected to withstand. But the complexity comes from the fact that the tables do not all work in the same way. For example:

- For concretes with a Design Chemical (DC) class, the limiting values are based on maximum aggregate size and water/ binder ratio (WBR) to determine the permitted 'combined performance category' (binder classes) and minimum binder content.
- For concretes exposed to chloride ingress from de-icing salts (XD exposure classes), the permitted combined performance categories are dependent on the minimum binder content and maximum water/binder ratio (WBR) in relation to the minimum cover to the reinforcement.
- For concretes exposed to carbonation, the minimum compressive strength of the concrete depends on the exposure class and concrete cover.

Where multiple exposure classes have been identified as applicable, the most onerous limitations are to be applied.

As the designed method of specification is more precise, it should be easier to achieve lower carbon concrete for each mix. Refer to section 5 for more detail on how to approach carbon reduction requirements in designed concretes.

4.3 Prescribed concretes

For this approach the concrete is specified to the producer stating the individual constituents and their target quantities, the specifier takes full responsibility for the performance of that composition; the concrete producer has only to accurately batch and deliver the concrete.

The specifier needs to be confident that the composition they have specified will achieve the strength and durability characteristics needed for their intended use, and for ensuring conformity with the BS 8500-1 limiting values of composition.

This is a less common method of specification as there is often little commercial benefit to taking on the responsibility for performance from the supplier. It may be appropriate for applications such as exposed aggregate finishes (where uniformity of appearance is important) but should only be used where adequate historic performance of the composition is available, either from previous use or from trials.

Where the specifier has good knowledge in the field of concrete decarbonisation, specification by prescription can result in lower carbon concrete, comparable with the opportunity offered by designed concretes.

4.4 Standardized prescribed concrete

This method is principally used for small volumes of site-mixed concrete. Unlike designated or designed concretes, standardized prescribed concrete can be produced by plants without accredited production control and product conformity certification and hence can be site mixed.

These mixes should not be specified where designed or designated concrete equivalents could be supplied by a third-party certified producer. Typically, the designed or designated concretes have lower embodied carbon values than standardized prescribed concretes.

4.5 Proprietary concrete

Proprietary concretes are a form of performance specification where the specific performance characteristics for the concrete are specified, and the producer designs a composition to guarantee performance is achieved. The producer does not usually share the details of the composition (and is under no obligation to do so) and can vary the mix constituents and proportions to suit performance (the mix design must still conform to the limiting values of composition stated under BS 8500-1).

This method is common for specialist concretes such as self-compacting concretes. Proprietary concretes are often reliant on proprietary admixtures and input from the admixture producer on dosage and intended application (26).

BS 8500-1 recommends that this method of specification might not be suitable for initial use in public procurement contracts, where doing so would effectively determine the producer.

Whilst proprietary concretes allow the producer flexibility over composition, the lack of transparency can be problematic, particularly when trying to verify carbon claims or in investigating problems.

4.6 Specification by concrete performance

The BS 8500-1 methods of specification use fixed limiting values of characteristic strength, minimum binder content, maximum water / binder ratio, and nominal cover that are deemed to satisfy the requirements of the exposure classes determined by the engineer. As the exposure class system from BS EN 1992-1-1 lacks granularity, the determined limiting values could, in some instances, be more conservative than required. The BS 8500-1 limiting values are provided for guidance only, but it is rare that the specifier deviates from these.

The constraints of needing to comply with BS 8500-1 can stifle innovation in concrete technology and decarbonisation and can negatively impact cost, where code compliance results in excessive performance. This is a particular challenge for the insurance sector, as deviations from codes will likely demand significant validation and may push premiums up to mitigate the perception of increased risk.

Specification by concrete performance enables the concrete producer greater flexibility in selecting different materials and their proportions to suit the specific application. Empirical evidence of performance gathered from previous use, concrete trials and ongoing testing provides engineers and other project stakeholders confidence that the concrete will deliver the required performance.

Developing a full performance specified mix requires greater technical competence and open communication between all parties (relative to designed mixes). In the UK (and Europe) the use of performance specification is still relatively new, but the growing demand-led activity to adopt lower carbon technologies in recent years has been looking towards performance specification as the logical way for standards and codes to accommodate innovation towards net zero concrete.

The BSI Flex 350 code of practice supports the Design Assisted by Testing (DAbT) approach permitted under Eurocode 2 and offers guidance for demonstrating the suitability of alternative lower carbon concretes using a performance-based approach (24,27). This should be used in conjunction with the Low Carbon Concrete Routemap, which provides guidance on understanding the technical readiness level of novel concretes and how to select the most suitable applications using a risk-based approach (1).

In principle, a performance specification can achieve even lower carbon concrete and help drive innovation. Using a

performance approach for internal, thin, unrestrained concretes should be relatively straightforward, as these parts of structures tend to face limited durability demands. However, with concretes subject to more severe environmental conditions or sensitive to internal heat gain, the process of developing a performance specification may be more challenging, as validation of the proposed concrete mix for its intended use will demand additional evidence.

Performance validation is particularly difficult when establishing long-term durability performance. Availability, accuracy and reliability of test methods need to be well-understood by the project team. Some recognised test methods might not be suitable for assessing concretes with novel or alternative constituents, and even with accelerated aging techniques, some test methods, such as acid resistance, creep and resistance to freeze-thaw cycles can require between 1 and 2 years to complete.

For this reason, early engagement and transparency between project participants is essential.

DAbT is likely to require the services of a concrete technologist to advise and/ or monitor the development and/or implementation (respectively) of an agreed testing regime. DAbT will incur significant additional costs and require several months to implement (subject to the selected testing regime).

Sharing the methodology and results of a DAbT process with industry is strongly encouraged to enable repetition and the wider, more meaningful, use of a lower carbon concrete. Information on performance-based approaches for specifying concretes could also benefit other key stakeholders, such as a developer's insurance company needing to evaluate novel mix designs risk, and potentially explore alternative insurance approaches.

Case Study

Keltbray

Applying a Design Assisted by Testing (DAbT) procedure to support the use of alkali-activated cementitious material

Keltbray, together with Capital Concrete and Wagners, carried out significant technical testing and practical trials of a zero-clinker concrete made with alkali-activated cementitious material. After third-party review, this material achieved approval for use in permanent work construction elements in the UK.[8] This process required and received the support of a committed client, British Land Company, and the structural engineers at AKT II.

The chemical composition of alkali-activated cementitious materials (AACMs) differs from conventional binder (i.e. materials covered by BS EN 197-1 (28) and can be varied to achieve a range of different properties. AACMs also have a significantly lower embodied carbon. However, when used as the basis of the concrete AACMs with the right formulation can be used to produce consistent concrete mixes.

Wagners Earth Friendly Concrete (EFC) C32/40 strength mix was produced to commercial scale at a ready-mixed concrete production plant in the UK using raw materials sourced in the UK that meet relevant British and European Standards, where applicable, and which contains no Portland cement (i.e. CEM I to BS EN 197-1). A 2021 trial was designed to measure the performance of EFC against a typical piling mix containing a blend of CEM I and GGBS (a C32/40 control concrete), using industry standard test methods.

8 The material was developed in Australia (where circa 50,000 m^3 has been used in a variety of applications) and had already been approved for used in Germany.

As AACMs are not covered in BS EN 197-1, and the resulting concrete therefore not in line with the requirements of BS EN 206, Keltbray and collaborators had to use another route to market: the specification document PAS 8820-2016 (29).

Use of an AACM concrete is permitted by following the guidance provided BS EN 206 and the Eurocode – Basis of Structural Design (BS EN 1990:2002 (30))

The Design Assisted by Testing procedure in BS EN 1990:2002 provides a suitable avenue to use novel binders, whilst the guidance for normal and high strength concrete as outlined in section 3.1 of BS EN 1992-1-1 sets out the physical properties any final concrete should meet, whether using AACMs, or any other cementitious materials.

In summary, the test results show EFC performs equal to or better than the CEM I blend concrete control and is suitable for resisting elevated sulphate levels in the soil and groundwater to at least the same degree. The outcome of this testing was the ability for Keltbray to use the material at scale (several 100 m^3) in a piling project in a UK first.

5.0

Embodied carbon considerations for concrete specifications

Including embodied carbon requirements in concrete specifications is vital to achieving lower carbon outcomes for projects.

However, embodied carbon is only one consideration amongst many in the specification of concrete. The concrete must also be workable (pumping, placing, finishing, striking etc.) and meet performance and durability requirements, while considering price and material availability constraints. Critically, factors in concrete mix design that modify embodied carbon have far-reaching implications on other material characteristics.

5.1 Overview of responsibilities when specifying concrete

Although the concrete mix structural specification is an engineer's deliverable (fresh and early age properties are usually determined and specified by the user), achieving lower carbon concretes is dependent on all preceding stages, such as strong client leadership, setting targets and early engagement.

The client's approach to low carbon materials, as defined in the brief, influences the overall approach to concrete specification (see Section 3). The client should remain informed of the implications of the various decisions which are taken to ensure the project brief is satisfied.

Similarly, the cost consultant should work with the wider team to ensure the financial implications of decisions are quantified.

All parties must remain conscious of avoiding the development of an overly prescriptive specification which constrains the mix designer's options to achieve the specified carbon target, e.g. by specifying a consistence class or an overly tight water/binder ratio. This reinforces the need for those responsible for various aspects of the specification to work collaboratively.

The responsibilities of relevant parties in the specification of concrete mixes are shown in **Table 4.**

Table 4: Responsibilities of relevant parties in UK concrete mix specification

Item	Client	Architect	Engineer	Contractor	Concrete Supplier
Concrete strength & density			X		
Max aggregate size			X		
Aggregate type					X
Acceptance of crushed concrete aggregate			X		
Min binder content			X		
Max water/ binder ratio			X		
Air content			X		
Consistence				X	

Item	Client	Architect	Engineer	Contractor	Concrete Supplier
Combined performance category (binder classes)[◊]			X[□]		X[□]
Chloride class			X		
Admixtures					X
Maximum embodied carbon (band or value)	X		X		
Early strength gain requirements			X	X	
Final mix design					X
Finish/colour	X[○]	X[○]			

□ Binder combinations are usually selected by the engineer, however alternatively, for internal concretes the concrete supplier could be given freedom to choose the appropriate binder combination to meet the technical requirements and embodied carbon limits. SCMs are usually selected by the concrete supplier, but the engineer may select e.g. for aesthetic reasons.

○ The architect and engineer may need to liaise to understand the compatibility of aesthetic and performance requirements.

◊ Combined performance categories in BS 8500-1 are aligned with the group designations of BRE Special Digest 1 – Concrete in aggressive ground (2005) to ensure concurrency for the assessment of concrete buried in aggressive ground conditions.

The architect and engineer may need to liaise to ensure compatibility between aesthetic, performance and sustainability expectations which may be strongly influenced by the selected concrete constituents.

5.2 Technical characteristics that affect concrete's embodied carbon

This section provides a summary of the factors that influence the embodied carbon of concrete and relate to choices made during the process of concrete specification.

5.2.1 Characteristic strength

Alongside reducing the total volume of concrete, reducing the final design strength of beams and slabs usually has the greatest impact on minimising the embodied carbon of a structure.

Reducing the design strength of slabs and beams, especially in benign environments, may be possible without causing significant impact on the member size. However, for highly stressed columns and walls, altering the design strength is likely to have little embodied carbon impact.

The effects of specified minimum binder content and maximum water/binder ratio on the design strength should also be considered when an element is being optimised for strength. Reducing the design strength will only be beneficial if the other limiting values also allow a reduction in the actual strength of the concrete used on site.

5.2.2 Binder content

As well as design strength, total binder content is heavily influenced by the environmental exposure (durability) requirements of an element. Chlorides from de-icing salts or sea water, design chemical and freeze-thaw classes each have associated minimum binder contents and maximum water/binder ratios. The final binder content of a concrete will be at least the minimum amount to comply with all the identified exposure conditions, but it is commonplace that the final binder content will be higher than the minimum. This is to account for fresh and hardened performance requirements such as strength and heat development, concrete placement and compaction methods.

Attempting to control the carbon intensity of concretes by setting a maximum binder content is not recommended. Doing so could preclude the use of lower carbon binder materials which often need to be used in greater proportions than the CEM I material they are replacing. Other characteristics such as self-compacting concrete (SCC) may be essential to the method of placing and compaction where there is no access for compaction equipment to be used. SCCs require increased binder and water content to achieve increased mobility. Care should still be taken to ensure where concrete strengths are consistently and significantly greater than needed, to reduce binder content where the performance is excessive.

Mandating fixed replacement levels for sustainability reasons (such as a minimum of 50% GGBS for all concrete on a project) is also not advised. Whilst this may result in lower embodied carbon it may well be unsustainable in terms of resource availability. This is particularly poignant for high proportions of GGBS, which can be essential for technical reasons such as controlling heat in deep sections but is not a viable solution for carbon reduction due to limitations of global supply. Further guidance on this can be found in IstructE paper "The efficient use of GGBS in reducing global emissions".

5.2.2.1 Measures to reduce binder content

The exposure class system defined by Eurocode 2 is quite coarse with large differences between each class. Taking care over selecting the exact exposure class for each concrete can thus lead to a significantly lower minimum binder content. Avoiding the aggregation of exposure classes for multiple structural elements together within one concrete composition therefore also has the potential to avoid excessive use of binders.

Where compressive strength testing is being carried out, results should be monitored closely to identify excessive strength performance. Where identified the compositions should be carefully discussed with the supplier with a view to reducing binder content (taking care not to impair other required characteristics and maintaining the required limiting values of composition). Reducing binder content in this way can potentially result in commercial savings for a project as well as avoiding unnecessary embodied carbon.

5.2.3 Water/binder ratio

Not over-specifying the maximum water/binder ratio can both reduce binder content and give the concrete producer more flexibility in the mix design.

5.2.4 Combined performance category

The selection of appropriate combined performance category (CPC) is important for concretes to adequately resist the environment to which they are exposed and should be considered with care.

However, for concretes subject to relatively benign conditions (such as internal concretes), it can be advantageous to give more flexibility by leaving the selection of the CPC to the concrete producer, with the embodied carbon intensity of the mix managed directly via embodied carbon limits/classes rather than via dictating specific CPCs or even SCM percentages.

This is due to the supplier needing to consider contractor requirements such as early strength gain, workability, finish quality, etc. in the mix design. They may need to artificially adjust the overall binder content to achieve these requirements if the combination type is specifically dictated by the engineer.

Specifying these [for embodied carbon purposes] can lead to an overall increase in binder content, which could be counterproductive to the intent. Nevertheless, in most cases, a pure CEM I combination type can be precluded in the engineer's specification, as this signals intent for pushing lower carbon concretes without restricting suppliers' ability to achieve a carbon-optimal mix design.

5.2.5 Aggregate size/type

An optimised concrete will have the largest proportion of aggregate possible within its volume, with gaps between individual particles of aggregate being filled with smaller particles of aggregate to give optimal packing. Where there is sub-optimal packing, such as with poorly graded aggregate, additional cementitious paste is required thus increasing the binder content. In general, concrete producers (providing they have enough aggregate bins) will look to source well-graded aggregates as the binder is the most expensive constituent of the concrete.

Maximum aggregate size is another consideration. Smaller aggregates have a larger surface area per unit volume, requiring more water to produce a concrete at equal consistence, so increasing the binder content at a specified water/binder ratio. Although 40mm aggregate may be specified, it is not usually stocked by suppliers, but it is worth considering for mass concrete construction. 10mm aggregate may be required where there is congested reinforcement or low nominal cover, however this will result in an increase in total binder content of the concrete. Therefore, wherever possible well-graded 20mm aggregate should be specified, with care taken to avoid congested reinforcement and hence smaller aggregate. The use of couplers rather than laps may also assist with this.

5.2.6 Early strength requirements

High early strength requirements can often result in a greater binder content than that required for the design strength; alternatively, this may result in binders with a greater proportion of CEM I being used to achieve the high early strength, with 28-day strength greater than that needed for the design. Both options will result in an increase in the embodied carbon of the concrete.

Wherever possible, early strength requirements should be determined by the specialist concrete contractor, as they will be in the best position to understand the balance between early strength and embodied carbon.

To reduce potential knock-on effects, programme constraints should be challenged. Digital sensors employing the maturity method can also be used to optimise strength attainment at the required time of formwork removal, stressing etc. An additional layer of back propping to manage slower strength gain may also be appropriate on some projects.

Consideration should also be given to when the concrete must meet characteristic strength relative to the construction programme. For example, can 56-day characteristic strength concretes be used in piles as full characteristic strength would not be required until after 56 days?

5.3 Novel concretes

In some ways, the term 'novel concretes' is a misnomer as it is rare that a concrete is truly novel. It usually refers to concretes that contain a constituent or constituents that either do not conform to a standard for their use in concrete, or BS 8500 does not give guidance on their use.

A range of concretes have been assessed by the BSI technical committee as being safe to use in concretes designed and cast to standards such as Eurocode 2.

Most 'novel' concretes will also meet these requirements but have not been assessed by BSI, and so assumptions about fire resistance, durability, creep, elasticity etc. may not hold. In these cases, the concrete will need to be tested to show that the requirements have been met.
It is important to note that BS 8500, BS EN 206 and Eurocode 2 all allow for concretes to be assessed by 'Design Assisted by Testing' and this route could even be used on codified concretes to optimise their performance.

The suite of tests required for 'novel concretes' depends on the risk and the application. To test the mechanical and physical properties of concrete can take a significant period of time. Measuring sulphate resistance, for example, could take up to 2 years. It is beneficial to undertake testing early in the specification process, and to only choose the tests required for the end use in mind. The Low Carbon Concrete Routemap offers further guidance on this matter (1).

5.3.1 BSI Flex 350 – Alternative binder systems for lower carbon concrete

At present, the principal means of developing a performance specification is via the BSI Flex 350 standard. Although this is not currently a recognised method under BS 8500 or BS EN 206 it can however support DAbT in accordance with BS EN 1990:2002 Eurocode - Basis of Structural Design cl. 5.2 'Design Assisted by Testing' (26).[9]

The BSI Flex Standards offer an effective means of quickly introducing standardisation in response to an identified market need. This route is particularly beneficial where knowledge and approaches are likely to develop rapidly, as each iteration of a BSI Flex reflects a current view of good practice and affords its users to provide feedback for incorporation into the BSI Flex as it is being developed.

The market need addressed by BSI Flex 350 is for a common approach to adoption of lower carbon concrete technologies which are not covered by recognised standards (Eurocodes, BS EN 206, BS EN 197-1 or BS 8500).

Although BSI Flex 350 has been written from the perspective of assessing alternative binder systems for lower carbon concretes, it provides a testing framework that could be used to assess any concrete for specification by performance through DAbT.

In practice, DAbT means that the designer produces their design using the Eurocode assumptions of the performance of 'conventional' concretes. These assumptions are well established but conservative.

The innovative, lower carbon concrete mix is then tested extensively to provide empirical evidence of performance. The data from these tests is then reviewed by the designer to validate the assumptions made, and the design is then adjusted accordingly.

BSI Flex 350 outlines a potential scope to support a DAbT specification, identifying the test methods for assessing various properties of the concrete. What it does not do is set out the limits for acceptance for test results, as the intention is for the data to be assessed by the designer to understand how the design might need to be adjusted to ensure durability of the structure.

Projects intending to use the DAbT method should be cognisant of Building Regulations' Materials and Workmanship: Approved Document 7, which places a responsibility on project teams to ensure that materials are of a suitable nature and quality in relation to the purposes and conditions of their use (30). Note also clauses 1.16 and 1.17 which refer to the use of independently accredited testing services by UKAS or equivalent. Whilst not mandatory, the use of accredited testing services provides a means of showing that the tests can be relied on.

9 Also see Annex D: D3.1b [material properties], D3.1d [confirm elements/ systems perform as expected] and D3.1g [confirm behaviour of as built elements].

6.0

Embodied carbon data management

6.1 Target setting

Project embodied carbon targets for concrete should be led by the client's ConcreteZero and wider net zero commitments and form part of the project brief. The structural engineer, civil engineer, principal contractor and contractor should be afforded the opportunity to challenge the brief and specification to align with their own net zero commitments.

Targets often take the form of:

- Overall project upfront and whole lifecycle embodied carbon maximum and target performance. For example, for building projects an upfront embodied carbon limit may comprise a limit on $kgCO_2e/m^2$GIA (lifecycle modules A1-A3); whereas infrastructure projects may find a weighted mean per unit volume more appropriate, such as $kgCO_2e/m^3$, lifecycle modules A1-A3 (17).
- A target SCORS rating for structural elements (18)
- (Sub) target to use concrete with (a weighted mean) embodied carbon below a certain threshold, often referring to a classification system (12), or the ConcreteZero Low Embodied Carbon Concrete Threshold (31).

While the market benchmarks and classification systems can be used to inform the selection of specific targets for concrete mixes, the client and engineer should remain sympathetic to the fact that many variables other than strength class (as highlighted in Section 5) affect the embodied carbon of concrete. Accordingly, project teams may seek to agree targets at a more granular level, where reliable data exists.

This section covers how high-level carbon targets can be translated into targets for the embodied carbon of concrete specified in a project.

6.1.1 Translating targets into concrete specifications

It may be useful to introduce quantitative embodied carbon targets into the concrete specification. The ability of specifiers to introduce these quantitative clauses will depend on the data they have available to them, the reliability of that data, and their confidence that they can avoid introducing any unintended consequences.

In general, the recommended approach to developing these quantitative clauses is that:

- Any data used to develop concrete specification clauses should be relevant to the specific use case in question.
  - For example, one should avoid applying an embodied carbon value from a foundation concrete to a slipform mix.
- The source of the data should be understood in as much as it impacts the use of any target developed from it:
  - For a specification clause developed using a dataset based on generic, sector-average emission factors, allowances should be made if process-specific calculations of embodied carbon (i.e. from an EPD) are provided by a supplier.
  - The embodied carbon emission factors used should be consistent or, if inconsistencies exist, their implications accounted for.
- The best available data should be used, and the underlying nuances contained in larger datasets leveraged to gain additional insight.
  - The best available data might be from a recently completed similar project, or an aggregation of data collected across an organisation, or an initiative, as in the case of the ConcreteZero reporting data, see Section 6.1.3. In these larger data sets, understanding why embodied carbon values vary for a particular application could further inform the specification process.
- The concrete specification clauses should be open to challenge, and feedback from stakeholders integrated where relevant.
  - This is crucial to ensuring that the specification reflects all the constraints which may impact a specification rather than specifying for a lower embodied carbon concrete in isolation, which will lead to unintended consequences.

6.1.2 Guiding parameters to inform embodied carbon targets in concrete specifications

As presented throughout this report it is recommended that embodied carbon targets are developed collaboratively and with the specific requirements of a project in mind.

However, it is recognised that poor data availability on what good and best practice embodied carbon targets are, is a barrier to the specification of lower carbon concrete. As such ConcreteZero has developed the guiding parameters set out in **Table 5** and **Figure 6** that can be referred to by specifiers, alongside other data where available.

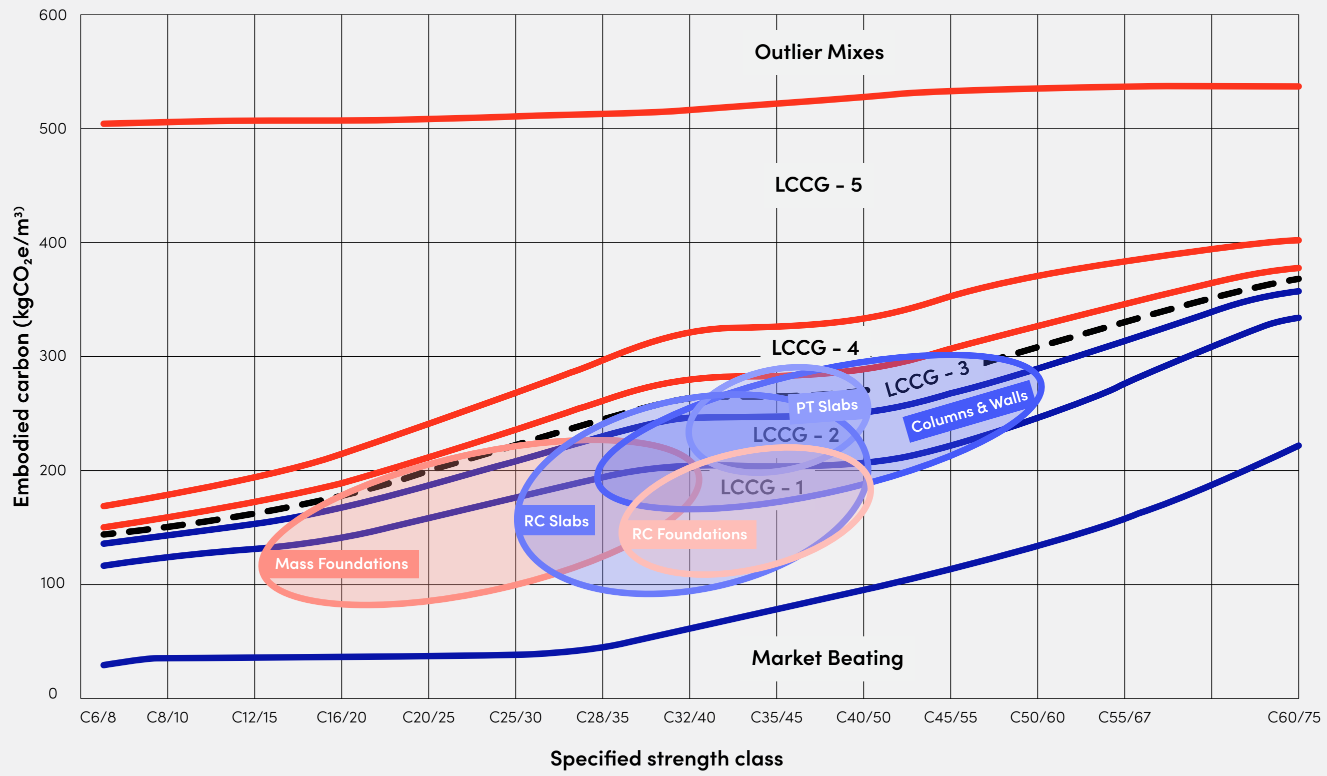
The best practice and good practice ratings shown for each element type are intended to represent concrete that is currently available on the UK market for each use case, and which would contribute to a general decrease in industry-wide emissions. However, it is also accepted that in specific cases with challenging constraints, these lower carbon values may not be achievable, in which case higher carbon targets may be suitable.

Table 5: Table of guiding parameters for concrete embodied carbon, referencing the 2024 LCCG Market Benchmark, for a range of common element types

Element type	Typical specified strength classes	Best practice specification	Good practice specification	Where specific challenging constraints apply
Mass foundations	C12/15 – C32/40	LCCG 1	LCCG 1	LCCG 2
Reinforced concrete (RC) foundations	C30/37 – C50/60	LCCG 1	LCCG 2	LCCG 3
Reinforced concrete (RC) slabs	C25/30 – C45/55	LCCG 1	LCCG 2	LCCG 2
Post tensioned (PT) slabs	C32/40 – C45/55	LCCG 2	LCCG 3	LCCG 4
***In situ* columns & walls**	C28/35 – C50/60	LCCG 2	LCCG 3	LCCG 4

Reference to only the LCCG Market Benchmark for these guiding parameters is to reinforce the fact that they have been developed for the UK market.

Figure 6: Graphical representation of the guiding parameters from Table 5, mapped onto the 2024 LCCG Market Benchmark, illustrating the typical range of strength classes specified, and embodied carbon levels achievable in the UK, for a range of common element types.



6.1.3 Plan to use ConcreteZero reporting to inform concrete specification targets

Since 2023, ConcreteZero members have been involved in developing and subsequently trialling a reporting pilot, in which mix-level data for the concrete they poured, procured, or specified is submitted on a six-monthly basis.

Reporting is key for monitoring member progress towards the targets that form part of the ConcreteZero commitment.

The resulting extensive dataset details what concrete mixes were used in what type of element across a range of member projects between July 2023 and December 2024. The next step is to analyse the data in order to develop guiding parameters that support specifiers and the wider market to better understand current business-as-usual and progressive best practice for concrete embodied carbon by element type.

Case Study

Byrne Bros

Using organisational data to inform element level embodied carbon limits

Byrne Bros (Formwork) Ltd is a specialist concrete frame contractor, headquartered in London, taking a data-driven approach to optimising the embodied carbon of the concrete on the projects they are involved in.

Byrne Bros has been increasingly focused on reducing the embodied carbon of the concrete they use, aiming to lower the associated emissions while improving their carbon reduction offering for clients. This led, in 2020, to the development of an internal process for collecting and analysing the embodied carbon from concrete used on projects by structural element.

This process required the compilation of data extracted from their internal accounting system, project concrete mix trackers, mix design certificates, as well as reference to best-available emission factors for the constituents of concrete. While the process continues, in 2021 Byrne Bros was the first contractor to openly share their concrete use data with the industry to help encourage a step-change in transparent reporting and ultimately support the specification and use of lower carbon concretes, see **Table 6** and **Table 7.**

Critically they also record where each delivery of concrete is used within the project, allowing for the analysis of concrete embodied carbon distribution not only by strength class, but also by use case, i.e. the type of concrete element. An excerpt from this analysis is presented in **Table 7.**

Initially developed using data from 12 projects completed during 2015 to 2020, this process continues to be applied by Byrne Bros to grow and refine an evidence base that allows them to inform an increasingly sophisticated specification process and continually maximise embodied carbon reductions from concrete across their projects.

Table 6: Emission factors used and transparently presented in the 2021 analysis. These emissions factors are included here for illustrative purposes only and should not be used instead of the latest industry values.

Material	Emission factor ($kgCO_2e/t$)	Reference
CEM I	860.00	(33)
GGBS	79.60	(33)
Fly ash	0.10	(33)
Silica fume	7.00 E-06	(32)
Limestone fines	8.00	(33)
Water	0.34	UK gov conversion factor
Quarried stone	3.63	BREEAM 2018 New Construction England 1.0, Table 10.10. London value was used for 'marine dredged sand or gravel'
Sand and gravel	3.43	
Recycled aggregate	4.65	
Secondary aggregate	3.82	
Marine dredged sand or gravel	8.43	
Lytag	249.00	From Lytag's Type III EPD

Note: Since 2021, more of the emissions associated with blast furnace steel production are being allocated to GGBS (because its value has increased), using the economic allocation approach. ConcreteZero currently uses 168kg/CO_2e/t in its reporting framework.

Case Study

Table 7: Excerpt from the 2021 analysis summarising the mean binder content, CEM I replacement, and embodied carbon, by concrete strength class and use case

Use	Strength class	Mean binder content (kg/m³ by mix)	Mean CEM I replacement (% by mix)	Mean CO_2e (kg/m³ by mix)
Basement suspended slabs	C25/30	377	40	217
	C32/40	378	46	200
	C40/50	437	35	263
	C45/50	460	50	226
	C50/60	483	50	236
	Total	**414**	**44**	**223**
Capping beam	C32/C40	240	40	201
	C50/C60	500	40	284
	Total	**420**	**40**	**242**
Columns and Walls	C32/40	366	40	213
	C35/45	443	28	288
	C40/50	453	32	283
	C50/60	470	27	312
	C60/75	475	40	269
	Total	**457**	**31**	**292**

6.1.4 Reporting

The core function of greenhouse gas reporting is to allow transparency and accountability of organisations' climate impact and provide them with the measurement needed to monitor and manage improvements in line with sector-wide decarbonisation targets. For concrete users the embodied carbon of concrete often represents a significant proportion of their indirect (scope 3) emissions, making collecting sufficiently accurate and granular detail an imperative.

Accurate data collection requires a consistent approach, data sharing, and collaboration. Those furthest removed from the purchasing and pouring of concrete, like clients and engineers, rely on the principal contractors to collate and share the appropriate data with them, which in turn is sourced from the various contractors on the project and ultimately the concrete suppliers.

Where available, a concrete mix's actual emissions as provided by an EPD should be used. EPDs for the concrete constituents should also be used where available. However, organisations and initiatives, including ConcreteZero, choose to also calculate the embodied carbon of concrete mixes using baseline emission factors included in recognised databases such as the ICE DB v4.0 (33), MPA Factsheet 18 (34) etc. Reasons for doing this include:

- EPDs are unlikely to be available at the design stage.
- Preference for a common set of assumptions, while EPDs can be developed using variable and difficult to identify assumptions.
- Easier evaluation of how mix design impacts embodied carbon.
- It is key to ensure that the carbon accounting process is agreed upon and is consistent within the relevant decision-making framework.

Collecting and progressing reporting towards actual emissions data should not be overlooked as:

- Actual emissions measurements will immediately capture any decarbonisation interventions that might take years to show up in the baseline emission factors.
- The data is specific to a particular supply-chain and can form the basis of enhanced supplier engagement, and prioritisation of decarbonisation efforts.
- Using actual emissions data doesn't prevent the baseline emission factors to be applied in the 'post processing' of collected data.

Data should then be presented in a consistent way that is easily relatable in the market in question. In the UK, the LCCG benchmark is a leading system, while the GCCA Global Banding and Universal EC classification systems are also widely recognised. Reporting the embodied carbon of concrete should be accompanied by the emission factors that were used and a measure of the quality of the underlying data, as described in the next section.

6.1.5 Data quality

To help drive increased accuracy in emissions reporting and allow data segmentation it is recommended that those reporting on concrete's embodied carbon include a rating as to the quality of underlying emissions data.

The proposed hierarchy (see **Table 8**) was developed by the Infrastructure Client Group's Concrete Decarbonisation Accelerator and is aligned with the principles of Figure 6 of the *UK Net Zero Carbon Buildings Standard* (21).

Calculating a volume-weighted data quality rating supports transparency as to the provenance of the underlying emissions data and encourage a shift towards higher-quality verified, reported data over time.[10] As overall reported embodied carbon will depend on the derivation of the underlying emissions data as well as fundamental changes in emissions intensity of the material, a way to track data quality over time is critical.

10 This approach is analogous to one established in the financial sector, by PCAF, for monitoring the data quality of emissions associated with financial activities (Scope 3 Category 15)

Table 8: Hierarchy of emission factor sources for concrete, with corresponding data quality ratings.

Data quality rating (1=best)	Categories of concrete emission factor sources	Description of data source hierarchy within the categories
1	An embodied carbon rating should be sourced from an EN15804+A2 compliant Environmental Product Declaration (EPD) if a product- or mix-specific EPD is available.	Where there are multiple EPDs available, the following hierarchy should be implemented: • Product/mix-, plant- and batch-specific EPD • Product/mix- and plant-specific EPD • Product/mix-specific EPD i.e. concrete family EPD • Products within a sector • Product sector EPDs
2	If a product- or mix-specific EPD is not available, the embodied carbon rating should be sourced from a product or mix specific calculation.	The supplier should use a verified or other auditable tool or method. The supplier may be asked to submit full details of embodied carbon rating calculations for independent audit. The following hierarchy should be implemented: • Product- or mix-, plant- and batch-specific calculation • Product- or mix- and plant-specific calculation • Product- or mix-specific calculation The calculation must be accompanied by the carbon conversion factors or EPDs used for the constituents and their source.
3	If a product- or mix-specific calculation is not available:	• Designers should use sector EPDs or industry databases until a product- or mix-specific embodied carbon rating is sourced. • Suppliers or contractors should use the embodied carbon value of the top of band E4 (5th percentile of the market) given by the LCCG Market Benchmark available 3 months prior to use.

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