DECARBONISING PRECAST CONCRETE

TANGIBLE INNOVATION THROUGH PARTNERSHIP

FORTERRA

Foreword

"Our research proves that if you have a long term view and can develop a repeatable design and pipeline of work that captures mature data through BIM processes, you can create a platform for continuous improvement. Our approach has enabled the right partners from the value chain to review every decision through the lens of carbon, resulting in both significant and marginal savings that are technically ready and commercially viable."

John Handscomb
Founding Partner, Akerlof

"This study demonstrates how collaboration through the supply chain can bring subject matter experts together to develop innovative solutions for decarbonising. We look forward to utilising and embedding such solutions in the Ministry of Justice's New Prison Programme."

Gareth Jones
Head of MMC & Technical Services, Ministry of Justice

"With the UK committed to net zero carbon by 2050, it's important for businesses to look for opportunities to innovate and collaborate with others to develop practical sustainable solutions that can be industrialised. Our involvement in this project was a natural and important step for us as we look to decarbonise our entire business. It's important to emphasise that the positive results achieved in this research scheme can be replicated across all construction sectors using precast concrete."

Mike Nelson
Bison Precast Commercial Director

"By looking in the round at one important aspect of delivering today's buildings, we are confident we'll find a relatively simple, cost-effective and eminently scalable way to reduce carbon emissions, benefiting our clients' communities as well as contributing to the UK's efforts to hit its net zero carbon target."

Simon Harold
Business Development Director, PCE,

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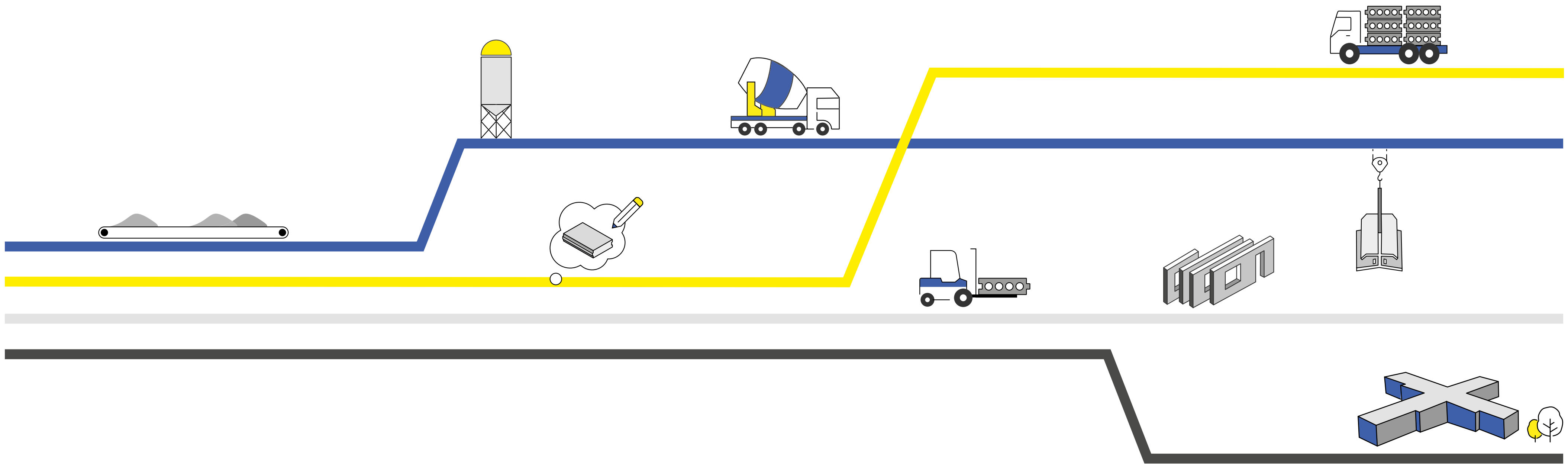


Context

PRECAST CONCRETE SOLUTIONS

Precast concrete is one of the most widely adopted Modern Methods of Construction (MMC), with AMA Research forecasting that the UK's precast concrete sector will grow by 18% to £2.3 billion by 2024.[1]

The advantages of using MMC are well-established. Manufacturing elements of a building offsite is associated with a variety of benefits including better quality construction, improved health and safety, a faster construction programme as well as predictability of time and cost - on both a whole life and project basis.[2]

Examples of MMC solutions using concrete can be found within all categories of the MMC definition framework, ranging from whole building and structural systems, to precast components such as walls, stairs and floors. Elements can be of bespoke design or standardised, offering the opportunity for creativity and efficient construction best suited to a project's requirements.[3]

ACHIEVING NET ZERO

At the same time, the globe and the UK are working towards 'net zero' carbon reduction targets that align with a 1.5C' temperature increase. As a cement-based product, concrete manufacture is a fuel-intensive, electro-intensive and CO_2 intensive process, said to be responsible for 4-8% of the world's CO_2 emissions.[4]

Research identifies that material structures can be refined to minimise their carbon impact. The Industrial Decarbonisation and Energy Efficiency Roadmap to 2050 exposes an urgent need for UK cement manufacturing to become more resource, energy and carbon efficient, outlining an action plan for Government and industry to pull together to ensure decarbonisation is achieved, cost-effectively.[5]

Through this project, our team has become more aware that the road to true net zero embodied carbon will be steep. However, we hope that the solutions provided within this report will help catalyse the implementation of future innovation, particularly those in the initial stages of technical readiness.

THE IMPACT OF CONCRETE

According to the sector Roadmap, the deployment of new cements, realised at design, could save circa 150,000 tCO_2 by 2050. Significant barriers exist however, on both supply and demand sides (not least cost and knowledge gaps) limiting their application to date.

The UK's first carbon neutral cement[6] was launched less than 18 months ago, yet has not been demonstrated at scale, with clients, specifiers and contractors cautious of novel building materials. Research by Chatham House identifies that the majority of products have failed to achieve commercial viability; that sector innovation is incremental, with concerted effort in large-scale demonstration projects required to realise a breakthrough.

In an industry challenged to reinvent and address strategic priorities, such as net zero carbon, business survival is a priority. The Minerals Product Association (MPA) has expressed the need to develop solutions that are technically feasible and economically viable, maintaining the competitiveness of domestic manufacturers.

However, increased demand for products and market growth, stimulated as a result of COVID, without corresponding innovation, could represent a threat to the clean growth strategy of the UK.

Focussed R&D is therefore required to work alongside accelerated infrastructure, to ensure this is not compromised.

[1] *AMA Research, "Bricks, Blocks and Precast Concrete Products Market Report UK 2020-2024", 2020*
[2] *CIRIA, "Methodology for quantifying the benefits of offsite construction", 2020*
[3] *Minerals Product Association, "Offsite Concrete Construction: A guide to the design and construction of precast concrete in buildings", 2019*
[4] *Chatham House, "Making Concrete Change Innovation in Low-carbon Cement and Concrete", 2018*
[5] *Department of Energy and Climate Change and Department for Business, Innovation and Skills "Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050 - Cement", 2015*
[6] *CEMEX Launches UK's First Net Zero Ready Mixed Concrete Product, https://www.cemex.co.uk/-/cemex-launches-uk-s-first-net-zero-ready-mixed-concrete-product, 2020*

Context

BREAKTHROUGHS IN CARBON REDUCTION

Ambition and intent to prioritise sustainable outcomes through innovation are often unrealised due to the perception of risk of prospective adopters. Low-carbon solutions demonstrated at small scale have regularly faltered in breaking into the mainstream due to concerns around uncertainty, particularly in reference to structural integrity. Status quo bias and loss aversion prevail.

Innovate UK's Sustainable Innovation Fund therefore provided a welcome opportunity to freely explore all areas of decarbonisation of a concrete structure, enabling us to challenge existing design and specification rules for optimum carbon outcomes throughout the value chain.

By building on the foundation of existing research we were able to expedite the development of a commercially-viable, decarbonised precast concrete product, using a set of solutions that can be implemented by companies in the immediate to considerably reduce the embodied carbon of structures against industry baselines.

By adopting our recommendations within this report, companies could achieve a 40% reduction in embodied carbon, against the Inventory of Carbon and Energy (ICE) embodied carbon database for building materials,[7] let alone when further innovation is applied.

Throughout this report, we signpost where sustainable solutions can be implemented to encourage and support the whole value chain to press forward to net zero by 2050.

It is our hope that this work will stimulate and form the basis of further advancements with the concrete sector and demonstrate the power of collaboration in providing inspiration to other net zero initiatives.

Precast houseblock at HMP Five Wells

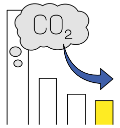
[7] *University of Bath, The ICE Database, https://circularecology.com/embodied-carbon-footprint-database.html, 2019*

Objectives: challenging our way of thinking

Concrete is a versatile material that can be manufactured in a variety of types and strengths to create specific properties for a diverse range of applications. The overarching ambition for our team was to reduce the carbon impact of structural precast concrete, however, all parties were resolved that any the solution must be suitable for practical application within the industry.

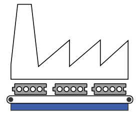
We therefore set out to achieve the following:

CARBON REDUCTION



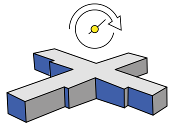
Solution achieves a significant carbon reduction from the baseline

EASE OF MANUFACTURE



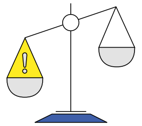
Solution is compliant with codes and regulation and is technically ready for application across multiple sectors including residential and healthcare

STRUCTURAL STRENGTH



Solution is optimised, eradicating carbon by focusing on interactions at every stage of the process

COMMERCIAL VIABILITY



Commercially viable option for the market in terms of price, risk and production

To best achieve these objectives, we decided to break from the default approach - shifting from traditional linear thinking to a circular, more collaborative process.

LINEAR PROCESS

Due to the linear nature of supply chains, organisational R&D has the tendency to be focused on a company's specific area of expertise, as well as being constrained by the inevitable barriers imposed by risk management and commercial agreements. Any innovation is therefore sub-optimal and confined to certain parts of the process, which precludes any influence over the system as a whole. Organisations are also typically risk averse, taking responsibility and ownership solely for their own operational impacts within the value chain.

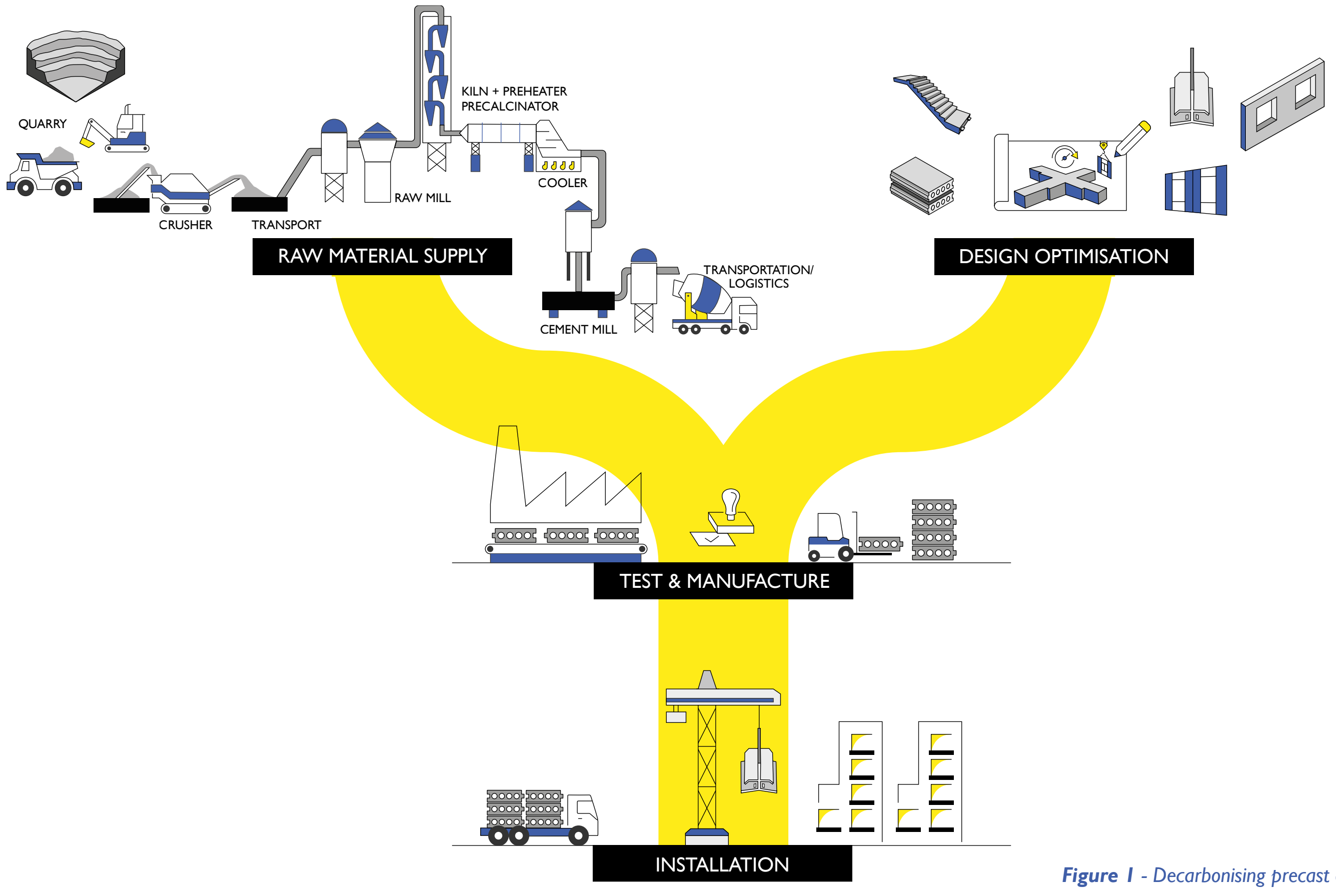


Figure 1 - Decarbonising precast concrete

Objectives: challenging our way of thinking

CIRCULAR COLLABORATIVE PROCESS

Supported by the Innovate UK Sustainable Innovation Fund, the project partners were able to create an integrated team from across the value chain, out of the constraints of both commercial agreement and project timelines. With a diverse range of knowledge and experience to challenge every decision through the lens of carbon rethinking the traditional linear process and developing solutions beyond our respective organisational boundaries, with all stakeholders co-responsible for sustainable outcomes.

Our approach was iterative and consisted of the following steps:

COLLABORATE - to understand where carbon existed within the value chain and the options for reduction

OPTIMISE - to research, model, trial and optioneer

TEST - to undertake large-scale tests to establish confidence and identify areas for further improvement

REFINE - to implement improvements or identify opportunities for future enhancements

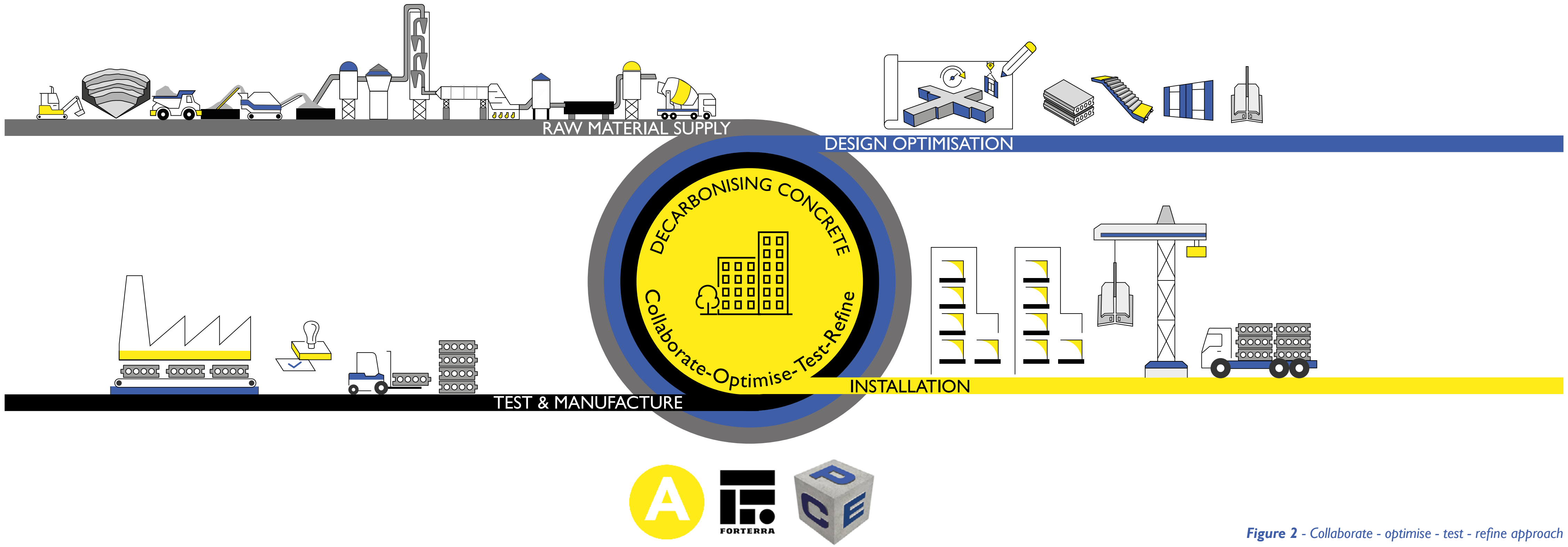


Figure 2 *- Collaborate - optimise - test - refine approach*

The partners

We recognised that sustainable development would be best achieved through multi-stakeholder partnerships that share knowledge, expertise, technology and financial resources, aligning with the UN Sustainable Development Goal 17[8] partnership for the goals. We therefore mobilised the value chain to look at all decisions made within design, manufacture and construction, through a carbon lens. Our *COLLABORATE - OPTIMISE - TEST - REFINE* approach meant we tested every decision as a collective, capturing each opportunity and driving out waste.

PARTNER COMPANIES

AKERLOF

A consultancy specialising in Modern Methods of Construction (MMC) and nominated as Offsite Pioneer of the Year (2020), Akerlof Ltd advises the private sector, Government departments and the Construction Innovation Hub (the Hub) in their adoption and implementation of MMC.

Akerlof led the Innovate UK bid, assembled the partners and managed the project as PMO, collaborating with all external stakeholders including Innovate UK and the Ministry of Justice.

FORTERRA

Forterra is a leading manufacturer of a diverse range of clay and concrete building products used extensively within the construction sector, and employs over 1,800 people across 18 manufacturing facilities in the UK. It is the second largest brick and aircrete block manufacturer in the country and the only producer of the iconic London Brick. Other trusted brands from Forterra include Thermalite, Conbloc, Ecostock, Butterley, Cradley, Red Bank, Bison Precast, Jetfloor and Formpave.

PCE Ltd
Est 1973

A market leader in the design and build of offsite hybrid engineered structures and a recognised integrator of MMC, PCE Ltd was overall winner at the Offsite Awards in 2018.

The company is also working in conjunction with Akerlof as part of the Hub Platform project and has worked with both Forterra and Curtins for many years across a wide range of projects, including MoJ prisons at HMP Five Wells and HMP Glen Parva.

SUPPORTING COMPANIES

curtins

An award winning engineering design consultancy, Curtins Ltd has collaborated with PCE for the past 15 years to develop innovative precast design solutions, providing a pivotal role in optimising designs and material use at source.

Curtins has played an important role, alongside PCE, to model the embedded carbon within the case study project and develop refined engineering solutions.

ACCELAR

A strategic consultancy helping clients manage risks and opportunities in moving towards clean growth, Accelar Ltd has worked closely with all collaborators to set the measurement standard and map carbon within the existing process, as well as undertaking further works to support the whole life assessment.

REVIEWING COMPANIES

ConstructionLCA

Jane Anderson of ConstructionLCA is an approved verifier for several EN 15804 EPD programmes, and has provided a critical review of our studies to ISO 14044 and EN 15978. Jane is the nominated UK expert to CEN and ISO standards committees, dealing with environmental assessment at construction product and building level, and has delivered the peer review of the carbon calculators within this project.

[8] *United Nations, "Goals - 17, Strengthen the means of implementation and revitalize the global partnership for sustainable development", https://sdgs.un.org/goals/goal17, accessed 26 May 2021*

Our team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PCE Ltd


LYNDSEY VIPOND
Senior Consultant (Carbon Strategies)
Accelar Ltd


JOHN HANDSCOMB
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PCE Ltd


JANE ANDERSON
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WAYNE CASTLEDINE
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Forterra Building Products Ltd


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MATTHEW DAVIDSON
Senior Engineer
Curtins Ltd


ALEXANDER LORINCZ
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Curtins Ltd

Our approach

Through our *COLLABORATE - OPTIMISE - TEST - REFINE* approach, our team focussed on the following workstreams:

1. **Production and logistics process review:** to identify opportunities for a reduction in carbon emissions
2. **Developing and testing the technical specification:** considering novel cement and / or clinker substitution technologies and admixtures (including testing mixtures that are workable and can be used productively in manufacture)
3. **Design solution optimisation:** focusing on reducing waste to ensure minimal material use at source

These workstreams were underpinned by the development of two Carbon Calculators:

CONCRETE CARBON CALCULATOR

Accelar initially designed a Concrete Carbon Calculator, aligned to PAS 2050 and EN 15804, to assess the carbon footprint of the concrete within the precast components, together with an assessment of the impact of other materials used such as rebar, insulation and pegs, as well as the overall manufacturing impact.

BUILDING LEVEL CARBON CALCULATOR

Outputs from the Concrete Carbon Calculator were then integrated within a Building Level Carbon Calculator, developed by PCE and aligned to EN 15804 and EN 15978, which evaluated our 'real world' custodial project constructed using these panels over its life cycle.

Both calculators were peer-reviewed by ConstructionLCA to ensure they complied with the relevant standards, demonstrating confidence in our approach and confirming that our calculations had been applied with professionalism and rigour.

A combination of optioneering of methods and meticulous testing of solutions ultimately enabled our product to reach technical readiness level 9, meaning that it was commercially viable and could be rolled out immediately for manufacture.

"Following the review, I am confident that the Concrete Carbon Calculator provides embodied carbon results for concrete and other materials used in the precast concrete factory compliant with the methodology of EN 15804, PAS 2050:2011 and EN 16757:2017.... I am confident that the Building Level Carbon Calculator provides embodied carbon results for the precast concrete elements and other related materials used in the prison building over its life cycle, compliant with the methodology of EN 15978, the RICS Professional Statement on Whole Life Carbon Assessment for the Built Environment and EN 16757:2017... Environmental Product Declarations (EPD) complying with BS EN 15804:2012 can be considered to be the same as the GHG emissions provided by PAS 2050:2011."

Jane Anderson, ConstructionLCA, May 2021

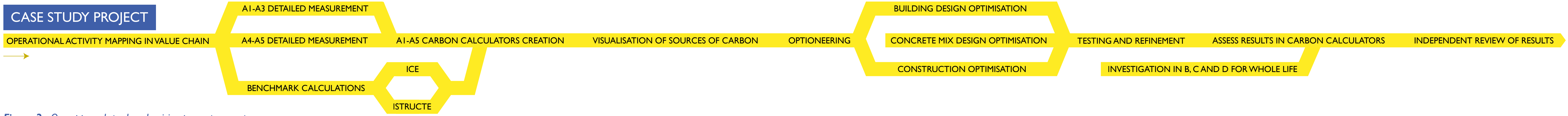


Figure 3 *- Our approach to decarbonising precast concrete*

Our approach

PROJECT SCOPE

The scope of our research included mapping the actual carbon from cradle to practical completion, using detailed data from our real world custodial project to ensure a high level of accuracy and understanding.

- Raw material extraction and supply [A1]
- Transport to manufacturing plant [A2]
- Manufacturing and fabrication [A3]
- Transport to project site [A4]
- Construction and installation [A5]

We also mapped from practical completion to grave, using industry-recognised data to better understand the impact of the precast system throughout its design life.

- Use [B1]
- Deconstruction and demolition [C1]
- Transport to disposal facility [C2]
- Waste processing [C3]
- Disposal [C4]
- Benefits and loads beyond the system boundary [D]

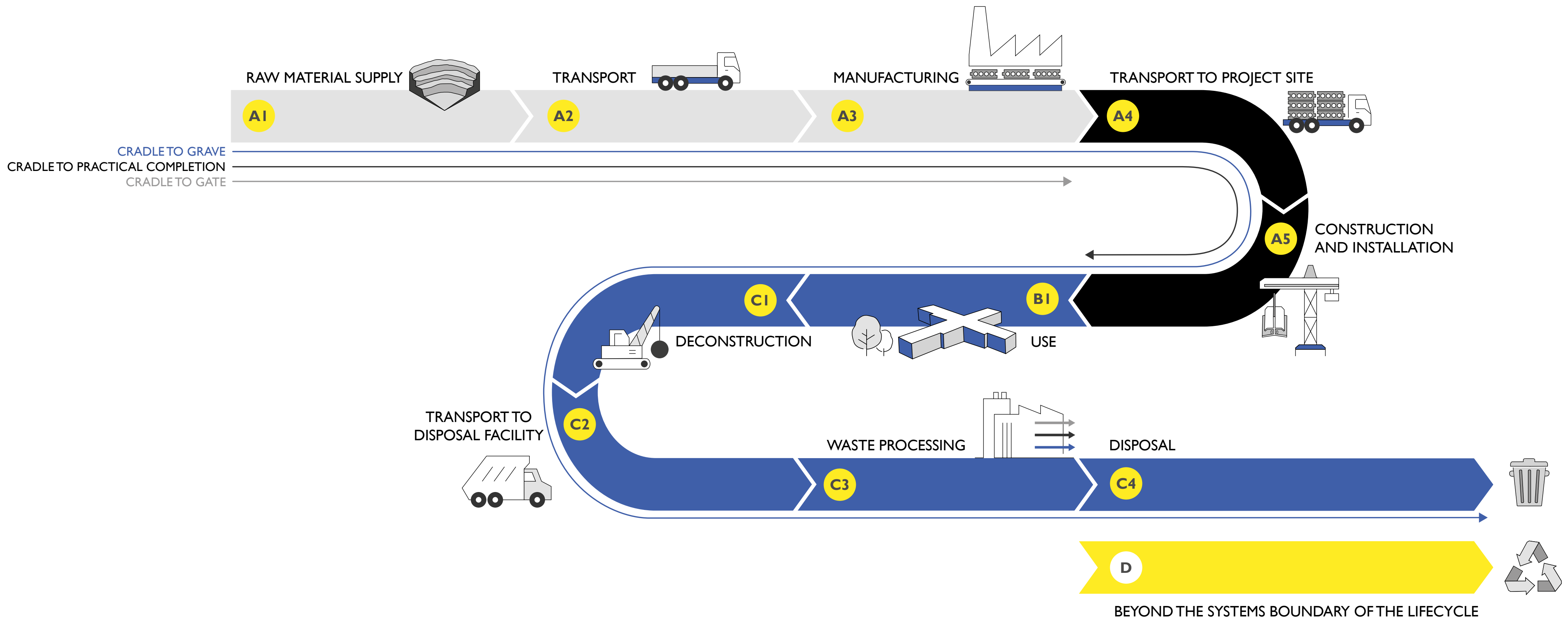


***Figure 4** - Lifecycle stages*

The 'real world' project

GROUNDWORK FOR THE CASE STUDY

Partner companies Akerlof, Forterra and PCE had previously worked together to deliver precast concrete solutions as part of a new standard - or 'platform' - prison design for the Ministry of Justice (MoJ).

The platform design applied to custodial facilities at HMP Five Wells and HMP Glenn Parva is maximising the use of repeatable, standardised precast components, with the aim of delivering prisons faster and more efficiently. The repeatable design is now being replicated further across the MoJ's 4 New Prisons Programme, which presented our team with the ideal opportunity for real world application. Leveraging our combined experience, we began to develop solutions against this baseline.

The Decarbonising Precast Concrete project supports both the MoJ's commitment to achieve net zero and deliver its modern methods construction strategy, whilst acting as a demonstrator to catalyse the broader industry to accelerate its decarbonisation commitments.

MINISTRY OF JUSTICE COLLABORATION

Our team and the project benefited hugely from close collaboration with the Ministry of Justice, not least due to the strong future pipeline for the platform design as part of the 4 New Prisons Programme, as well as possessing a standardised design that is considered exemplary to many, and that can be translated to other sectors and building types within the industry.

The MoJ's application of a platform design and standardisation of components enabled the wider impact of results to be better understood. In addition, their strategic focus on digitisation meant we had access to well-structured data from the design, manufacturers, suppliers and site teams, allowing the MoJ's digitised design to be optimised and providing us with a solid foundation for evaluation.

HMP GLEN PARVA

The data below was extracted from the HMP Glen Parva Houseblock Revit model, where the volume and weights for each precast package were considered.

- Number of identical houseblocks: 7*
- Number of units: 1,725
- Floor area: 1,560m^2
- Volume: 2,942m^3
- Total weight: 7501t
- Cement strength specification: C40/C50
- Design life: 120 years

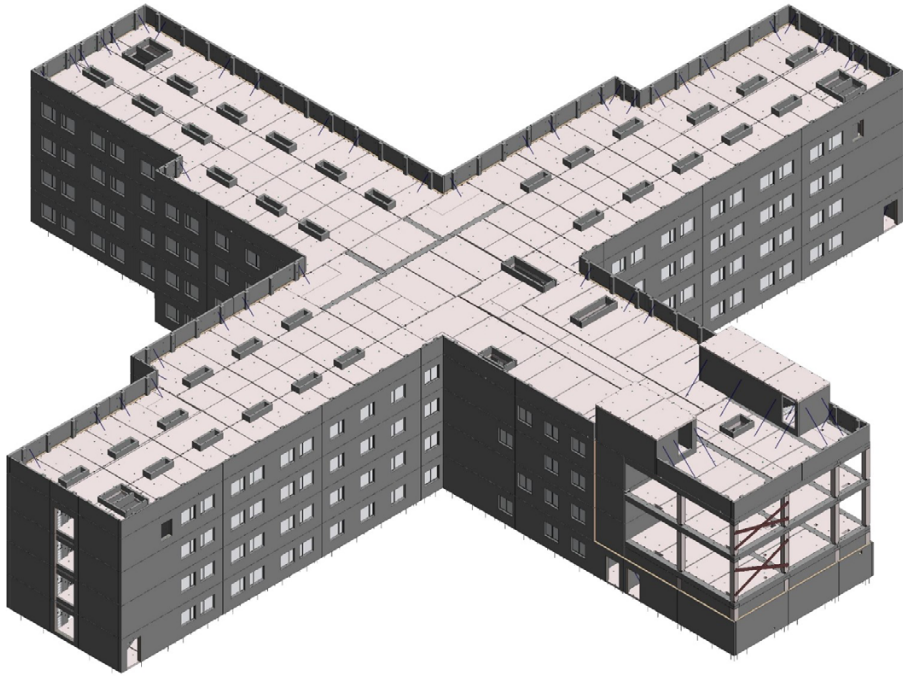


Figure 5 - Revit model of a houseblock (custodial accommodation) for HMP Glen Parva

*Entrance block and Care And Seperation Unit (CASU) were out of scope

Our journey to carbon reduction

By leveraging expertise from across the value chain, our team was able to achieve significant carbon savings. Our key activities are summarised below:

Establishing a method of measurement: We measured the embodied carbon (CO_2e) of the concrete structure of HMP Glen Parva, specifically, carbon emissions from the sourcing, transportation, fabrication and construction of all materials and products [A1-A5].

Establishing a baseline: Carbon savings were benchmarked against both the Inventory of Carbon and Energy (ICE) database and the Institution of Structural Engineers (IStructE) Structural Carbon Tool. The difference between the two databases is the assumption they make about rebar sourcing. The ICE database assumes rebar is sourced worldwide, whereas the IstructE tool assumes rebar is sourced more locally with a high recycled content. There was a varied approach across the supply chain to rebar sourcing and no mandate within the project specification for meeting a carbon factor. Throughout this report, we have quantified savings against both databases, appreciating that setting carbon content when sourcing reinforcement is a very easy win.

Improved mix: We developed and tested concrete mixes including the current HMP Glen Parva design and our optimised design, improving the mix to achieve a carbon saving of 12%.

Improved design: We further optimised the HMP Glen Parva design to minimise the use of materials, cutting down embodied carbon at the source by 5%.

Improved construction: We reviewed production and logistics operations, identifying opportunities to improve transport to site and installation, ultimately saving 3% carbon.

Whole life cycle: Finally, we investigated the carbon impact across the lifecycle.

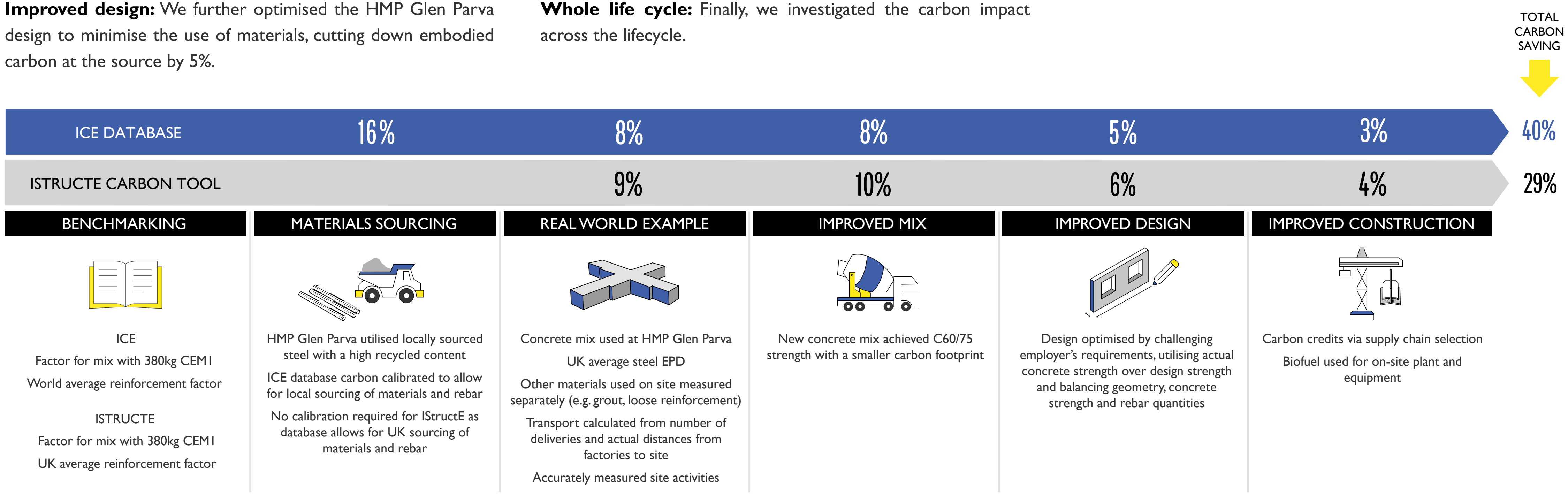


***Figure 6** - Optimised carbon reduction against ICE and IStructE benchmarks*

Visualisation of findings

The improvements made at each stage of our journey to carbon reduction are cumulative, with a net saving of 40% from the baseline ICE database scenario of 1,951,381 kgCO_2e per houseblock.

As HMP Glen Parva features seven identical houseblocks, the potential reduction across one new prison would be sevenfold at 5,454,091 kgCO_2e, quadrupling to 21,816,366 kgCO_2e across the entire 4 New Prisons Programme.

	PER PRISON HOUSEBLOCK	PER PRISON	4 NEW PRISONS	
ICE scenario kgCO_2e [A1-A5]	1,951,381	13,659,670	54,638,680	
Optimised scenario kgCO_2e (all solutions) [A1-A5]	1,172,226	8,205,579	32,822,315	
Reduction kgCO_2e	779,156	5,454,091	21,816,366	40%

Figure 7 *- Our reductions are within A1 and A5. Lifecycle B,C and D are not taken into account in this comparison. For the whole lifecycle view, please see pages 31-33*

A1- A5 CARBON REDUCTION PER HOUSEBLOCK

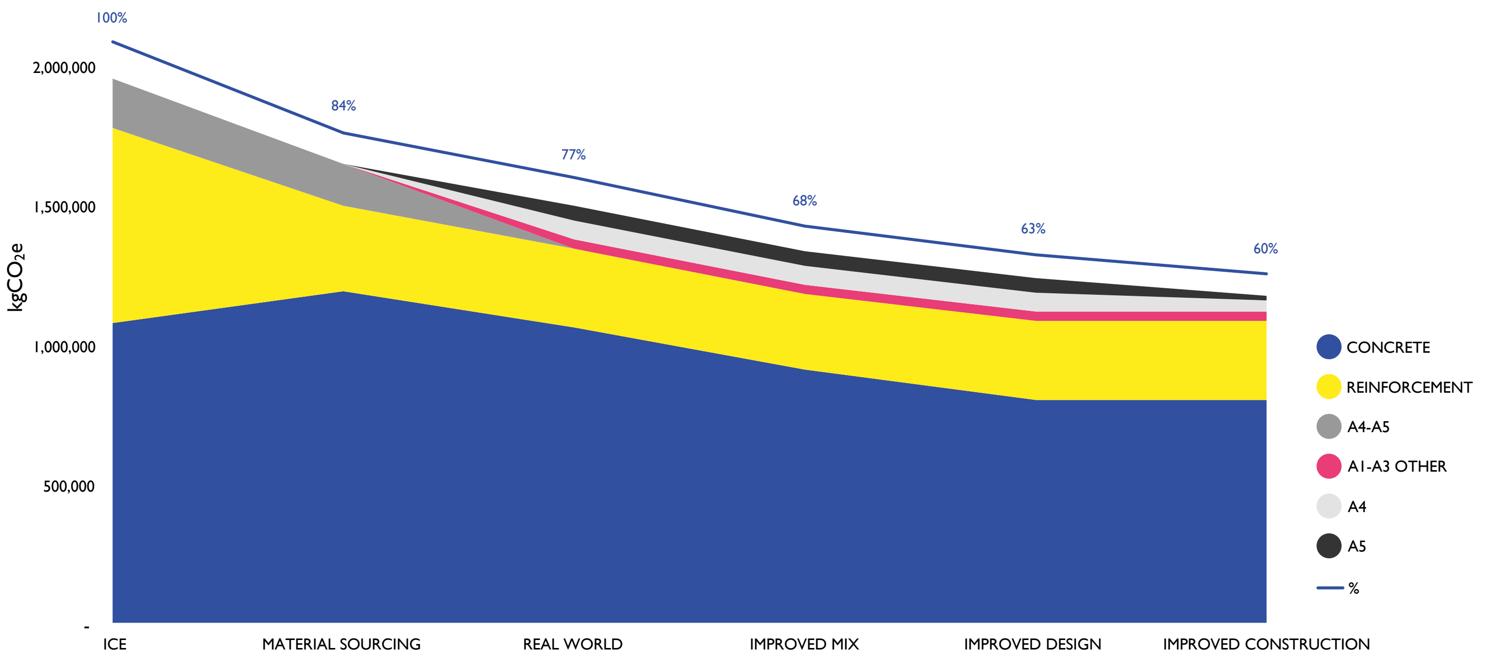


Figure 8 *- Carbon reduction per houseblock by reducing carbon within the sourcing, transportation, fabrication and construction of all materials and products*

Carbon-mapping

The starting point in our journey was to . Forterra undertook a detailed mapping exercise across their operations, determining both sources of carbon and their associated carbon emission factors. From this, we were able to visualise where carbon sat within the process and then work to optimise the process, providing solutions to reduce carbon at all stages.

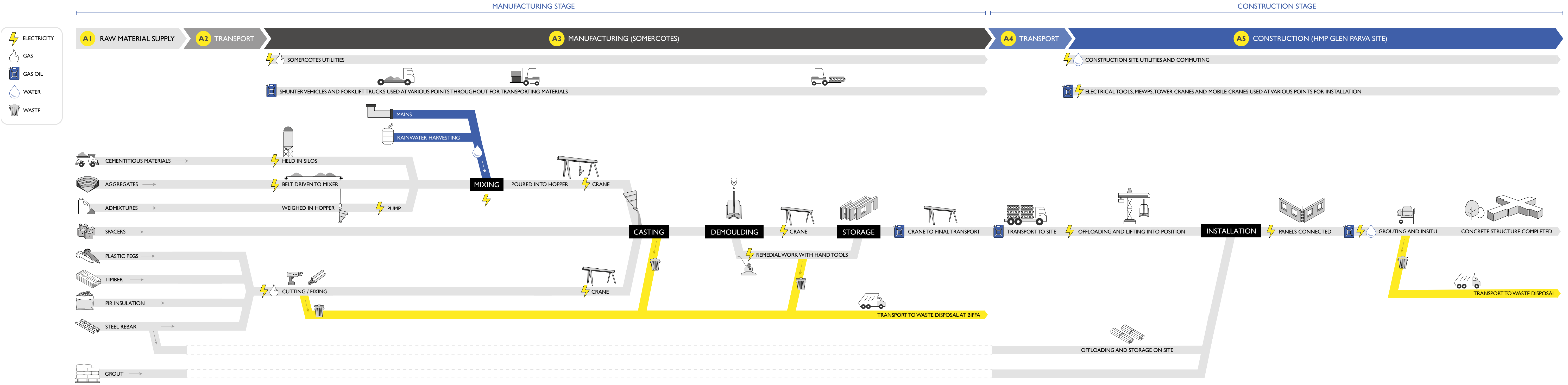


Figure 9 - Glen Parva precast carbon-mapping from cradle to practical completion [A1-A5]

Establishing a method of measurement

CARBON CALCULATORS

Initially, Accelar worked with Partner companies Akerlof, Forterra and PCE to establish a common measurement strategy based on best practice.

We then took the precast structure for HMP Glen Parva and broke this down into panels, and again into composite parts. We also looked at operational activities on site, precast production offsite and the supply chain to assemble an accurate overview of cradle to practical completion [A1- A5] carbon impacts. Using industry data we also measured cradle to grave [A1-C4] and beyond the building lifecycle [D], with Accelar providing insights on B, C and D impacts.

All activities were mapped, sources of carbon identified and assigned with appropriate carbon factors to obtain kgCO_2e per unit of measure. This resulted in two carbon calculators, reviewed by ConstructionLCA to the standards shown in the Figure 10.

SCENARIOS AND CARBON FACTORS

To establish carbon factors for every element and item, we used Environmental Product Declarations (EPD) data.

By working through the different benchmarks and sourcing Environmental Product Declarations (EPD)[9] data, we developed a real world scenario, with a combination of carbon factors that most accurately reflected the supply chain from the Concrete Carbon Calculator, prior to any attempt to optimise the concrete mix, or improve the design and construction.

Where possible, we sourced the carbon factors of raw materials or goods provided to manufacturers through provider-specific EPDs. These include embodied carbon (otherwise known as global warming potential). Where these were available, we utilised specific EPDs from a similar product in the same industry. If this was not available, we utilised a generalised EPD based on the product group. In the event that these were also unavailable, the carbon emission factor was based on the ICE database.

CALCULATOR	STANDARD	DESCRIPTION
CONCRETE CARBON CALCULATOR	PAS 2050:2011	A product carbon foot printing methodology developed by the British Standards Institute (BSI)
	BS EN 15804:2012	The European Standard developed to provide "Core Rules" for the environmental life cycle assessment and production of Environmental Product Declarations
	EN 16757	The product standard developed by the CEN Technical Committee responsible for concrete and provides a further specification of EN 15804 for concrete
BUILDING LEVEL CARBON CALCULATOR	EN 15978	The European Standard developed to provide overarching methodology for the environmental life cycle assessment of buildings. It follows the same principles and methodology as EN 15804 for construction products
	RICS Professional Statement on Whole Life Carbon Assessment for the Built Environment	An implementation of EN 15978 provided for the UK, giving relevant defaults, sources of data and proposing a recommended scope for assessment
	EN 16757	Provides guidance on the assessment of carbonation for concrete. This has also been considered as part of the review

Figure 10 *- Carbon calculator assurances*

[9] An Environmental Product Declaration (EPD) is an industry-approved document that transparently communicates the environmental performance or impact of any product or material over its lifetime

Visualising the baseline

DATA-DRIVEN APPROACH

Curtins and PCE worked together to produce carbon heat maps of the building, as well as graphical representations mapping the carbon within each precast element. These visualisations allowed our project team to establish areas of opportunity and helped the wider team understand the benefit or consequence of decisions made at different points in the process.

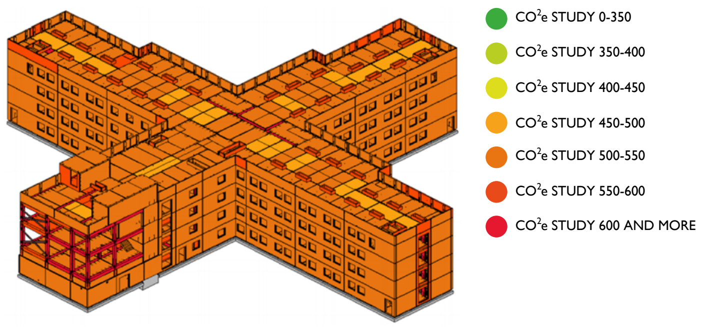


Figure 11 - HMP Glen Parva houseblock structure with ICE concrete carbon factors and IStructE reinforcement carbon factors

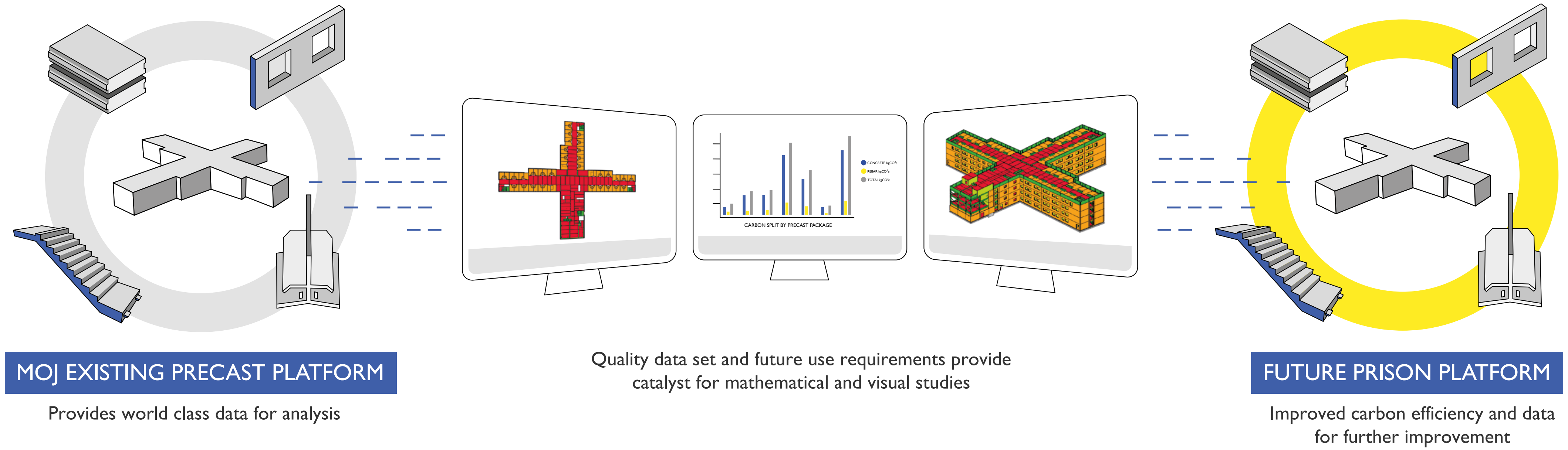


Figure 12 - Data for continuous improvement of MoJ's platform design

Improved concrete mix

UNDERSTANDING CARBON IN CONCRETE

Concrete is a unique material, in that the specifier can directly influence its constituent parts to ensure an optimum carbon footprint. Certain aspects can be adjusted to meet performance criteria, address design imperatives of resource and energy efficiency within a whole life context, and tackle the precepts of a circular economy.

Cement only makes up a small percentage of concrete mixes, however it is almost exclusively responsible for the CO^2 emissions associated with concrete production.[10] By replacing a proportion of cement with alternative materials, the environmental impact of concrete production can be lowered. Accordingly, our team investigated the increased use of Supplementary Cementitious Materials (SCMs).

OPTIONEERING SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMs)

A significant amount of work has been undertaken, mainly within the academic fraternity, on Limestone Calcined Clay Cement (LC^3), which can reduce CO_2 emissions by up to 40%.[11] Within the industry there is also interest in this product as a timely alternative to pulverised fuel ash (PFA), which is slowly losing its prominence due to being sourced from coal-fired power stations, which are progressively being decommissioned. It also has a commercial and availability advantage compared with Ground Granulated Blast-furnace Slag (GGBS), a waste product from the steel industry. Unfortunately, time constraints on this project negated further exploration, however we recommend this as an area for future research.

Forterra also identified a source of waste LC^3 i.e. waste bricks, that could be a suitable replacement for more conventional SCMs. Clay is readily available in the UK, however, the project timeline did not allow for a more thorough investigation of this alternative. We also recommend this as an area for future research.

The team also investigated the viability of alkali activated cements. However, it was found that this option would not be feasible, as productivity would be negatively affected at the plant. Precast components at Somercotes are produced with a 16-hour turn-around i.e. components must be de-moulded and moved within 16 hours of being cast for the factory to run efficiently. At the time of this research, the specification required that the concrete reach a minimum strength of 15N/mm^2 before being moved (this was later found to be possible at 10N/mm^2). Our review found one-day compressive strengths for alkali activated cement were lower than 5N/mm^2, making it unsuitable for precast production. However, alkali activated cements could prove viable in specific instances in the future so we recommend further research in this area.

Ultimately, Ground Granulated Blast-furnace Slag (GGBS) was deemed the most appropriate substitute, due to its proven performance within the industry and availability at Forterra's plant in Somercotes. Using the original mix design used at Somercotes for the HMP Glen Parva project as the control mix (Mix 1), the team undertook a desktop review of Forterra's other concrete mixes, identifying a suitable mix design previously used at the Swadlincote plant. This formed the basis for the first trial mix, which immediately netted a 35kg/m^3 CO_2 saving over the original design, and was therefore issued as the reference mix design.

IMPROVED CONCRETE MIX

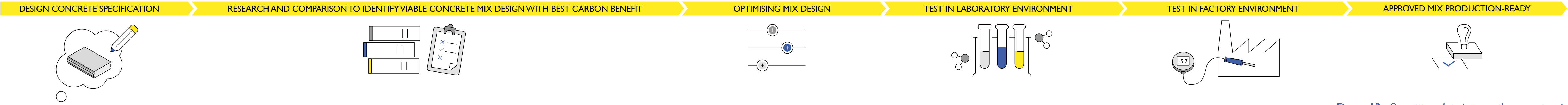


Figure 13 - Our approach to improve the concrete mix

[10] McKinsey & Company, "Laying the foundation for zero-carbon cement" https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement, accessed 14 July 2021

[11] Limestone Calcined Clay Cement, https://lc3.ch/, accessed 4 July 2021

Improved concrete mix

OPTIMISING MIX DESIGNS WITH A CARBON FOCUS

The main objective for the revised concrete mix designs was to reduce embodied carbon, whilst targeting a lifting strength of 15N/mm^2 at 16 hours to ensure a feasible production schedule for the factory.

Our combined strategy of increasing SCMs and incorporating admixture technology was selected as the most viable approach. SCMs such as GGBS can have a retarding effect, meaning a slowed setting time where the concrete mix stays in a fresh mix state for longer. A suitable accelerating admixture was therefore required to prevent this. To facilitate this development, admixture companies were engaged to increase SCM quantity, whilst at the same time maintaining the strength requirements.

After optimising the mix design, we tested the mix within a laboratory environment, with final testing taking place within a factory environment at scale.[12]

Due to the strength requirements for lifting, we needed to develop a mix that was relatively high in cement content. The resulting concrete panels consequently achieved a significantly higher strength (C75) than required in the design specification (C40). Therefore, design engineers at Forterra investigated if we could decrease the volume and mass of the precast panels by using less material (explained in more detail on page 25).

The original concrete cement mix was a Portland Limestone Cement (CEM11/B-L). Our optimised concrete mix design incorporates a Blast Furnace Cement (CEM III-A) with a 21% carbon reduction versus the benchmark mix design.[13]

We believe there is potential to reduce cement and total binding agents further by lowering the lifting strength requirement to 10N/mm^2, however, due to the limited timescale for development work our initial research was based on 15N/mm^2 at 16 hours.

CARBON IMPACT OF NEW MIXES

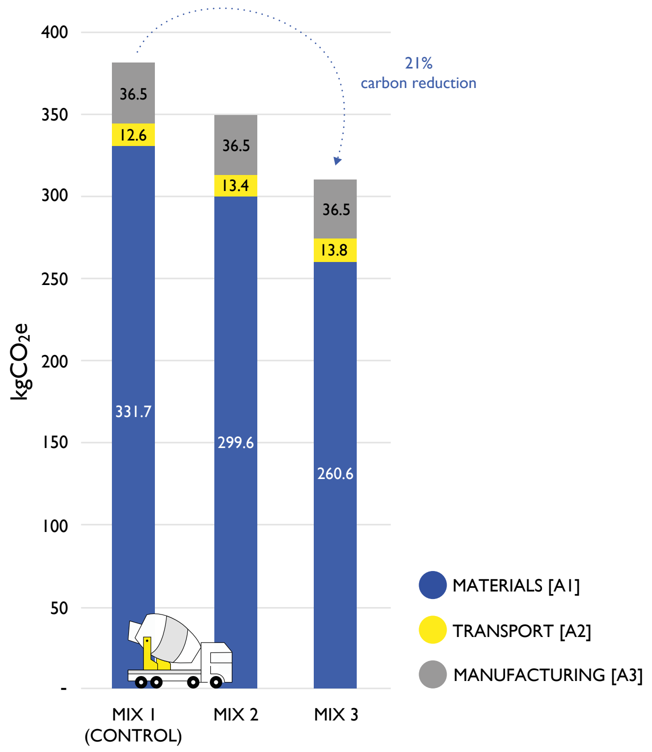


Figure 14 - Carbon impact of new design mixes

MATERIALS SOURCING

Understanding the material supply chain and mandating sustainable materials at every level can have great outcomes for projects and programmes. Whilst much of the supply chain for HMP Glen Parva was made up of highly reputable suppliers located geographically close to manufacturers, this is not always the case, with decisions still often made on commercial grounds.

The material we found to have the biggest variant in carbon content was reinforcement, reflected in the two benchmark assumptions from ICE and IStructE databases. Not all reinforcement has the same carbon content and, whilst supply chain length can have an impact, the make up of raw steel and the level of recycled material has a much bigger impact. Sourcing from the most sustainable sources represents a 16% saving against the ICE benchmark.

Chain of custody is also an issue that should not be taken for granted. Specifying a maximum CO_2kg content per tonne of rebar, as well as mandating certified schemes such as CARES Sustainable Constructional Steel, is a simple step that isn't always taken by specifiers, but one that can have a large impact. It also often means that steel is subsequently sourced from UK suppliers.

[12] *Forterra Building Products Ltd, "Concrete Technical Report: Reducing Embodied carbon of precast concrete whilst maintaining productivity", 2021 (see end of document for details)*

[13] *Aligned to BS EN197-1:2011 "Composition, specifications and conformity criteria for common cements", 2011*

Improved concrete mix

READY FOR PRODUCTION ASSURANCE

Full scale production trials were conducted on five mix designs for three precast components; floor unit, vertical wall and column. In total, 11 of each component were cast and all concrete mixes were cured using different techniques; curing blankets, tarpaulin and curing compound.

Due to the reaction between cement and water (hydration), heat develops rapidly as the concrete sets, gradually declining as hydration slows. Temperature data was collected to track this process, as well as humidity and temperature measures throughout the plant. We then verified strength results through a combination of cores and cube tests.

Two concrete mixes proved to be satisfactory for use in future projects; Mix 2 and Mix 3. These mixes resulted in a carbon reduction of 39.72kg/m^3 and 75.38kg/m^3 respectively, compared to the HMP Glen Parva baseline. Both concrete mixes possessed good workability and were exceptionally stable, neither exhibiting segregation. In the case of Mix 3, performance was very easily controlled through the use of an O-funnel, a tool used to test and measure concrete flow.

Due to the additional information provided by the O-funnel, it is recommended the same testing methodology be implemented to effectively control the workability of these mixes in the future.

Precast column formwork

O-funnel testing and measuring concrete flow

Forterra operatives preparing a precast wall slab mould

Precast wall slabs

Improved concrete mix

28-DAY STRENGTH

After demoulding, precast concrete is stored for further curing. The strength concrete has after it has been fully cured after 28 days is key. Compressive strength is defined as the capacity of concrete to withstand loads before failure. Mix 3 and Mix 3 exhibited good 28 -day compressive strength and achieved an average compressive strength of over 80N/mm^2, with Mix 3 performing slightly better than Mix 2 in both cube and core tests. Our results allowed for a mix design to C70 strength and potentially a reduction in concrete due to the higher strength performance.

The concrete finish was satisfactory and could be improved through additional preparation of the formwork (the temporary mould into which concrete is poured). There were no issues with the placement of the concrete or finishing of the horizontal components. Shrinkage cracking was noted on all columns regardless of how they were cured, however, as these elements would be axially loaded, this was not considered an issue.

We measured the strength at 7 days and 28 days, whilst an external concrete testing company undertook testing of 23 concrete cores. These were taken from each element and tested at 14 days and 28 days.

TEMPERATURE MONITORING

Our team monitored and measured the temperature of both the internal concrete and factory environment throughout our trials, which proved to be very revealing.

During full scale production trials, the internal factory temperature was regarded as too low to facilitate effective strength development, particularly for mixes high in GGBS content. We therefore applied temperature controls. Various curing options were trialled, using passive systems to ensure we did not increase embodied carbon. These included curing blankets, curing compounds and tarpaulins. Curing blankets proved very successful, particularly for the thicker components, such as columns, however their benefit was reduced for flat slab cast and vertical components due, in part, to the increased surface area and the fact that the concrete was coming into direct contact with cold steel shutters.

We believe that further improvements could be made, such as spraying insulating foam onto the outside of the mould and heating the formwork elements prior to casting. However, all solutions should be considered with regard to the additional embodied carbon contribution.

The column formwork was of wooden construction, which facilitated improved insulation. As this will not be a practical solution in all circumstances, alternative moulds should be investigated, that do not result in the heat transfer observed during our trials, particularly for vertical components.

TESTING REGIME

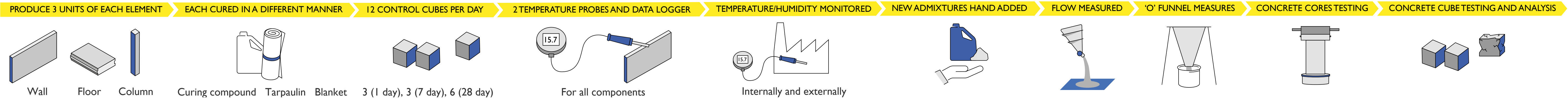


Figure 15 - Our approach to testing

Improved concrete mix

REAL TIME DATA FOR SMART DECISION-MAKING

The team recognised that the existing methodology for the testing of concrete prior to lifting required further review. Currently, rebound hammers are used to assess the quality of hardened concrete to determine when it can be demoulded and moved. The Decarbonising Precast Concrete team sought to improve upon this existing technique by using smart technologies to monitor temperature development. Our approach proved highly successful and enabled us to safely reduce the lifting strength to 10N/mm^2.

The technology provided our team with real time data, resulting in increased accuracy of early age strength, as well as providing the potential for reducing embodied carbon further by optimising the production schedule dynamically in accordance with live weather information. This is recommended as an area for further research and implementation.

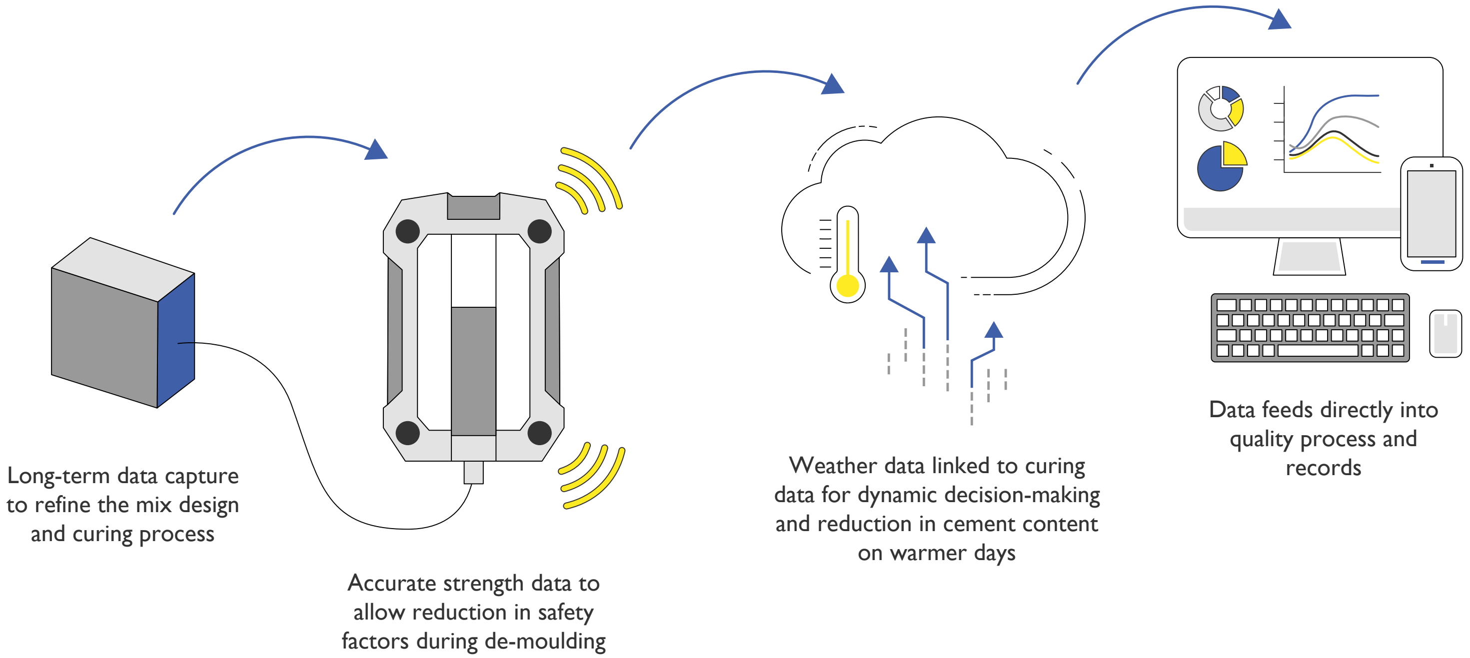


Figure 16 - Accurate temperature data for smart decision-making

CONCLUSION

Our optimised concrete mix design incorporates a Blast Furnace Cement (CEM III-A) with a 21% carbon reduction versus the HMP Glen Parva benchmark mix design.

During our research we acknowledged a number of potential options requiring further investigation. These include the use of LC^3 as an SCM and the potential use of alkali activated concrete binders. We recommend that work to develop these options continues, as well as efforts to further improve upon the successes achieved as part of this project.

Improved structural design

VISUALISATION

PCE and Curtins worked together to assess all data extracted from the HMP Glen Parva Houseblock Revit model, in conjunction with PCE's package plan, where the volume and weights for each precast package had been considered. Figure 17 depicts the proportion of embodied carbon across each package in terms of concrete [A1-A3], rebar [A1-A3] and total package contributions [A1-A5].

The chart confirms that slab packages (PC6-PC7) contained the highest total embodied carbon, followed by wall packages (PC1-PC5). Whereas beam, column, landing, stairs, parapet and up-stand packages (PC8-PC15) were found to be low in total embodied carbon.

This data was then used to develop heat maps within the BIM model, to visually communicate the carbon content of each precast component.

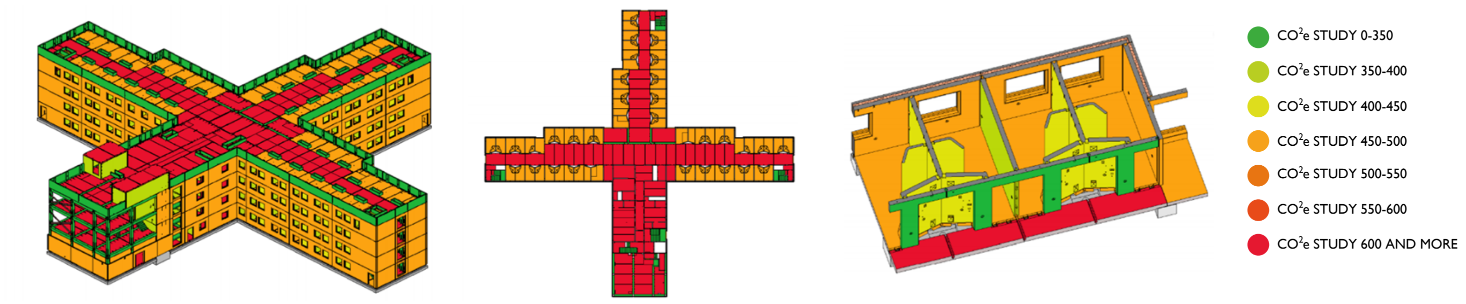
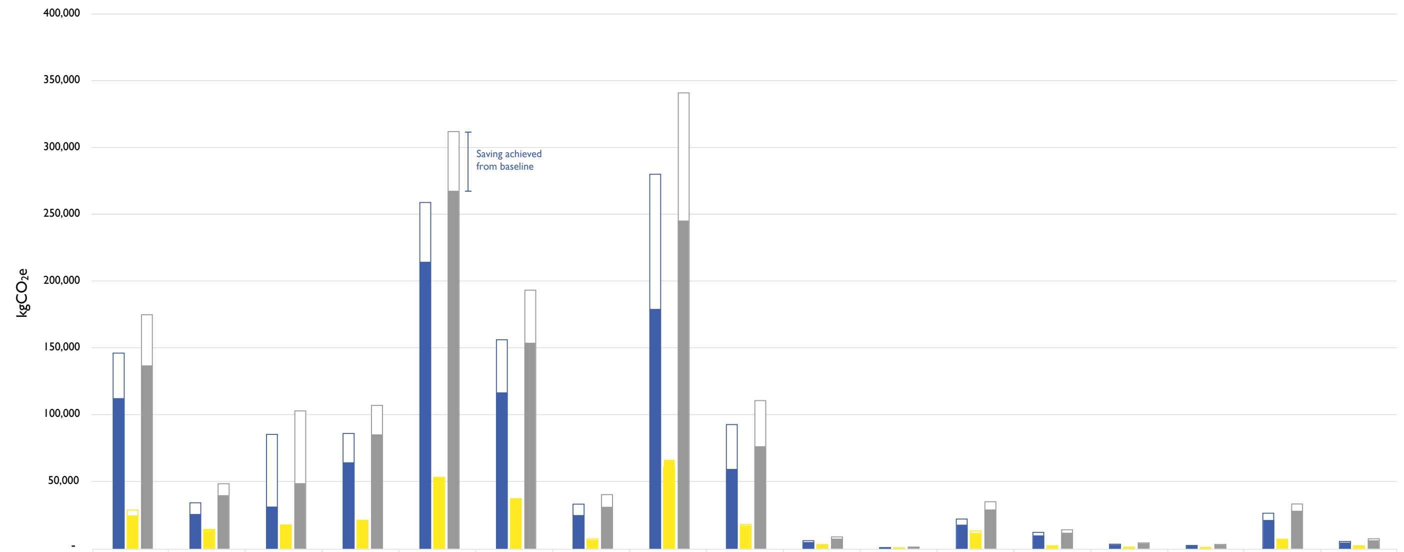


Figure 17 - BIM model heat maps for HMP Glen Parva houseblock

OPTIMISED CARBON SPLIT BY PRECAST PACKAGE



OPTIMISED SOLUTION DATA	PC1 DUCT WALLS	PC2 CORRIDOR WALLS	PC3 CELL CROSS WALLS	PC4 MISC WALLS	PC5 SANDWICH PANELS	PC6 CELL SLABS	PC6C CELL SLABS	PC7 MISC SLABS	PC7C MISC SLABS	PC8 SQUARE COLUMNS	PC8 CIRCULAR COLUMNS	PC9 BEAMS	PC10 STAIRS	PC11 LANDINGS	PC13 ROOF UPSTAND WALLS	PC14 PARAPETS	PC15 ROOF UPSTANDS
CONCRETE kgCO^{2}e	112,250	25,495	31,072	64,224	214,452	116,580	24,716	179,157	59,299	4,544	434	17,523	9,539	2,514	1,778	21,045	4,132
REBAR kgCO^{2}e	24,586	14,160	17,572	20,955	53,170	37,221	6,235	66,113	17,001	2,574	370	11,437	1,945	932	594	6,867	1,736
TOTAL kgCO^{2}e	136,836	39,655	48,644	85,179	267,622	153,801	30,951	245,270	76,300	7,118	804	28,960	11,484	3,446	2,372	27,912	5,868

Figure 18 - Comparison of optimised vs. baseline embodied carbon split by precast package for a single houseblock at HMP Glen Parva

Improved structural design

DESIGN SOLUTION OPTIMISATION

Design solutions for structural systems play a significant role in steering the direction and form a built asset takes, particularly from an embodied carbon perspective.

The manufacturing process or cradle to gate stage [A1-A3] for a precast solution, which forms the structure, façade and internal partitions, is in excess of 75%. Reducing concrete and reinforcement volume consequently has a big impact on both the carbon content, foundation design and cost. Reducing the overall volume of concrete within a structure also has the added benefit of freeing up budget to be allocated to concrete mix or other carbon reduction solutions.

Optimisation is the process of adjusting the design solution against set criteria, so that the component and / or system reflects the most efficient and fit for purpose form. To optimise the components and / or system used for the precast prison, we needed to understand and appreciate the drivers that govern the design in terms of embodied carbon for value to be added.

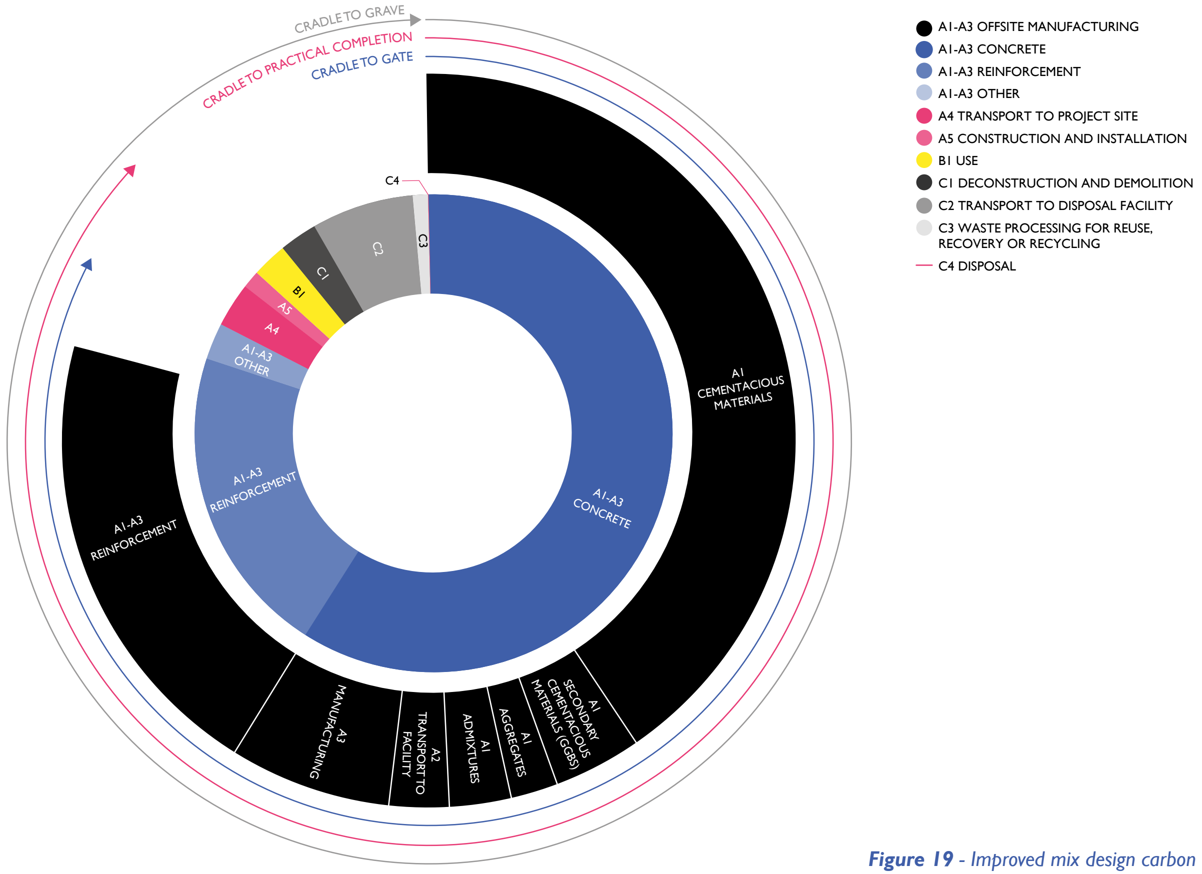


***Figure 19** - Improved mix design carbon impact across the lifecycle*

Improved structural design

DESIGN DRIVERS

The main structural drivers governing the design included geometry, loading, material, strength, robustness and disproportionate collapse requirements, durability and fire. This list, whilst not exhaustive, represented a broad overview and was used for the purpose of promoting discussion within our project team to establish what opportunities to target and develop.

Geometry: We reviewed the impact of openings on panel design and embodied carbon

Load assumptions: We compared actual loadings to code required loadings, investigating the potential for over-designing

Design utilisations: We targeted design utilisations at key stages of the project lifecycle to seek out design efficiencies

Design life: We reviewed the impact that a 50-year vs 100-year design life would have on component's cover and mix design, as this could yield a long-term embodied carbon saving over lifecycle of the built asset

Smart connections: Drawing upon universal connections, we looked to achieve economy of scale in terms of embodied carbon

Materials: We researched the ratio between concrete and rebar in terms of embodied carbon impact and break point, as different rebar sizes offer more flexibility (e.g. H10,12,16,20,25,32 & 40) c. mesh vs loose rebar

Strength: We explored typical design vs typical manufacture, aiming to balance the ratio between strength provided from using more concrete compared to increasing the percentage of reinforcement

Material waste: We reviewed couplers vs lapping, detailing processes

Lifting requirements: Finally, we challenged the status quo in terms of minimum strength required, targeting 10N strength at demoulding and its impact on embodied carbon

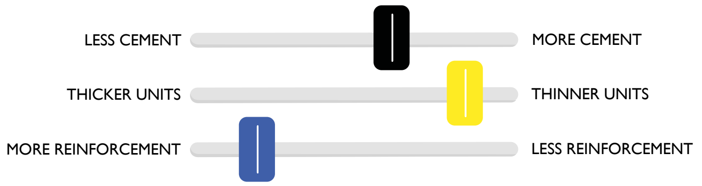


Figure 16 - Approach to optimising the structural design

CARBON-THINKING IN STRUCTURAL DESIGN

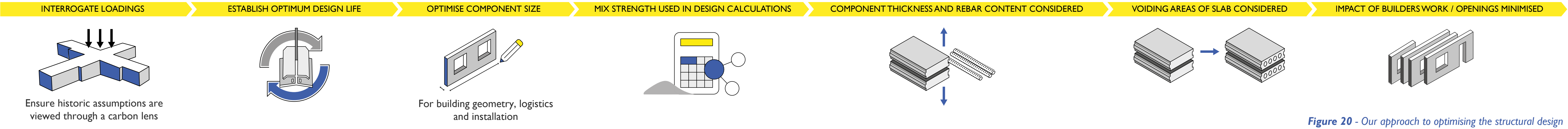


Figure 20 - Our approach to optimising the structural design

Improved structural design

OPPORTUNITIES

The project team reviewed the design opportunities for reducing embodied carbon in precast concrete components and agreed to proceed with the following detailed studies:

1 Review of impact of imposed loading and concrete strength on the slab

Floor slabs were identified as the biggest contributor and thus our biggest opportunity to reduce carbon. We reviewed the impact of imposed loading and concrete strength on slab thickness, reducing the live loading (i.e. Eurocode vs actual imposed loads) to reflect a more realistic floor plate loading in conjunction with utilising an optimised mix strength (C60/75). This translated into material savings on the concrete floor slabs.

It is worth noting that the high strength mix (C60/75) meant panels were less sensitive to long term deflection due to having an increased flexural stiffness, however the concession was that more reinforcement was required due to the higher mean value of axial tensile strength of concrete. Overall, the material savings on concrete were found to outweigh the increase to the reinforcement. Achieving the perfect balance between the factories is a key driver for slab thickness reduction and the removal of building weight.

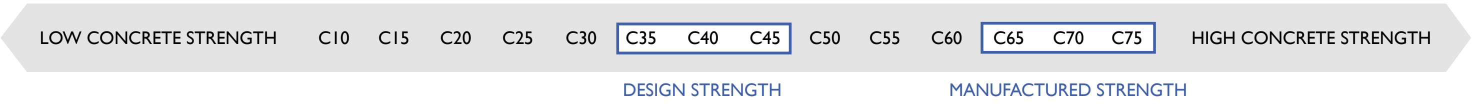


Figure 21 - Concrete mix strength comparison

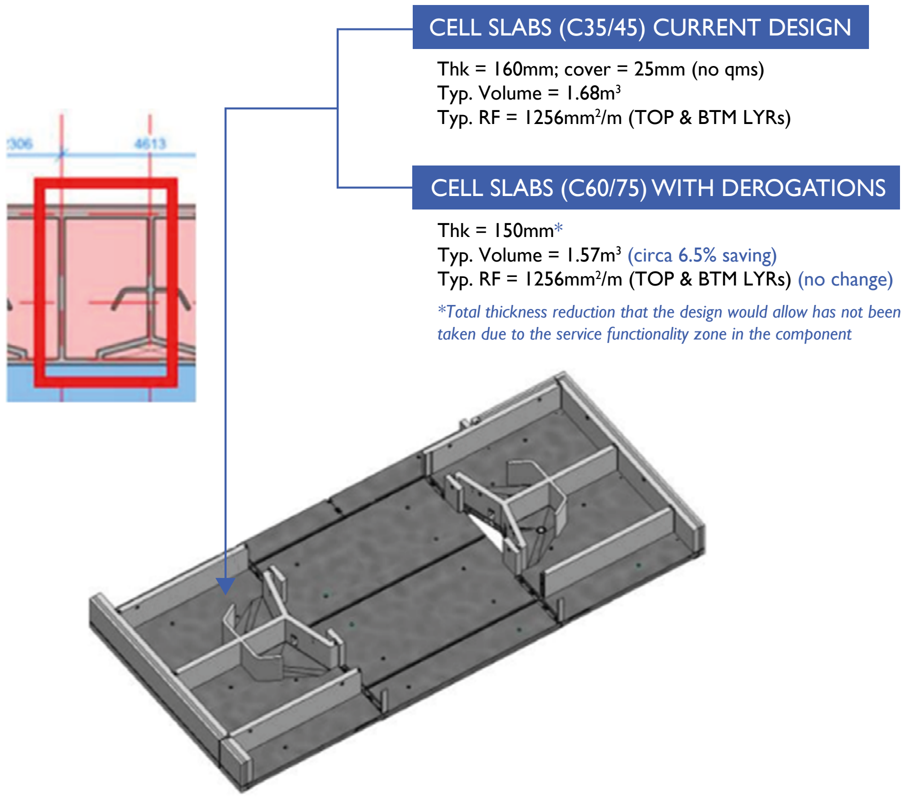


Figure 22 - Concrete slab calculations demonstrating material savings

Improved structural design

❷ Optimal wall thickness and concrete strength mix

The wall design was governed by wall slenderness, bending moment capacity and serviceability cracking. We calculated that the most optimal wall form would be 130mm (reduced from 150mm) under the proposed loadings and balance between concrete strength and rebar content.

❸ Design working life (50 years vs 120 years)

The optimal slab thickness is influenced by the design working life, quality assurance monitoring controls, concrete mix strength and aggregate depth. The volume cost of achieving a 120-year design work life is minimal and has the potential to offer a long-term saving in embodied carbon when viewed against the built asset's total embodied carbon.

In this sample exercise, any repairs or refurbishment exceeding 4% of the 50-year design working life, meant a 120-year design working life is the most effective solution in terms of reducing embodied carbon. This also aligns with the opportunity to repurpose rather than rebuild.

❹ Geometrical patterns

Components with less builders work holes have a lower amount of reinforcement per m^3 of concrete, which results in lower embodied carbon. On this basis, the M&E strategy plays a key role in influencing the embodied carbon savings that can be made on precast prisons, with efficiency in design, alignment and maximum use of service risers having a direct impact on carbon.

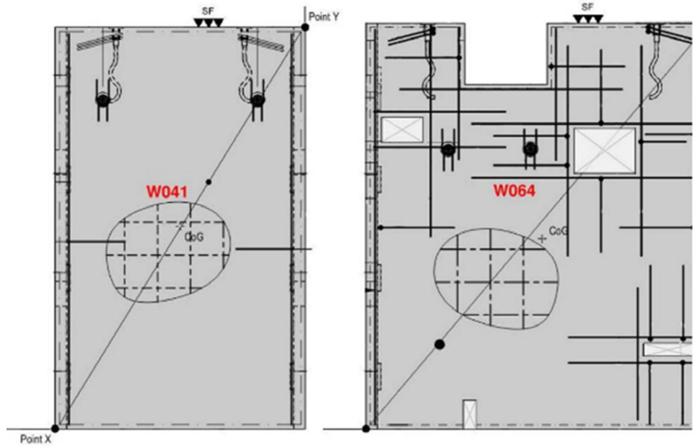


Figure 23 - Illustration of increased reinforcement around openings

❺ Impact of demoulding panels with a 10N strength

With GGBS typically slowing the rate of reaction and strength development, we found the change in concrete strength from 15N to 10N to have a minor impact on the worst-case selected element for the beam (PC9), wall (PC1-5), column (PC8) and up-stands / parapets (PC13-15) packages, in terms of anchor and component reinforcement checks.

It should be noted that the walls act as deep beams, hence our low utilisation for the component reinforcement check.

We found slab packages (PC6-7 and PC11) to be more sensitive depending on the lift (i.e. vertical vs shear), and depending on the presence of re-entrant corners.

We recommend that further research be undertaken to assess if more accurate data, gathered by thermocouples, can reduce safety factors within the calculation to reduce the demoulding strength.

Improved construction

Lifecycle stages A4 and A5 respectively capture the emissions associated with the transportation of materials and components from the factory gate to the project site and their assembly into a building. PCE collected extensive supply chain data from HMP Glen Pava[14], from which the team sought opportunities to reduce its impact.

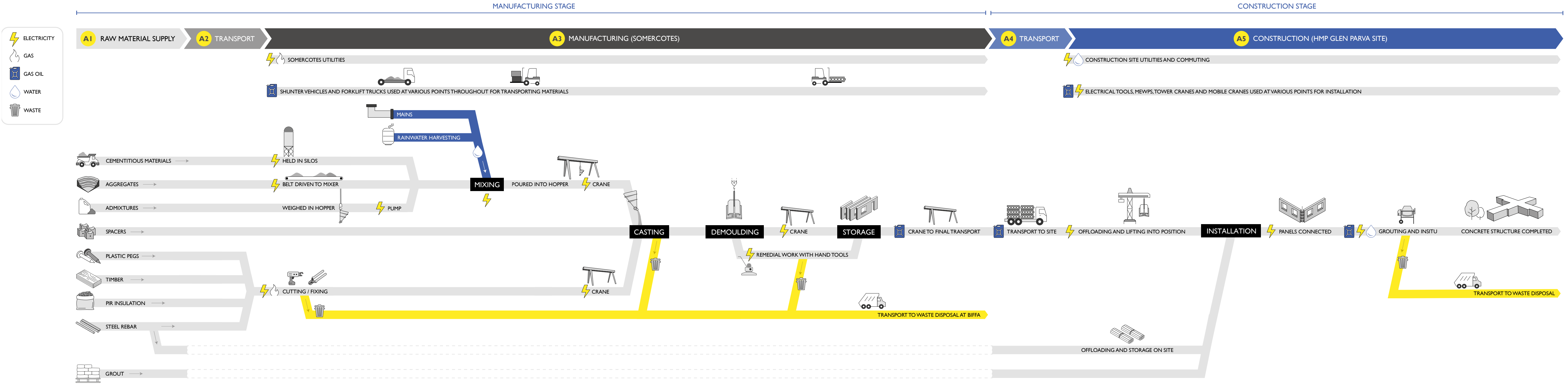


Figure 24 - Glen Parva precast carbon-mapping from cradle to practical completion [A1-A5]

[14] *PCE Ltd, "Decarbonising Precast Concrete: Gate to Assembly Carbon Capture", 2021 (see end of document for details)*

Improved construction

Whilst the overall impact of carbon within stages A4-A5 is considerably lower than those incurred in A1-A3, our team found a number of opportunities for improving embodied carbon within lifecycle stages A4 and A5, based on the research outlined in this study.

SILO MATERIAL

A significant development in PCE's structural grouting methodology was the adoption of a silo-fed system. This negated the need for additional palletised deliveries, reducing fuel usage, as well as minimising paper, plastic and timber waste. This also had an indirect impact on waste logistics fuel, skip collections were significantly reduced.

The process was implemented during the HMP Five Wells project, resulting in a carbon saving of approximately 3,800 $kgCO_2e$. Since then, this has been further refined for HMP Glen Parva.

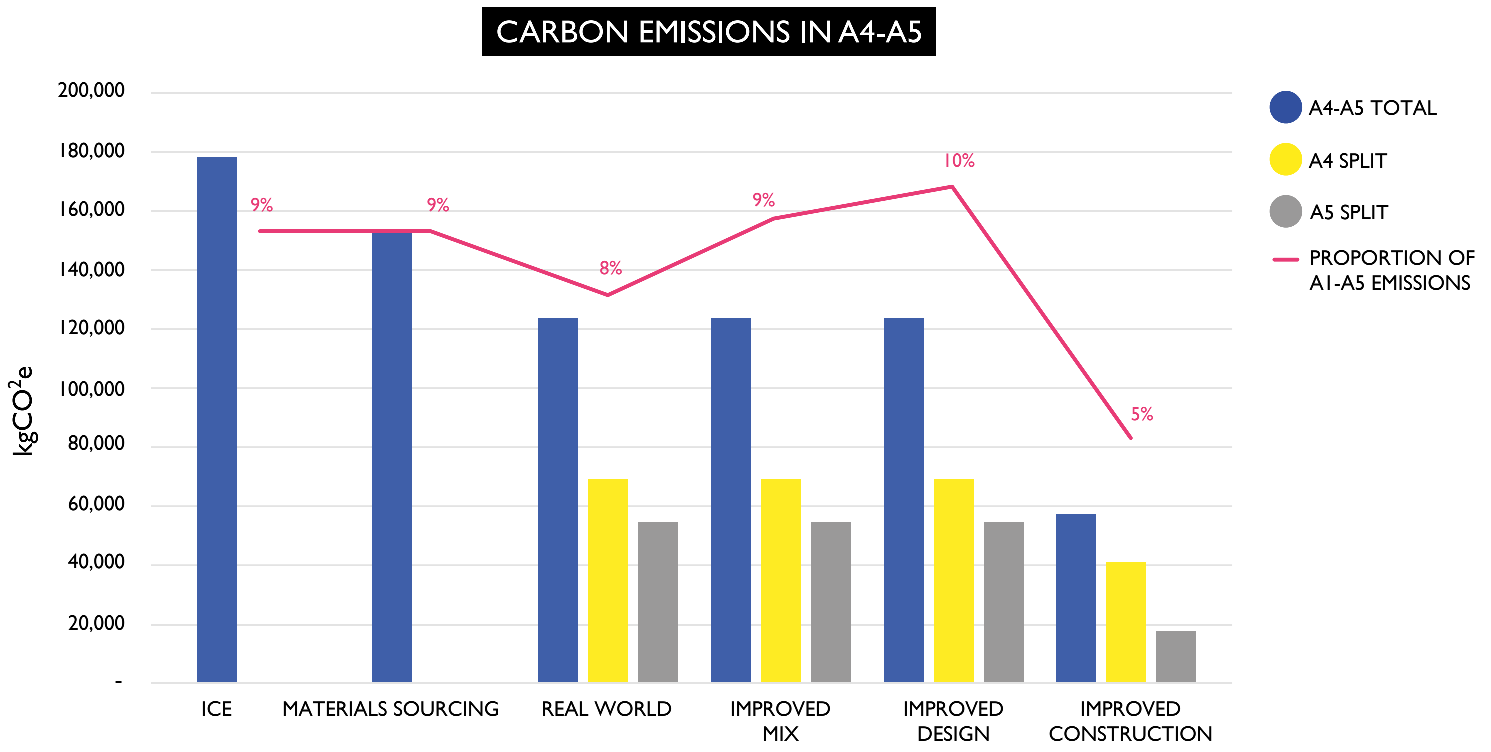


Figure 25 - Carbon emissions from the transport of materials and components from factory to site, and assembly of the precast structure

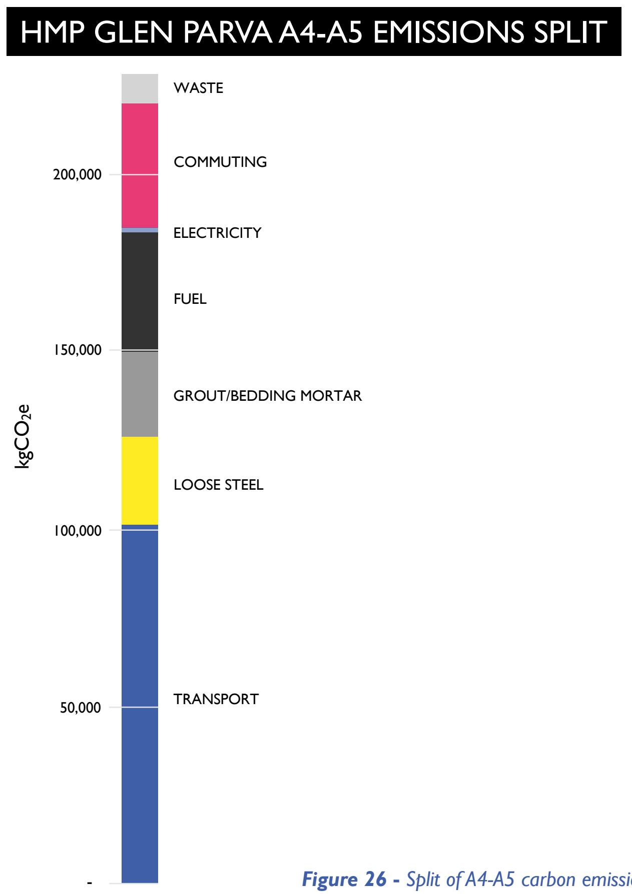


Figure 26 - Split of A4-A5 carbon emissions

Improved construction

LOGISTICS

72% of precast components for HMP Glen Parva have been sourced from circa 50 miles or less from site (4,934 tonnes of 6,849 tonnes); with a further 17% sourced from within 75 miles of site. This gave a total embodied carbon value of 66,000 kgCO_2e; a significant benefit toward stage A4 embodied carbon.

This forms an ongoing target for PCE, who will be procuring a supply chain with a combined contribution of 50,000 kgCO_2e per houseblock for future prison projects. There is the potential for betterment within stage A4 by sourcing locally. Ways of providing local supplier's with additional capacity should be reviewed, such as allowing greater lead times and increasing factory storage through local holding yards or site storage facilities.

BIO DIESELS AND ELECTRIC CRANES

With the development of biodiesels and electric cranes, further and regular analysis should be conducted by industry with respect to practicality and suitability within offsite construction projects.

Potential limitations with biodiesel include warranty restrictions by crane manufacturers, plant manufacturers and hire companies, however, this may become less restrictive with further testing, development and regulation.

It is anticipated that with the adoption of such technologies, and further review of construction methodology, a stage A5 fuel consumption target of 35,000 kgCO^2e should be set; equating to a circa 20% saving on the current embodied carbon contribution.

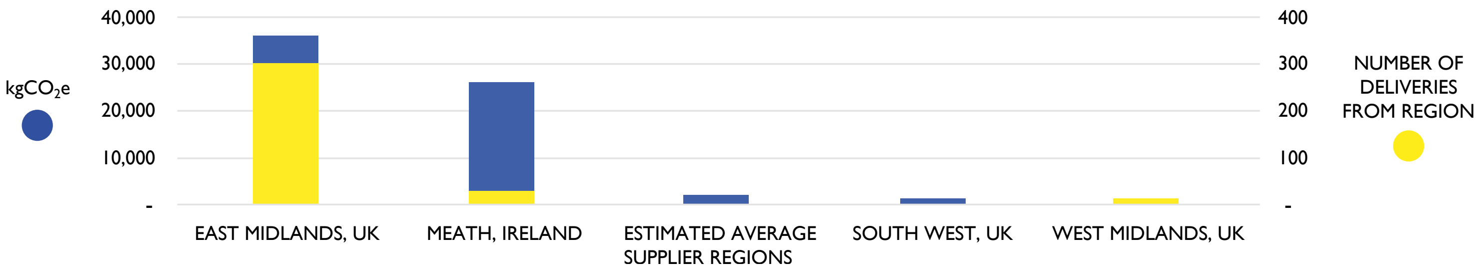


Figure 27 *- Carbon emissions associated with the transport of deliveries by region*

Precast panels manufactured by Forterra for HMP Five Wells

Whole life carbon assessment

ASSESSMENT

The initial scope of the decarbonising precast concrete project was to measure and improve the carbon involved within stages A1 to A5, i.e. the product and the construction stage - otherwise known as the cradle to practical completion lifecycle.

This was expanded to a cradle to grave lifecycle assessment for the precast concrete and overall precast structure of the prison houseblock. The Concrete Carbon Calculator was developed to cover the following lifecycle stages of the building structure, as outlined previously, with the calculations integrated into PCE's existing building level carbon tool:

- Use [B1]
- Deconstruction and demolition [C1]
- Transport to disposal facility [C2]
- Waste processing [C3]
- Disposal [C4]
- Benefits and loads beyond the system boundary [D]

STAGE B - USE

The designers anticipate no maintenance, repair, replacement or refurbishment of the building structure i.e. the reinforced concrete components.

As this study only covers the precast concrete structure of the building, the operational energy and water use was not considered in scope. What remained was within [B1], the in use stage.

Within concrete, carbonisation occurs, which is the process by which building elements containing cementitious materials, such as concrete, absorb CO_2 when their surfaces are exposed to air. This natural process results in concrete removing CO_2 from the atmosphere. As the scope of this project focuses on the concrete structure, carbonation was considered a material impact to quantify.

Carbonation was quantified using the methodology outlined in the BRE Global Product Category Rules (PCR) for Type III EPD of Construction Product to EN 15804: 2012.[15] It should be noted, that from a carbon focus, carbonisation is a benefit, however, there is a risk of corrosion of the reinforcement thus impacting the life of the building. This is mitigated through design standards, as concrete structures are designed with appropriate 'exposure' class for different structural applications and environments. Finally, more carbon absorption due to carbonation occurs in concrete with more cementitious material, which we have consciously tried to reduce for the overall carbon impact. The B stage reflects -2% absorption within the overall lifecycle.

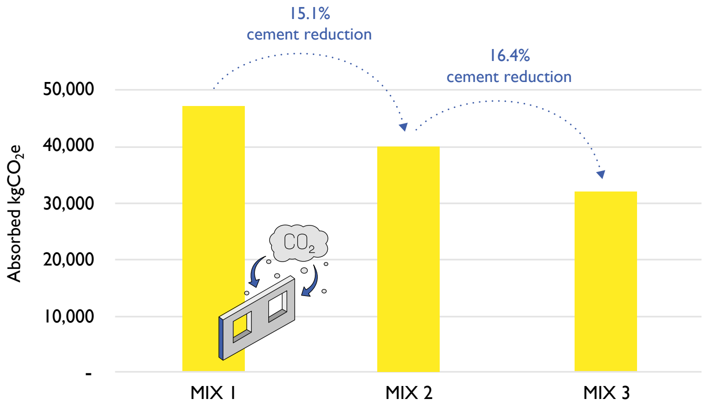


Figure 28 - In Use [B1] carbonisation over the concrete's lifetime

STAGE C - END OF LIFE AND STAGE D - BEYOND THE LIFECYCLE

Deconstruction and demolition [C1] and transport emissions to end of life facility [C2]

Project specific information for calculating emissions from deconstruction and demolition [C1], transport emissions to end of life facility [C2] of the building at the end of its lifespan was not available. This was not unexpected given the priority of the project being the measurement and management of the concrete and construction of the building [A1-A5]. Therefore the C1 and C2 stages had to be appropriately estimated and calculated. The British Constructional Steelwork Association RC50 (reinforced concrete) CEM I data sheet[16], developed in line with EN 15804, was used to determine the carbon emissions for deconstruction and demolition. It contains a carbon factor for C1 based on 1kg of reinforced concrete manufactured with CEM I Portland cement. This was deemed an appropriate source for the C1 carbon factor, given that the scope of the project is based on a reinforced concrete building structure, with the concrete containing CEM

[15] *Accelar Ltd, "Decarbonising Precast Concrete: Calculation of Use and End of Life Carbon Emissions", 2021 (see end of document for details)*
[16] *British Constructional Steelwork Association, "RC50 CEM I data sheet", https://www.steelconstruction.info/images/1/1b/RC50_CEM_I.pdf*

Whole life carbon assessment

I cement. Furthermore, the RICS guidance states that datasets in accordance with EN 15804 are acceptable and the most preferred source of carbon data. For transport emissions to end of life facility [C2] default data on end of life scenarios taken from the RICS Professional Statement was used as a proxy. This included the assumption that any materials to be reused or recycled offsite would be transported approximately 50km one way. For materials sent to landfill or incineration, an average distance between two close landfill sites was taken. For the transport carbon factor, an average heavy goods vehicle with 50% loading (to account for the vehicles travelling to the site empty and leaving 100% laden) was assumed, allowing for selection of the appropriate carbon factor from the 2020 Defra conversion factors database.[17]

Waste processing [C3], waste disposal [C4] and benefits and loads beyond the system boundary [D]

For calculating emissions of waste processing [C3], waste disposal [C4] and benefits and loads beyond the system boundary [D], carbon factors from appropriate sources, such as EPDs, were used. The total masses of each material were applied to the relevant carbon factor in Figure 29 to determine total emissions of each lifecycle stage. The concrete carbon factor for C4 is negative, as the impact of carbonation of concrete in landfill has been accounted for.

MATERIAL	CARBON FACTOR (kgCO_2e PER TONNE MATERIAL)			SOURCE
	C3	C4	D	
Concrete	2.4	-6	-5.3	British Constructional Steelwork Association, C50 CEM I data sheet[18]
Steel	0	1.19	351	UK CARES Carbon Steel Reinforcing Bar (secondary production route –scrap), Sector Average EPD[19]
PIR insulation	0.00036	447.6	N/A	Kingspan Insulation Ltd EPD[20]

Figure 29 - Carbon factors used for the lifecycle stages of waste processing [C3], waste disposal [C4] and benefits and loads beyond the system boundary [D]

[17] *Department for Business, Energy & Industrial Strategy, "Defra conversion factors", https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020*
[18] *British Constructional Steelwork Association, "C50 CEM I data sheet", https://www.steelconstruction.info/images/1/1e/C50_CEM_I.pdf*
[19] *UK CARES, "Carbon Steel Reinforcing Bar (secondary production route - scrap), Sector Average EPD" https://www.ukcares.com/downloads/general/CARES%20Sector%20Average%20EPD%20Report%20for%20Constructional%20Steel%20Issue%202.pdf*
[20] *Kingspan Insulation Ltd, "Kingspan Kooltherm K5 External Wallboard, Kingspan Kooltherm K20 Concrete Sandwich Board" https://www.greenbooklive.com/filelibrary/EN_15804/EPD/BREGENEPD000311.pdf*

Whole life carbon assessment

Loads beyond the boundary [D]

RICS whole life carbon guidance states:

"(Loads beyond the boundary) [D] covers any benefits or burdens accruing from the repurposing of elements discarded from the built asset, or any energy recovered from them beyond the project's life cycle. Module [D] is intended to provide a broader picture of the environmental impacts of a project by accounting for the future potential of its components when these are repurposed i.e. recovered and reused and/ or recycled. Module [D] captures the avoided emissions (or potential loads) from utilising repurposed items to substitute primary materials. Module [D] can be used as a metric for quantifying circularity and assessing future resource efficiency."[21]

As shown within Figure 30, the carbon factor for steel within the D stage is therefore significantly higher, in alignment with secondary production routes that are currently practiced within the industry as part of a circular economy.

When the real world scenario and the optimised solution scenario are compared, stage D for the optimised scenario is higher than the real world example. This is due to an increase in reinforced steel in the final design and reduced cement content within the new concrete mix, which means less carbonisation and carbon absorption. However, this slight increase of 6,407 kgCO_2e emitted at the end of life is far offset by the overall reduction of 360,681 kgCO_2e carbon across the lifecycle, achieved in A1-A5.

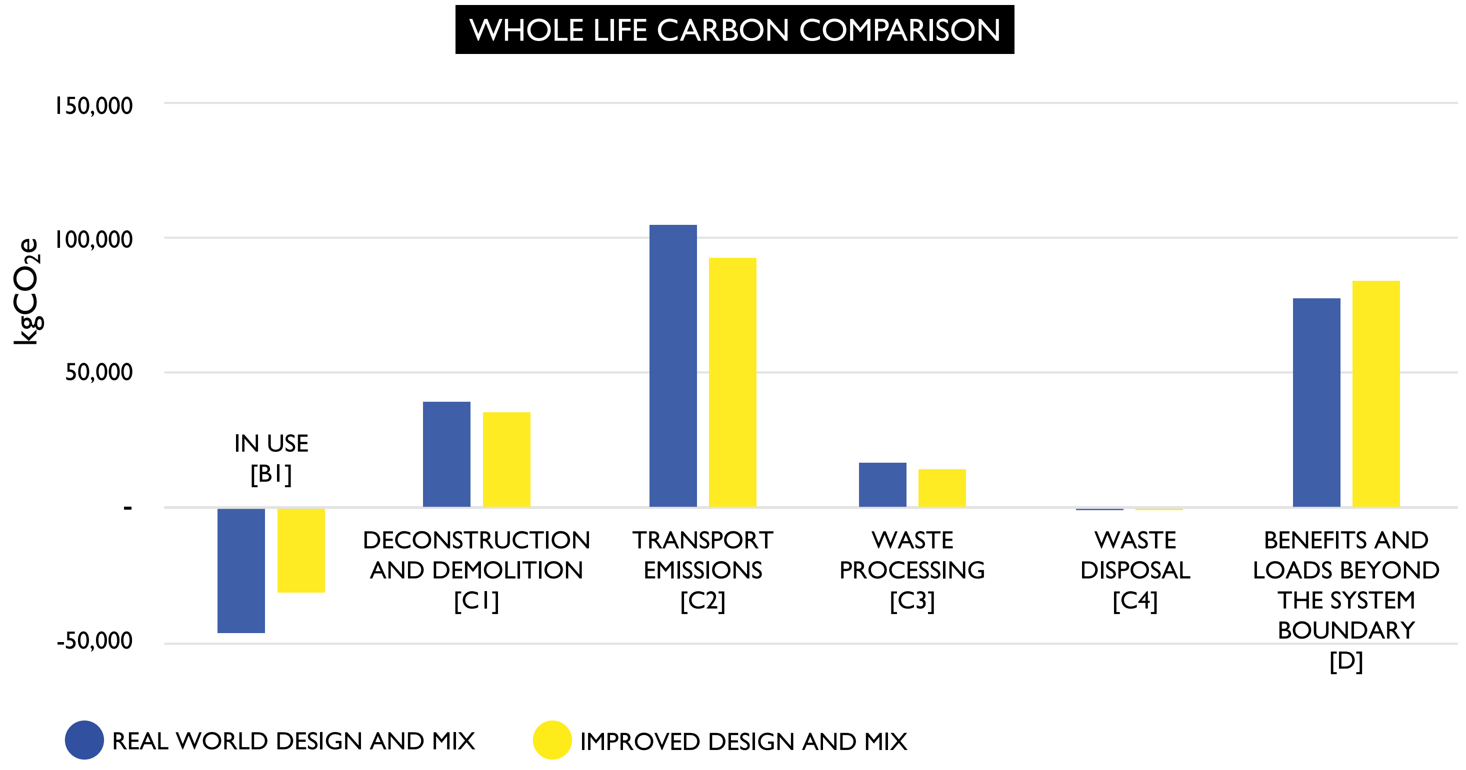


***Figure 30** - Whole life carbon comparison of real world mix and improved mix*

[21] *RICS professional standards and guidance, "Whole life carbon assessment for the built environment", 1st edition, 2017*

Conclusions

At the start of the Decarbonising Precast Concrete project, our partnership set out to achieve four objectives, the results were as follows:

CARBON REDUCTION	EASE OF MANUFACTURE	STRUCTURAL STRENGTH	COMMERCIAL VIABILITY
Solution achieves a significant carbon reduction from the baseline	Solution is compliant with codes and regulation and is technically ready for application across multiple sectors including residential and healthcare	Solution is optimised, eradicating carbon by focusing on interactions at every stage of the process	Commercially viable option for the market in terms of price, risk and production
We realised a 40% reduction against the ICE database and 29% against the IStructE	We achieved this by taking existing research and testing this within the laboratory and at scale in the manufacturing environment, whilst challenging custom and practice such as safe lifting strength	We achieved this by challenging the Employer's Requirements and balancing reinforcement and concrete strength	We achieved a commercially viable solution that is technically ready

These solutions were achieved through an improved mix design, which has delivered increased concrete strength, an improved houseblock design, as well as an optimum new concrete strength developed with carbon in mind.

When focusing on the optimised design and the impacts across lifecycle carbon due to reductions, the proportions as per Figure 31, become apparent. Nearly 80% of all carbon impacts are within A1 and A3 of the lifecycle, with a high proportion within the steel and concrete. It is also clear that cementitious content within the concrete is still responsible for 87% of the carbon associated with concrete.

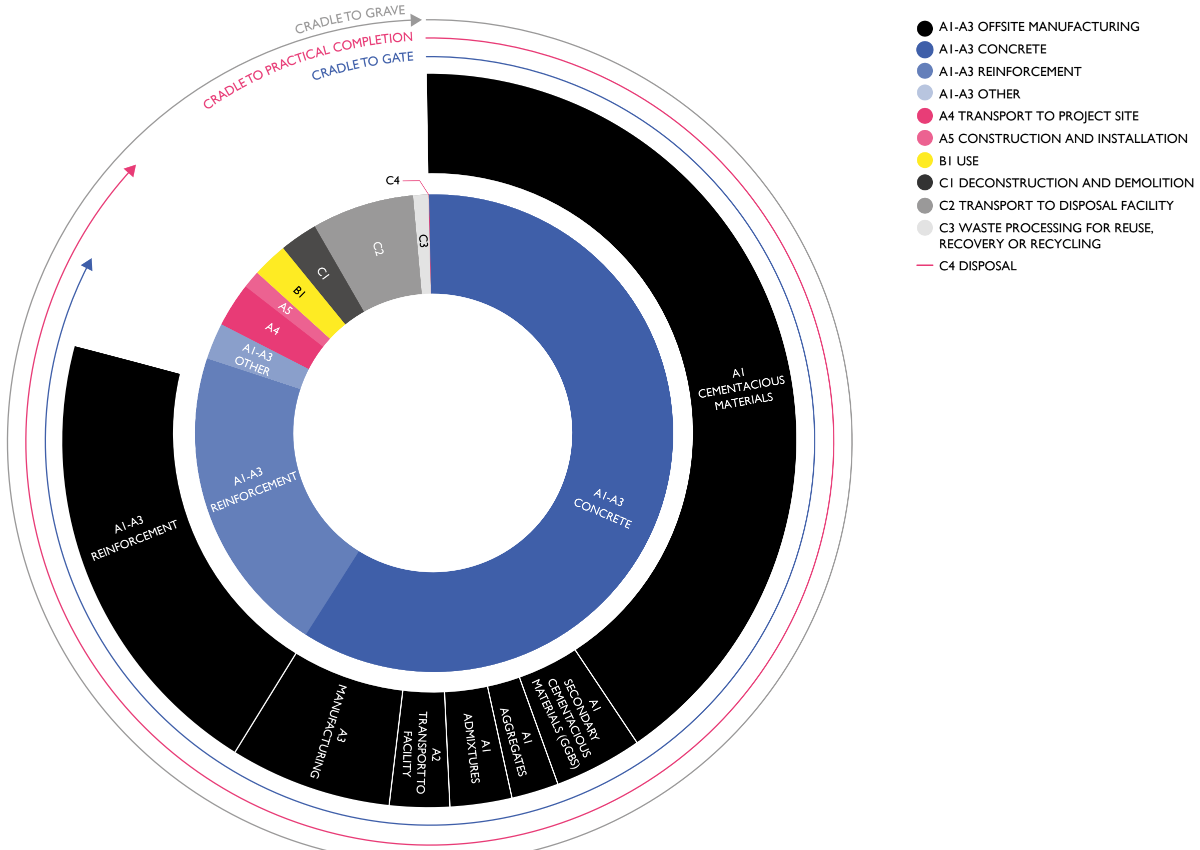


Figure 31 - Improved mix design carbon impact across the lifecycle

Recommendations for future research

Though much rigour has been applied in our efforts to decarbonise precast concrete for immediate application through Innovate UK, further investigation could have been undertaken regarding concrete mix solutions. We would have also endeavoured to achieve full third party verification of results against ISO 14040, to ensure full compliance with the technical screening criteria of the EU.

We recommend that others undertake further research to understand and transparently communicate the embodied carbon impact, design and value chain considerations of a wider scope of construction products and services. We suggest that this review incorporates cladding, mechanical services, electrical services and insulation.

From our brief review of insulation impacts, we noted that when comparing PIR and Rockwool insulation, one should do so on the equivalent U-value, as both insulations have different lambda values. We suggest basing the comparison on a square panel, without any recesses or openings, for purely carbon comparison purposes, in order to achieve a U value of 0.15W/m^2. 140mm PIR insulation and 250mm rockwool insulation would be required. When carbon factors are compared for equivalent thicknesses, 1m^2 of 140mm thick PIR insulation contains 23.71kgCO_2e and 1m^2 of 250mm thick rockwool contains 48.3kgCO_2e.

"We wholeheartedly believe that through wide collaboration across the value chain, the optimisation of solutions, testing of the application and refinement, the built environment can move beyond harm, beyond unintended impacts, to achieve in full the sustainability opportunities available through its integral role in society."

Decarbonising Precast Concrete Team

Forterra crane moving a precast panel to storage

Further project outputs

For further details on our methodology, please get in touch with one of our team.

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This summary has been developed from the following research papers undertaken during the course of the project:

"Decarbonising Precast Concrete: Calculation of Use and End of Life Carbon Emissions", Accelar Ltd, May 2021

"Decarbonising Precast Concrete: Gate to Assembly Carbon Capture", PCE Ltd, February 2021

"Concrete Technical Report: Reducing Embodied carbon of precast concrete whilst maintaining productivity", Forterra Building Products Ltd, June 2021

"Measurement of cradle to gate carbon profile", Forterra Building Products and Accelar Ltd, June 2021

"Decarbonising Precast Concrete: Recommendations and Further Questions for Reducing Embodied Carbon in Precast Concrete Prisons", PCE Ltd and Curtins Ltd, April 2021

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