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Boston Consulting Group

Scaling Low-Carbon Design and Construction with Concrete: Enabling the Path to Net-Zero for Buildings and Infrastructure

WHITE PAPER

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Foreword

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Mitigating climate change by decarbonizing construction, and more specifically materials used in construction such as concrete and steel, is a crucial and complex priority. This report focuses on addressing the challenges in reducing emissions from cement and concrete by deploying low-carbon design techniques and using low-carbon materials at scale.

Over the past several years, our organizations and others have done much work to create demand for low-carbon concrete and construction from public and private buyers, in order to catalyse investment in concrete decarbonization. Examples of this work include our previous publications such as Green Public Procurement: Catalysing the Net-Zero Economy and Low-Carbon Concrete and Construction: A Review of Green Public Procurement Programmes, which provide frameworks for green public procurement; as well as initiatives such as the First Movers Coalition, which at COP27 in November 2022 launched a private-sector commitment framework for purchasing near-zero cement and concrete.

To build on our previous work, and to support the design and construction of lower-carbon projects at scale, it became clear that we must also engage the design and construction players that operate between project procurement and material production and make critical decisions about concrete use, which influence projects' carbon footprint. Architecture, engineering and construction (AEC) firms must scale the use of low-carbon materials and design techniques in order to reduce the carbon footprint of buildings and infrastructure.

To produce this report, we undertook a series of discussions across the AEC and cement and concrete production communities. During these discussions, company leaders shared their objectives, strategies, reservations and challenges related to scaling low-carbon design and reducing concrete emissions. We encountered a range of complex concerns and in some cases frustrations, but also examples of promising progress and innovations, which have helped to mould this report.

The purpose of this report is to provide a framework for scaling low-carbon design with concrete that players across the value chain can adopt. While our primary focus is on the solutions that the AEC and cement and concrete manufacturing industries can act upon, we also recognize the critical influence of project buyers and governments and have included the actions they can take to support low-carbon design. Additionally, while the focus of this report is on cement and concrete, many of the ideas described can be applied to reducing emissions from other building materials and from entire projects.

Implementing these solutions will not be easy but defining them is an important starting point and one that we hope will inspire action. Trends in corporate decarbonization commitments and green public procurement programmes – as well as the growing pressure on companies to live up to their sustainability goals – indicate that low-carbon design and production of low-carbon materials will increasingly become capabilities that AEC firms and materials producers will need to adopt to remain competitive in the future. We believe that firms that begin the journey of scaling low-carbon design now are making smart investments, not only in the sustainability of our planet, but in the sustainability of their businesses.

Executive summary

The world is in the midst of an infrastructure and buildings boom. In every part of the globe, and especially so in the developing world, urban commercial centres and residential housing are expanding as economies grow. At the same time, new roads and bridges are being paved and designed to provide logistics channels for moving parts, supplies, manufactured goods as well as commuters, while old infrastructure is being modernized. This is all potentially good news for the global economy, except one glaring downside: buildings and infrastructure are responsible for approximately 40% of global carbon emissions each year, around 15 gigatonnes (Gt).[1]

Unabated, this number could grow dramatically, effectively undercutting decarbonization efforts in other sectors.

A substantial share of these emissions is released before an asset is ever used. The production of materials accounts for 15-20% of buildings emissions and 50-60% of infrastructure emissions (see Figure 1). Among building materials, concrete accounts for around 30% of building materials emissions (see Figure 2) and 7% of global carbon emissions.[2]

Yet, concrete possesses qualities that make it ubiquitous and important in construction – durability, resilience, thermal capacity, local availability, relative affordability and the ability to meet highly variable functional requirements. Therefore, in order to reduce the carbon footprint of buildings and infrastructure, it is critical to examine the manufacture and use of concrete. In 2021, the cement and concrete industry published its roadmap to net-zero concrete by 2050 through the Global Cement and Concrete Association, in which it identified the actions and policy enablers necessary to decarbonize the entire value chain of the sector. The roadmap identified the valuable role of low-carbon design and construction.

This paper examines how to scale this lever.

The potential

The decisions made by AEC firms about how to use concrete have an impact on – and if decided with intentionality, can reduce – a structure's lifetime emissions in several ways. Most immediately, decarbonizing the cement manufacturing process using near-term (available by 2030) technologies, specifying lower-carbon concrete formulations, and optimizing the volume of material used, can reduce project-level carbon emissions from concrete by up to 40% (see Figure 4). Furthermore, the way concrete is used in a structure's design can be optimized to improve its thermal efficiency, longevity and circularity, further reducing its carbon footprint.

The obstacles

Although reducing carbon emissions in buildings and infrastructure is an important opportunity requiring swift action, a series of obstacles prevents low-carbon design and construction with concrete from being deployed at scale today.

To begin with, measurement of carbon emissions across the entire life cycle of a project, and use of data to improve design decisions and track progress, is not the industry norm. This is, in part, because of the complexity of lifetime carbon assessment calculations and a lack of available data inputs. It can also be attributed to a lack of mandates for carbon measurement from governments, clients and firms.

Fragmentation in the design and building process also stands in the way of achieving lower-carbon outcomes. Different phases of design and construction are handled by different teams and firms, often with minimal coordination, limiting visibility into supply chains and impeding exchanges of information and ideas.

Adding to these challenges, low-carbon design techniques and products are not always aligned with industry norms and documented codes and standards, making it risky for firms to deploy them.

Perhaps most importantly, many clients, public and private, are not prioritizing carbon reduction (which can sometimes increase material and project costs) in their procurement decisions. This not only makes it difficult for AEC firms to prioritize low-carbon design, but creates uncertainty among cement manufacturers about the demand for low-carbon products, discouraging them from investing in decarbonizing their production processes. This adversely affects the economics and supply of low-emissions cement and concrete products, creating circular challenges and making designers hesitant to specify them.

The solution

This report offers a seven-part framework for overcoming the challenges and concerns that have stymied low-carbon design of buildings and infrastructure projects with concrete. Enacting this framework requires action and support from AEC firms, cement and concrete manufacturers, project buyers and investors, and governments.

1. Adopt consistent life-cycle emissions measurement

   AEC firms must conduct project-level, life-cycle carbon assessments, and do so consistently, in order to inform responsible design decisions and create accountability. The cement and concrete industry, on its part, must more frequently provide detailed environmental product declarations (EPDs).

2. Increase collaboration across the value chain

   Enhanced communication during the project design process between AEC firms and concrete manufacturers can improve supply chain visibility and facilitate lower-carbon project outcomes.

3. Reduce risk through piloting, data and engagement

   When standards, codes and industry norms work against reducing carbon emissions on buildings and infrastructure projects, AEC firms and cement and concrete producers must be willing to push for change by participating in dialogues with clients, academia and industry bodies to run pilots, invest in research, gather durability data and update standards.

4. Evolve operating models with extensive leadership support

   AEC firms must have clear mandates from the highest levels of leadership to prioritize low-carbon design, so that they can effectively upskill and enable teams to achieve lower-carbon outcomes.

5. Signal demand and scale supply

   By committing to specify and design for an increased volume of low-carbon materials and projects, AEC firms can help make the business case for cement and concrete manufacturers to invest in the plant upgrades needed to produce these materials at scale, improving their economics and availability.

6. Prioritize carbon reduction in procurement

   Project buyers, both public and private, can have meaningful influence in driving the AEC and cement manufacturing industries to act, by requiring disclosure of project and materials emissions and prioritizing carbon reduction in the partner selection and design process. Alongside demand signals from AEC firms, this can also help drive the necessary investments in technology and manufacturing.

7. Establish supportive public policy

   Governments can support the above steps and accelerate progress through a range of policy actions including regulation, incentives and funding, and by providing leadership to address key industry challenges.

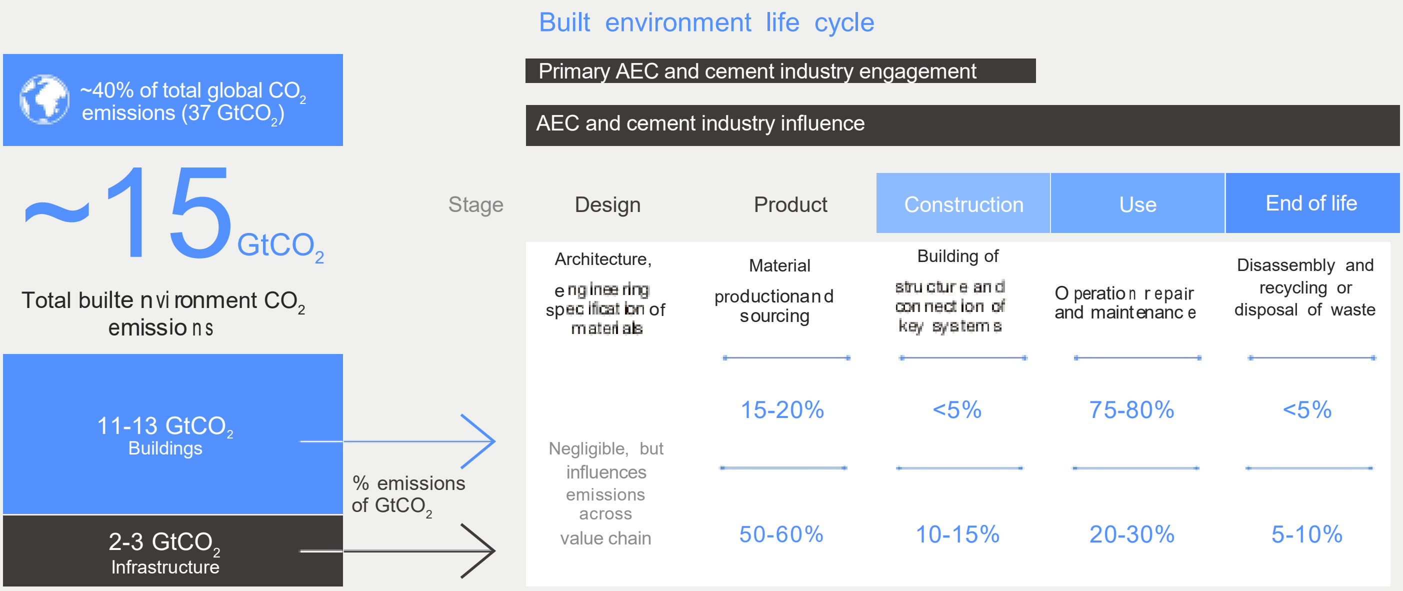
Given the urgency of reducing emissions from buildings and infrastructure, and the potential of low-carbon design and construction using concrete, all stakeholders – AEC firms, cement and concrete manufacturers, public and private buyers of construction projects and governments – must take these actions earnestly and speedily.

1 Introduction

Scaling low-carbon design with concrete: A path to net-zero construction.

Buildings and infrastructure are responsible for approximately 40% of the world's carbon emissions each year. A meaningful share of these emissions is released before an asset is ever used – through the production of building materials (an estimated 15-20% for buildings and 50-60% for infrastructure, although it can vary widely by project and geography) and construction activities. The remainder are emitted during the use of an asset through energy consumption, repairs, maintenance and at the end of its life, from demolition and waste. The design decisions made by project buyers and investors, architects and engineers before construction begins, and the choices that contractors make throughout the building process about which materials to use and how to use them, have a meaningful impact on the total life-cycle emissions of an asset.

FIGURE 1 The built environment is responsible for around 40% of global emissions across the full project life-cycle



Sources: IEA, "2020 Energy Technology Perspectives"; IEA, "Tracking Report - Buildings"; BCG analysis.

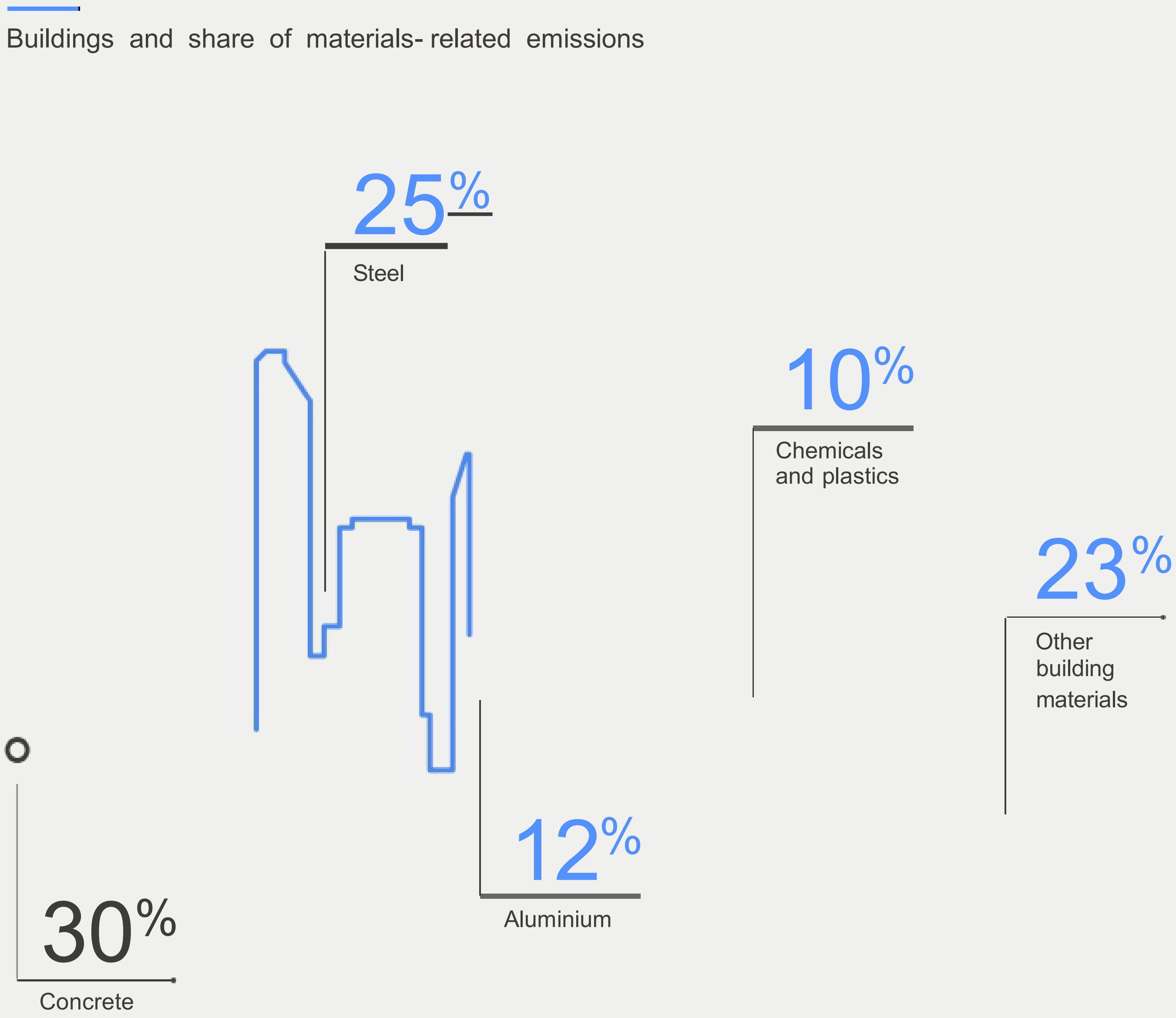
Note: Life-cycle analysis based on European Standards EN-15978 – includes materials, construction, operation and end-of-life emissions; excludes credit of material reuse and recycling.

The role of cement and concrete

Concrete and cement (an essential material in concrete) are the most consumed human-made resources on Earth, responsible for approximately 7% of global carbon emissions and 30% of material emissions for buildings. The centrality of concrete and cement affects the carbon footprint of buildings and infrastructure in two crucial ways: directly through their own carbon emissions generated during manufacturing and construction, and indirectly through their positive contribution to the built project's energy efficiency, durability and longevity.

Global demand for cement is increasing, and in the absence of any action to respond to calls for net zero emissions, it is forecast to grow by 20% from 2020 to 2030.[3] Many of concrete's properties including its strength, durability, fire resistance, circularity, availability, resilience, thermal properties and affordability make it indispensable for critical infrastructure and buildings, which ultimately impact the health, safety and quality of life of billions of people. Therefore, in order to reduce the emissions of buildings and infrastructure while meeting societal needs, it is imperative to examine the use of concrete, and ways to reduce the carbon emissions related to it.

FIGURE 2 | Concrete is responsible for approximately 30% of materials emissions for buildings



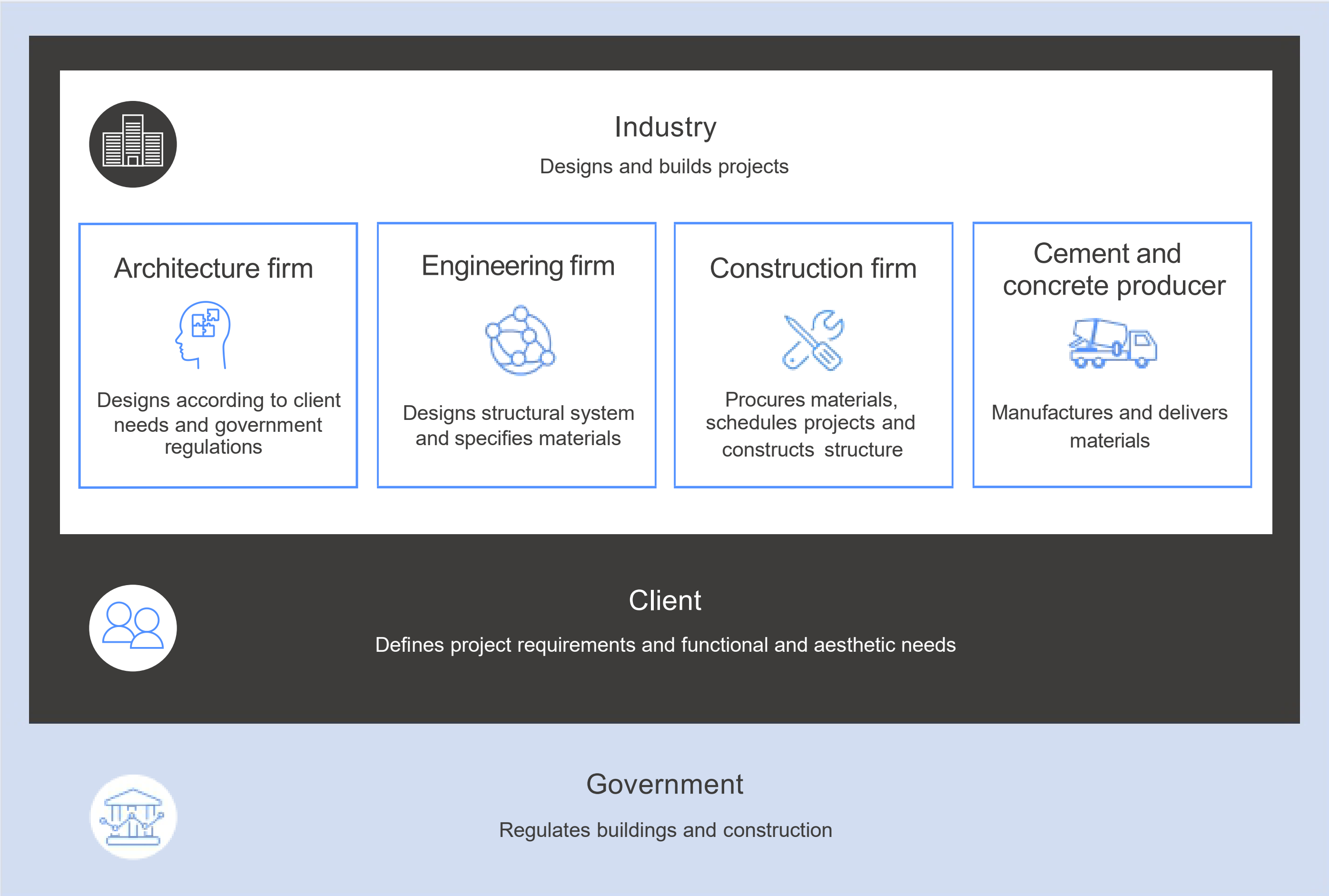
Source: BCG analysis.

The role of design

Along with materials producers that supply the cement, concrete and other materials used in construction, AEC firms can significantly influence a project's carbon emissions. The choices these firms make in the initial stages of a project determine the materials and construction techniques used, the energy consumption, repairs and maintenance during operation, and the resilience, longevity, circularity and recyclability at the end of life. These factors ultimately determine a project's total carbon emissions over many years. These design decisions are of course also influenced by project buyers (public and private), who set project priorities and budgets, and by governments that issue building and construction regulations.

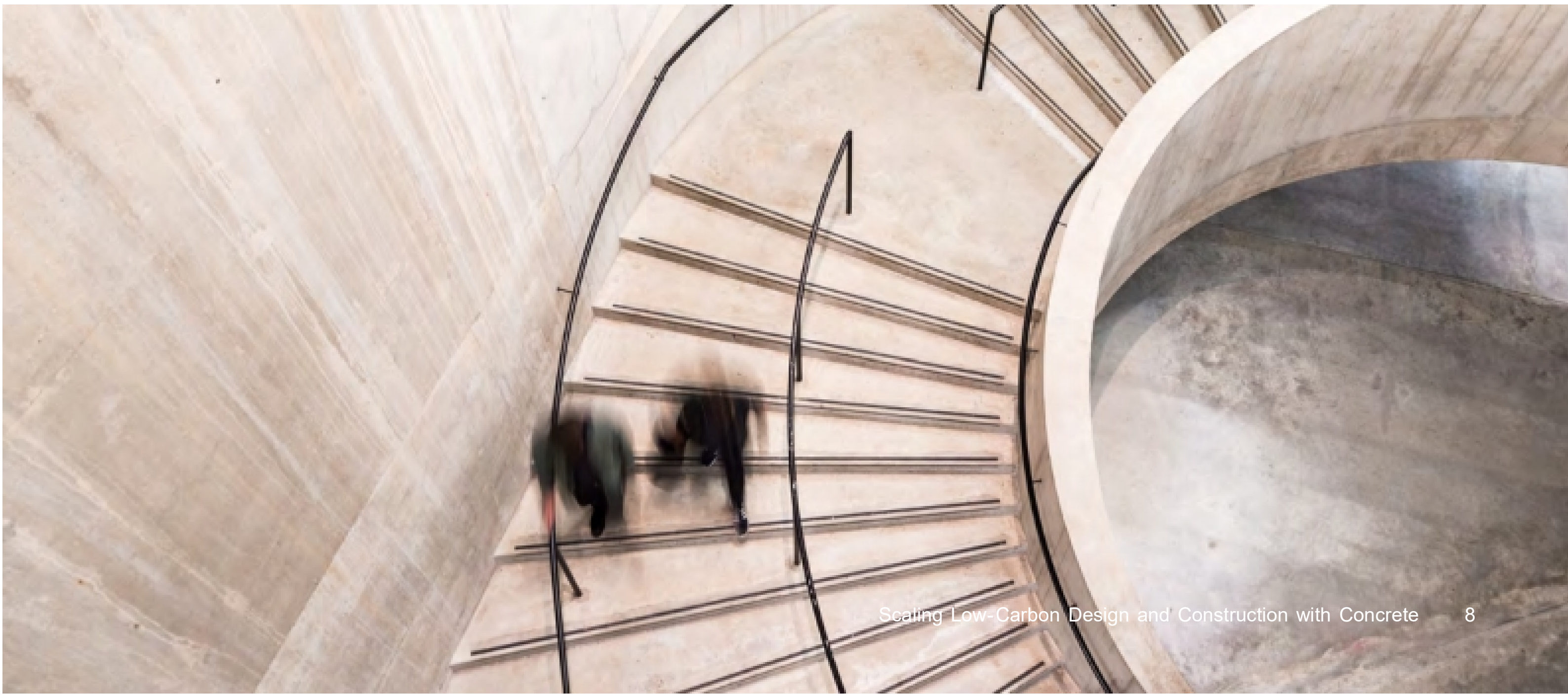
By setting and working towards a goal to minimize carbon emissions from the very beginning of a project, project buyers, AEC firms, and cement and concrete producers can collaborate to reduce carbon emissions across the building and infrastructure life cycle. There are obstacles to doing this and challenges to address, but this is a huge opportunity that could make a critical difference in reaching the goal of limiting the global average temperature increase to 1.5°C above pre-industrial levels.

FIGURE 3 | An illustrative view of the buildings and infrastructure value chain



Source: BCG analysis.

To scale low-carbon practices in the industry, low-carbon design and construction must be recognized as a critical enabler for reducing the carbon footprint of buildings, and must accordingly be prioritized by AEC firms, cement and concrete producers, project buyers, investors and governments.

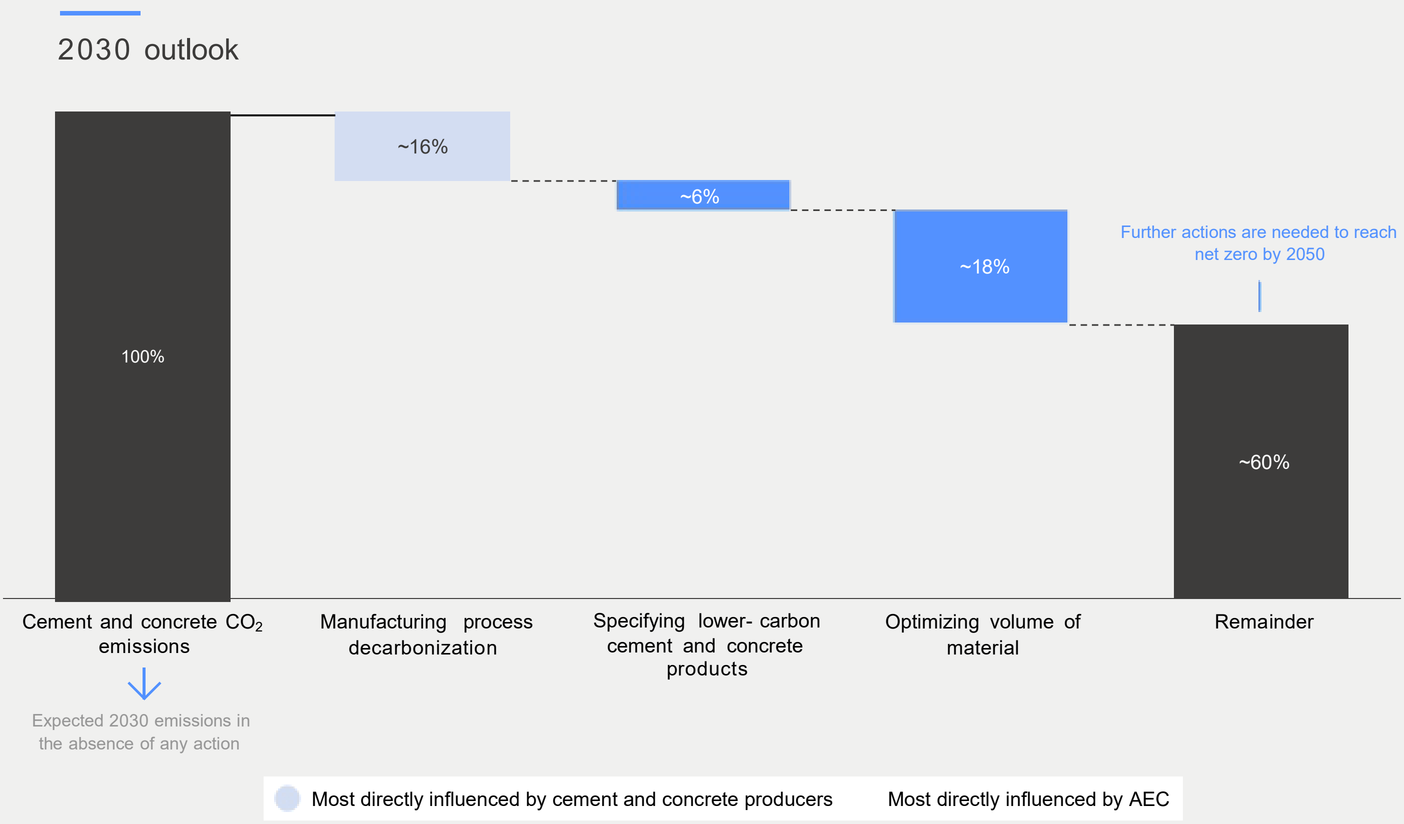


2 The potential of low-carbon design and construction

Large-scale deployment of low-carbon design tactics and the use of existing and upcoming manufacturing technologies can meaningfully reduce the carbon footprint of construction projects.

The total concrete emissions in a project can be reduced by up to 40% by 2030 (see Figure 4) by using existing or upcoming technology in the manufacturing process, specifying the use of low-carbon concrete products, and optimizing the volume of materials used. Additionally, other techniques related to the construction, use and end-of-life stages can further shrink a structure's carbon footprint over its life cycle.

FIGURE 4 Low-carbon design can reduce the cement and concrete emissions of construction projects by up to 40% in the near term



Sources: Global Cement and Concrete Association, Concrete Future – The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete, 2021; Institution of Civil Engineers, Low Carbon Concrete Routemap, 2021; A Project-Based Comparison Between Reinforced and Post-Tensioned Structures from a Sustainability Perspective, 2011; University of Wollongong, Environmental impact assessment of post tensioned and reinforced concrete slab construction, 2013; BCG analysis.

BOX 1 | Holistic design decision-making

Designers must holistically assess the various levers they use, and over the whole project life cycle, in order to maximize emissions reductions while meeting project goals. For example, designs that maximize energy efficiency may require more carbon-intensive materials.

Clients and designers face choices while designing the service life of a project: do they want to design a long-lasting, resilient project with low maintenance, or a project with a shorter lifespan that will need higher maintenance and earlier replacement? These alternatives should not be compared only on initial carbon impacts, but over the entire lifetime.

Clients and AEC firms must also consider trade-offs between emissions reduction design tactics and other project criteria such as cost, project scheduling and aesthetics. They must also be thoughtful about how much new construction is undertaken while keeping in mind opportunities for refurbishing and repurposing existing structures.

Four significant low-carbon design levers include:

1. Reducing the carbon footprint of materials

Manufacturing process decarbonization: A number of decarbonization levers can be deployed in the cement manufacturing process that do not affect the properties of the end products other than their global warming potential (GWP, the standard unit of measurement of carbon emissions). Examples include the use of alternative fuels and renewable energy and efficiency improvements. While largely being deployed as first of their kind projects, carbon capture and storage (CCS) technologies are also critical production-side decarbonization levers and are needed to fully decarbonize cement and concrete manufacturing. Although these decarbonization levers fall largely on manufacturers to implement, AEC players can make specifications and purchasing decisions based on the GWP of materials.

Specification of lower-carbon concrete products: Architects and engineers typically specify the materials that should be used in the projects they design, sometimes with input from construction firms and materials producers. Specifying concrete products with lesser GWP (while meeting technical performance and safety requirements) can make a significant difference in a project's emissions. The most common product of this type is blended cement, made with supplementary cementitious materials (SCMs), reducing the volume of clinker used. However, use of SCMs at high percentages typically reduces the strength gain rate of concrete, which can impact construction schedules (and costs) – an element that engineers and construction firms must bear in mind.

Optimization of material volume: The overall quantity of concrete in a project can be reduced through design choices, such as the spacing and width of slabs and columns, and the use of hollow spaces (most frequently applicable in buildings). Additionally, the carbon intensity and quantity of cement can be optimized for lower emissions. For example, the use of higher-strength concrete, which is often more carbon intensive, sometimes enables the use of lesser volume. These trade-offs have to be assessed on a case-by-case basis. Beyond the design phase, efficient use of cement and concrete during construction can also reduce the volume of material used and the associated carbon footprint.

2. Enabling thermal efficiency

In many situations, designers can use concrete's high thermal capacity, that is, its ability to store heat, as part of a heating and/or cooling strategy to reduce operational energy. This is a complex and nuanced consideration as design tactics that incorporate thermal efficiency depend on geography, use, environmental design and other factors.

3. Increasing structural resilience and longevity

Given the increase in extreme weather events due to climate change, concrete is an especially valuable material since it has inherent properties that enable designers to deliver longevity and resilience with little or no extra materials. Concrete's high density and rigidity make it extremely durable against rain, flooding, humidity, strong winds, freezing, chemicals and other threats. Therefore, concrete can be used to increase the overall lifespan of buildings and infrastructure and minimize repairs and maintenance, delaying or avoiding additional product- and construction-stage emissions.

4. Designing for disassembly

"Design for disassembly" (DfD) is an approach that uses modular building techniques to allow for reusing materials after building deconstruction. The DfD planning process makes material reuse and return plans clear early in the design phase in order to maximize the reuse of elements and avoid waste at the end of life.

The framework described in this report focuses primarily on the first lever: reducing the carbon footprint of materials. This lever has the greatest impact on product stage emissions, which also represent a meaningful share of overall project emissions (See Figure 1). Moreover, it can make a significant difference in the short term, compared to design tactics targeting buildings or infrastructure usage or end-of-life emissions. In addition, this lever was the highest priority of many of the firms interviewed for this report. Nevertheless, many of the obstacles and solutions presented here are also applicable to other design decarbonization levers.

3

Obstacles to scaling

AEC firms and producers of cement and concrete face a series of challenges in delivering low-carbon materials and projects at scale.

Although swift action is needed to address carbon emissions from buildings and infrastructure – and proven techniques can have a meaningful impact – low-carbon design strategies are not being used at scale today. AEC firms are raising a variety of interrelated concerns about the feasibility of implementing low-carbon design and construction approaches – many of which they feel are beyond their control. The obstacles that remain significant barriers to scaling low-carbon design include:

– Difficulty in measurement. Assessing the entire carbon footprint of a project accurately and consistently is hard for many AEC firms, because of major capabilities gaps related to technology, data, process and expertise.

While software exists to estimate whole life-cycle emissions for entire projects, collecting and refining the data to make these assessments accurate is difficult. Despite concrete having more environmental product declarations (EPDs, which document the emissions of materials) published than any other material, EPDs with sufficient specificity are not always available. In addition, EPD formats and product category rules (PCRs), which define how EPD measures are calculated, can vary by region and materials, making interpretation and comparability of data troublesome.

In practice, project-level carbon assessments are typically conducted only when a client or a government demands it, or an AEC firm mandates it. For example, the French government requires carbon assessments for select types of buildings through its RE2020 regulation. However, this is far from a global norm today. Given this lack of consistency in assessing projects and the lack of infrastructure for utilizing emissions data, teams are not consistently trained, structured and resourced to measure project emissions – or to use emissions data to inform design decisions.

– Fragmentation of the design and build process. AEC firms typically make design and construction decisions in separate stages of projects, with limited coordination between them. Design and construction firms as well as concrete producers have expressed interest in more upfront collaboration to drive low-carbon outcomes, but many are unsure how to achieve this, especially when it is not part of a client's project requirements. Without a more collaborative approach, decisions made in the initial stages of the project may obviate the low-carbon solutions that can be used in later stages. And they are frequently made without sufficient visibility into local supply chains to understand options for low-carbon materials for the construction phase of the project.

– Established norms and potential risks' potential to hinder innovation. AEC firms are often reluctant to choose certain techniques and products that would reduce project emissions because they run counter to the industry norm or, in some cases, are not compliant with industry standards and codes. Furthermore, it can be the case that some clients have in-house specifications and these may not be updated to newer standards that permit certain blended cements and SCMs, as well as lower clinker factors. In other cases, standards and codes themselves do not include newer innovations and less conventional products, such as recycled materials from construction and demolition waste (CDW), in their definitions and frameworks. In addition, testing of these techniques and products to prove their safety and durability can be an expensive and lengthy process, which further slows their adoption.

– Supply and demand imbalances and uncertainties. Cement and concrete producers must make capital investments to manufacture lower-carbon materials at scale. Generally, new equipment is needed, older plants must be retrofitted or newer ones built in order to begin using new fuels or raw materials or to deploy new and innovative technologies. It is a chicken and egg situation: if AEC firms and their clients as well as policy-makers don't prioritize the use of low-carbon concrete in buildings and infrastructure projects, many manufacturers will be loath to allocate capital expenditures for materials production. And until low-carbon cement and concrete products are produced at greater scale, their availability and cost will be a concern for the industry.