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Concrete Destruction: Costs and Damages of the Concrete and Cement Industry and the Future of Construction

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Study commissioned by the Rosa-Luxemburg-Stiftung

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Ulrich Brand, Stefan Thimmel

Concrete is Everywhere. And That’s the Problem.

No other building material has shaped our world quite like concrete — and no other building material causes so much damage. Some 40 percent of all human-made substances on our planet are cement-based: the “liquid stone” is poured into structures such as bridges, dams, apartment blocks, and data centres. The AI boom literally rests on a concrete foundation. Responsible for between eight and nine percent of all global CO_2 emissions, devastated ecosystems, polluted air, sinking cities, and mountains of rubbish, concrete’s toll is truly devastating. But despite this, production and consumption continue to grow: 25 billion tonnes a year and rising.

The study “Concrete Destruction: Costs and Damages of the Concrete and Cement Industry and the Future of Construction” by Tom Ackers, Conrad Kunze, Paulina Orozco, Matthias Schmelzer, and Nils Urbanus reveals that cement is the obvious lubricant of “imperial construction”.[1] A great deal of effort goes into ensuring that the material’s adverse effects remain concealed. And this is no coincidence, given that there are powerful industry players who have a vested interest in keeping things that way. Cement facilitates relatively inexpensive, rapid, scalable construction — and with it, the growth of a type of construction that, according to architecture professor Werner Sobek, contributes more than 50 percent of all CO_2 emissions if transport, demolition, and recycling are taken into account. Concrete is not a neutral material. It is the very stuff of which the imperial mode of living[2] is made, both at the expense of our natural world and on the backs of workers — such as on building sites, around the world and above all in the Global South.

This can be clearly seen in the case of one of the biggest players: Heidelberg Materials, which is among the world’s largest cement manufacturers, operates factories and quarries via its Israeli subsidiary not only in the occupied Palestinian territories (the West Bank), but also in places like Western Sahara. Farmers in Pakistan are suing the company on the grounds that its emissions are destroying their livelihoods, as evidenced by the devastating floods that tore through the region in the summer of 2022. Collapsing bridges the world over reveal the dark side of cheap mass construction: concrete has a relatively short lifespan, is not built to last, and ultimately ends up in landfill. Every year, ten billion tonnes of concrete waste are either downcycled or discarded. This is not a fault in the system; it is by design.

The industry has come up with its own solutions: “net zero by 2050”, which does not actually translate to zero emissions, but rather to achieving a balance whereby no net additional CO_2 is released into the atmosphere. The idea is that this will be achieved via reforestation and technological innovations such as carbon capture and sequestration — the industry sees this as the ace up its sleeve. But what lurks behind these promises is an aggressive lobbying machine that is blocking attempts at climate control, cashes in on billions in unused carbon credits, and relies on technologies that either do not yet exist or are progressing much too slowly. Emissions have tripled since 1990 — and production has quadrupled in the same timeframe. The industry’s “net zero” rhetoric amounts to nothing more than greenwashing — or rather “concrete-washing”.

So the question we should be asking ourselves is not “How can we produce concrete in a more environmentally friendly way?” but rather “How can we build less, and change and improve how we build?” Away from imperial building techniques, and towards locally sourced, regenerative construction materials. Wood, clay, straw, bamboo, stone: these are materials with an ancient history, a promising future, and local roots. In cases where the use of concrete is unavoidable, we will need to find alternatives that boast lower emissions and a significantly longer lifespan. And more than anything else, we will need the political will to question whether — and, if so, when and where — new construction is necessary at all. We need to ask: Where could existing stocks be redistributed, land divided up, and residential spaces organized with a view to the common good? In Germany, the average living space is 45 square metres per capita, with this figure having risen steadily in recent decades. According to some estimates, up to 158 square kilometres of land are still paved over every year, whether for construction or for traffic infrustructure. Germany is still many kilometres away from reaching its "30-hectare target".

But none of this is a natural phenomenon; it is outdated and unsustainable.

All in all, it is evident that this is not a technical issue, but a political one. And this means that what is needed are bold political solutions: moratoria on senseless demolish and rebuild projects (such as the 2024 Anti-Abriss-Allianz [Anti-Demolition Alliance], which was supported by Germany's Chambers of Architects and other organizations), a systematic phase-out of the conventional production of Portland cement akin to the coal phase-out that was passed in 2020, as well as a democratization of housing by means of socialization, common property, and participatory planning. A number of architects and planners have already made more progress in this respect than politicians. Further progress will also require pressure from below — from local residents and activists, for example.

The ecological crisis is not a distant future prospect; it is our current lived reality. Carrying on with business as usual is not an option — and neither is a strategy of "build, build, build" that focusses solely on financial figures. Concrete not only reinforces buildings and road infrastructure; it also consolidates structures of power and exploitation, as well as an imperial mode of living that has long since exceeded the planet's limits. This study exposes the costs. The time has come to shake the foundations.

Vienna / Berlin, March 2026

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Endnotes

1 S. Thimmel, "Der Markt regelt es nicht", *Stadt.Land.Politik*. Henselmann Journal no. 7., pp. 27–28. June 2022, Berlin.

2 U. Brand and M. Wissen, *The Imperial Mode of Living: Everyday Life and the Ecological Crisis of Capitalism,* London: Verso Books, 2021, translated by Z. M. King.

Glossary

Alternative fuels: Fuels used to power cement kilns in order to replace conventional fossil fuels. They typically consist of waste materials co-processed with coal, petroleum coke, or natural gas.

Aggregates: The sand (fine) and gravel (coarse) components of concrete that provide bulk, strength and volume. They are the largest components of concrete mixes by volume and by mass.

Basic needs: The minimum material and social requirements necessary for human well-being, including housing, water, sanitation, and energy access.

Built environment: Human-made surroundings, primarily buildings and infrastructure.

Bullshit construction: Construction that serves speculative, luxury, or non-essential purposes, instead of meeting basic social needs.

Bullshit demolition: Demolition undertaken not because a building is structurally unsound or socially obsolete, but rather for economic, cosmetic, or profit-driven reasons.

Calcination: The thermal decomposition of calcium carbonate ($CaCO_3 \rightarrow CaO + CO_2$) that occurs during kiln processing above 1000 °C. This reaction is the primary source of unavoidable process emissions in cement manufacture.

Carbon Capture, Utilization, and Storage (CCUS): A suite of technologies designed to capture CO_2 from flue gases, transport it, and either use it in products (CCU) or inject it into geological reservoirs (CCS).

Carbonation: The uptake of (usually atmospheric) CO_2 by slaked lime within hydrated cement over time ($Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$). This occurs naturally over long timeframes but can be artificially enhanced, for example by injecting CO_2 during batching.

Carbonatable cement: A type of cement that hardens during carbonation, not during hydration (like Portland cement does). Also referred to as carbonation-based cements.

Cement: A powdery mineral binder that hardens when mixed with water and binds aggregates into mortar or concrete. In this report, "cement" usually refers to industrial Portland cement unless otherwise specified.

Circular construction: Design and building practices aimed at extending material lifetimes through reuse, adaptability, and disassembly.

Clinker: The intermediate, nodular product formed in the cement kiln from the high-temperature processing of limestone and clay. It is ground with gypsum and any additional supplementary materials to make cement.

Clinker substitution: The practice of reducing the proportion of clinker in cement by adding supplementary cementitious materials to lower emissions and material intensity.

Concrete: A composite material made by mixing cement, water, fine (sand) and coarse (gravel) aggregates. It hardens into an artificial stone that is strong in compression but weak in tension. In this report, the term "concrete" also encompasses mortar, unless otherwise stated.

Decarbonization: The process of reducing or eliminating carbon dioxide emissions from energy systems, industries, and materials production.

Depaving: Community-led removal of sealed surfaces and their replacement with soil and plants, undertaken as a local, restorative practice to reduce ecological harms and improve urban resilience.

Emissions intensity: The amount of greenhouse gas emitted per unit of product, usually quantified according to the "equivalent" quantity of CO_2 that would produce the same amount of global warming over a 100-year period. Often used to measure progress in industrial decarbonization (e.g., CO_2 per tonne of cement).

Embodied emissions: The greenhouse gases released in the production, transport, construction, maintenance, and disposal of a material or asset. However, the term often refers more narrowly to the "cradle-to-gate" emissions of building materials and components prior to construction and use. These contrast with "operational emissions", which arise during the use phase of a building or piece of infrastructure, excluding maintenance (e.g. heating, cooling, electricity consumption).

Imperial mode of living: A socio-ecological pattern in which affluent populations (in rich countries and poor countries alike) sustain high levels of consumption through the externalization of environmental and social costs (e.g. unemployment, pollution) onto poorer populations worldwide. The concept was coined by Ulrich Brand and Markus Wissen.

Just transition: A framework for ensuring that the shift to a low-carbon economy protects workers, communities, and vulnerable populations, promoting fairness and inclusion in structural change.

Karst: A distinctive type of landscape formed in areas rich in limestone, characterized by caves, sinkholes, unique hydrology, and ecology.

Limestone: A sedimentary rock made mainly of calcium carbonate ($CaCO_3$). It is the principal raw material for cement and the main source of process-related CO_2 emissions during cement manufacture.

Mortar: A paste of cement, sand, and water used to bind masonry units or render surfaces. In this report, "mortar" is included under general references to "concrete" unless otherwise noted.

Nature-based infrastructure: Design approaches that use or mimic ecological systems (e.g., wetlands for flood protection) instead of using built, materials-intensive structures.

Nowtopias: Small-scale, community-based experiments and social "niches" (e.g. housing cooperatives, depaving initiatives, self-build projects) that prefigure alternative, more sustainable and democratic ways of living.

Planetary boundaries: A set of ecological limits (e.g., climate stability, biodiversity, freshwater availability) that define a "safe operating space" for humanity; cement and concrete production contribute to transgressing several of them.

Portland cement: The dominant industrial cement type, produced by high-temperature clinkering of a mix of mainly limestone and clay in rotary kilns. It is a hydraulic cement that hardens by hydration.

Process emissions: Greenhouse gases released directly from chemical or physical transformations in production processes (rather than from fuel combustion). In cement, these mainly arise from limestone calcination.

Rebound effect: A phenomenon whereby the effect of efficiency improvements per unit is, in total, less than expected and may even (paradoxically) lead to greater overall material or energy use. For instance, measures that lower the material or energy use per unit (e.g. more efficient kilns) can also lower production or usage costs, and this can encourage higher total consumption, counteracting some or even all of the expected resource savings.

Reinforced concrete: A composite of concrete and reinforcement (usually steel rebar), in which concrete supplies compressive strength and steel provides tensile strength. It enables the creation of more capable structural elements such as beams, slabs and columns.

Retrofitting: Upgrading existing buildings or infrastructure to improve energy efficiency, safety, or usability; an alternative to demolishing and rebuilding.

Rotary kiln: A long, rotating cylindrical furnace used in modern industrial cement plants to heat raw limestone, clay, and other ingredients through preheating, calcination, and clinkering stages. The rotary kiln greatly increased the speed at which batches of cement could be produced, and it enabled the mass production of cement based on fossil fuels.

Social metabolism: The flow of energy and materials through societies and economies, shaping ecological impacts and social relations; a key concept in political ecology and material flow analysis.

Sufficiency: An ethical and policy approach in sustainability that avoids overconsumption of materials, energy, water, land, and other natural resources, ensuring an equitable distribution of natural resources and a decent standard of living for everyone within planetary boundaries. In contrast to efficiency measures, sufficiency measures are primarily driven by non-technical solutions.

Supplementary cementitious material (SCM): Materials such as fly ash, granulated blast-furnace slag, or calcined clays that partially replace clinker in cement. They lower CO_2 intensity and can enhance the material properties of the final product.

Techno-fix: An attempt to address a societal problem by engineering or technological solutions, with little or no change to societies structures or social behavior, often focusing on the symptoms of a problem (e.g., CO_2 emissions removal) without tackling underlying social or structural causes. An example is electric cars: they can lower CO_2 emissions but do not tackle the underlying norm of individual mobility and therefore remain highly materials-intensive.

Vernacular architecture: Traditional, place-based building practices that use locally available materials and crafts. Vernacular architectures are typically resource-light, climate adapted, and socially embedded; they often embody regenerative design principles.

Preface

> Given the share of global CO_2 emissions from the cement-concrete production chain, it is perhaps surprising that climate activists haven’t targeted clinker-producing cement plants directly in the same way that they have gone after coal-fired power stations.
>
> *David Perilli, Editor at Global Cement (2021)*

Concrete, the final product of cement, is both omnipresent and invisible. It is the most-used man-made material and responsible for 8 % of global carbon emissions. It is associated with the destruction of soils, lifeless “concrete jungles” of modern cities, and climate breakdown. Even so, the industry that produces it has so far largely avoided public attention, compared to aviation or fossil fuels. It is rarely targeted by activists, and the social and ecological costs and damages of this material have eluded public debates. Concrete is so extensively used, so abundant in our surroundings, that its presence is simply taken for granted. It appears to be so useful that its ever-expanding artificial landscapes are seen as inevitable, even natural.[1] Just as water is invisible to fish, concrete escapes our critical analysis. This is even more true of the cement industry, which, as the “infrastructure of infrastructure”, is even more hidden from everyday life.[2]

Unlike the extraction of fossil fuels that has increasingly come under scrutiny, the production of cement, dependent on the release of CO_2 from limestone, is largely accepted as a fact. The greenhouse gas emissions from the cement industry are considered largely unavoidable. The only reasonable path forward, according to this line of reasoning, is the large-scale capture and containment of the resulting CO_2, with an extensive carbon capture and storage infrastructure.[3] The discussion surrounding the cement industry’s decarbonization is either nonexistent or dominated by merely technical measures. More radical and transformative steps are urgently needed, yet mostly left out of the picture.

We are thankful to the Rosa Luxemburg Foundation for providing us with the opportunity and support to carry out a critical report on this seemingly technical topic. After a call by the foundation for studies on this theme, we formed as a research team spanning different academic disciplines, including transformation studies, sociology, philosophy, chemistry, and economics, as well as activist viewpoints and even an insider perspective from within the cement industry itself.

We are enormously grateful to all the individuals and organizations who were crucial in the creation of this study. In particular, we want to thank Aaron Vansintjan for the meticulous and critical editing of this study, which proved immensely helpful. We also thank Anastasia Blinzov and Stefan Thimmel from the Rosa Luxemburg Foundation for enabling this work to be done. Furthermore, we are grateful for the guidance and feedback from Wanja Wedekind, Daniela Gottschlich, Jan Eilts, Janty Jie, Simon Pirani, John Ackers, Luisa Zenker, Anna Schmidt, Leonie Tasse, Mario Kolkwitz, and EJ Williams, as well as the experts from End Cement, A100 Stoppen, Dachverband der Kritischen Aktionärinnen und Aktionäre, and Jaringan Masyarakat Peduli Pegunungan Kendeng. Thank you to Eli Zeger for help with copy-editing, and to Dominik Wiedenhofer and colleagues at the University of Natural Resources and Life Sciences, Vienna, for sharing with us their MISO2 global material stock-flow modelling data.

Finally, this study wouldn’t exist without the countless grassroots struggles and initiatives fighting for a better and just built environment. We hope we have done justice to their efforts.

Endnotes

[1] Compare Wieser et al. 2023: 23.

[2] Fivez & Motylińska 2022.

[3] IPCC 2022a: 36, 430, 1190-1191; UNFCC 2024.

Executive Summary

Cement is an ancient material that now sits at the heart of modern societies. Its main derivative, concrete, is the most ubiquitous man-made material on Earth, second only to water in the scale of annual consumption. From homes, offices, and retail spaces to dams, bridges, tunnels, and sanitation systems, it defines much of the built environment. Yet this material is also a growing global problem as it contributes to the transgression of multiple planetary boundaries while, quite literally, cementing exploitative power structures.

History and Development
Cement powder is essentially a glue – the product of burning limestone together with other materials and grinding them down. When cement is mixed with water, sand, and gravel, the combination hardens to form concrete. Cement has long histories of use. However, its global dominance in the form of Portland cement only began after 1945 as the result of a specific coherence between the material's properties, the requirements of industrial modernity, and the interests of capitalist development.

While today concrete forms 40 % of all anthropogenic mass, its enormous production (25 billion tonnes annually) is often projected to rise even further due to global housing and infrastructure needs. However, prevailing economic structures fall short of directing the materials to where they are needed most; while its harms stack up.

Costs and Damages
The various social and ecological damages caused by the (concrete and) cement industry directly and through the widespread use of its products span six major areas:

1. Carbon Emissions: Cement and concrete production accounts for 8–9 % of global anthropogenic CO_2 emissions. Its emissions stem both from fossil fuel combustion and from the calcination of limestone; processes that are currently unavoidable in the production of Portland cement.
2. Ecological Destruction: The extensive extraction of limestone, gravel, and sand needed for concrete have emerged as humanity's primary extractive front, as these are mined in larger volumes than any other material (23 billion tonnes annually), now even surpassing fossil fuels. These mining activities reshape landscapes, damage water systems and local communities, and devastate ecosystems, accelerating biodiversity loss and species extinction.
3. Air Pollution: Cement plants severely impact surrounding communities through substantial air pollution, including nitrogen oxides (8 % of all global emissions), sulfur oxides (5 %), and heavy metals such as mercury (9 %) released through particulate matter. Additionally, toxic dust (5 %) is generated throughout the entire concrete production chain – from quarrying to final batching – primarily harming workers and nearby communities.
4. Sinking, Heating, and Sealed-off Cities: The accumulation of concrete causes large-scale urban consequences. Cities experience higher temperatures, more intense flash floods, and sinking foundations – all partly due to concrete's heat retention properties, its sealing of surfaces, and its weight.
5. Excessive Waste: Concrete structures mostly have a limited lifespan (typically around 50 years), especially when reinforced with steel or built for "throwaway architecture". The resulting concrete waste (10 billion tonnes annually) is either landfilled or downcycled.
6. Consolidation of Power and Exploitation: Concrete's moldability and standardization enable greater worker exploitation and centralization of control, embedding power hierarchies both within the industry and the built environment. Its ease of use and rapid deployment make it an important tool of war and displacement.

The Cement Industry's Climate Response
The damages across all areas are considerable. However, it appears especially impossible to fully eliminate CO_2 emissions in the production of Portland cement. Nevertheless, the industry has pledged to reach "net zero" by 2050. Analyzing the cement industry's lobbying practices, its past measures, and future roadmaps reveals that these claims rest on weak foundations.

Technological measures implemented so far have been limited to efficiency improvements, such as better kiln designs, fuel switching, and partial clinker substitution. These have achieved only modest CO_2 reductions, which have been overcompensated by total production growth (the sector's emissions tripled while production quadrupled since 1990). The sector's current "net-zero"-plans essentially rely on carbon capture and storage (CCS) on a massive scale and other uncertain future innovations. The industry's dominant firms do not intend to switch to alternative cements, which are often more sustainable, despite CCS requiring extensive new infrastructure and being significantly costly, energy-intensive, risky, and deployed at a rate far slower than has been promised. We find that the industry's "net-zero" narrative amounts to wishful thinking.

Moreover, the industry itself has consistently sought to weaken climate regulation and other forms of environmental protection, including efforts to dilute the EU Emissions Trading Scheme. Major firms have additionally obstructed alternative technologies while forming alliances with fossil fuel companies to advance CCS to retain invested capital.

Alternative Measures
To meet global housing and infrastructure needs despite the destructive impacts of the cement industry, three alternative measures are necessary:

1. Improve cement: Traditional Portland cement can be improved or altogether substituted with lower-emission alternatives, many of which are currently being researched and used in niche settings. However, there is no new miracle cement waiting in the wings. These alternatives rely on relatively scarce raw materials, and more expensive manufacturing processes, with each alternative flawed to a certain extent. Their use is likely limited to situations where no other solution is possible.

2. Switch materials: Concrete can often be replaced by other building materials, especially by traditional and mostly regenerative materials such as timber, bamboo, hemp, straw, stone, and earth. Locally sourced and designed using traditional architectural knowledge – enhanced with modern techniques – these can avoid many of concrete's ecological and social costs. However, replacing the entirety of concrete with alternative materials is improbable, especially as land for plant-based materials is scarce and needed for biodiversity protection and food production.

3. Use less material: The consumption of construction materials can be reduced through technological and social changes. New construction, especially in the Global North, can largely be avoided – through redistribution and enhanced longevity of buildings, a ban on demolitions, restrictions on luxury, prestige, and speculative projects, as well as a focus on meeting basic needs. Excess can additionally be reduced through more efficient construction methods, material reuse, and a more compact and nature-based built environment.

Taken together, these measures point toward a vision of transforming our built environment from an extractive, globally uniform, and profit-driven system built on concrete to one that is regenerative, vernacular, and people-driven.

Political Levers
Collective struggle of activists, workers, and communities that confront entrenched power is needed to achieve this vision – ranging from disruptive action to transformative reforms to prefigurative practices. Seven political levers, drawn from existing and past struggles, can play an essential role:

1. Contest the cement industry: Challenge the cement industry's narratives, expose its damages, and confront its false solutions through public campaigns and direct action.

2. Stop bullshit construction: Halt unnecessary construction and demolition projects through direct actions, worker strikes on harmful projects (a.k.a., "Green Bans"), and moratoria on demolition.

3. Regulate Construction: Fight for binding rules that enforce durability, repairability, community co-design, and higher quotas of regenerative and local building materials. Achieve expansion of public housing built with sustainable materials and focused on sufficiency.

4. **Phase out Portland cement:** Secure a state-led phase-out of Portland cement, similar to coal, oil, and gas, paired with just-transition measures for workers.

5. **Phase in the regenerative and vernacular:** Win public regulation and investment to scale up regenerative building practices based on stone, earth, timber, and other alternative materials.

6. **Redistribute and democratize:** Redistribute and democratize the built environment, for example through the socialization of large housing companies, collective forms of ownership, and participatory planning processes.

7. **(De-) construction from below:** Support grassroots depaving initiatives and community-led, self-built housing as living laboratories of alternative construction practices.

Cement and concrete are among the defining materials of modern civilization – but they are also among its most destructive. The evidence presented in this report shows that their continued expansion is incompatible with planetary and social stability. The world must move beyond the illusion of infinite concrete growth. Instead, cement production must be redirected towards meeting basic needs while rapidly reduced and replaced elsewhere. Only then can the foundations of a truly sustainable, equitable, and livable world be laid.

Introduction

Wherever we look, there is concrete. From our homes and offices to the lining of dams, to bridges, tunnels, and sanitation and energy systems, this "liquid stone" underpins modern societies and stands as one of the defining geological markers of the Anthropocene.[1] Over the past two centuries, concrete has become the single most widely used man-made material, comprising about 40 % of all of the accumulated human-made materials in the world by mass.[2]

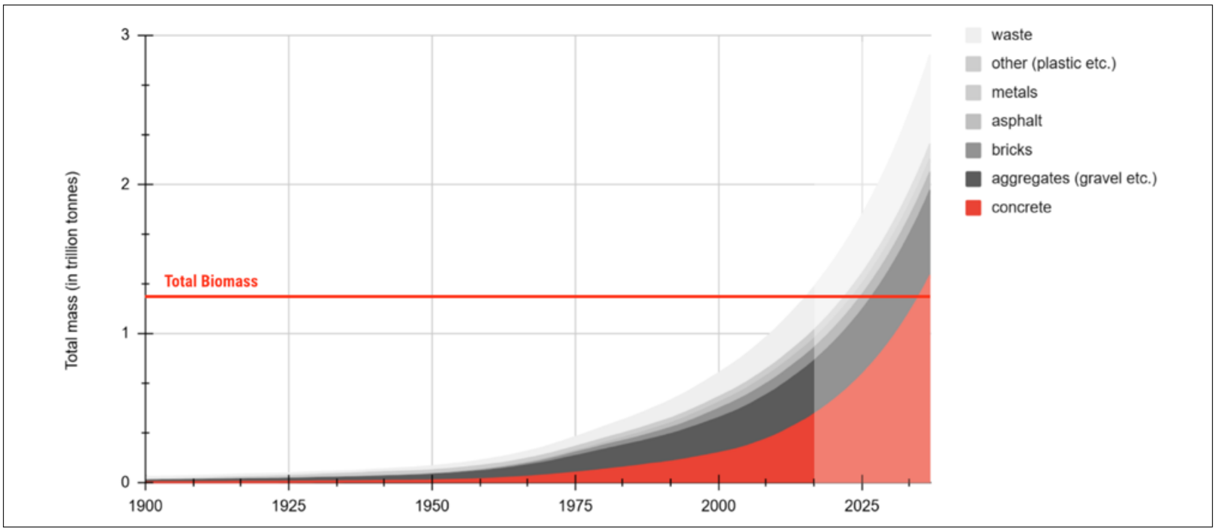
At the centre of this lies the global cement industry, which transforms limestone into the powder that binds sand and gravel into concrete. Cement has enabled a vast expansion in the built environment, but the costs and damages of this have also been mounting: enormous CO_2 emissions, local pollution, the extensive mining of raw materials, exploitative labour practices, the destruction of cultural heritage, sealed and overheating cities, and growing waste.

At the same time, the need for construction materials appears immense, as urbanization accelerates and basic needs remain unmet.[3] By 2060 the global urban population is projected to exceed six billion. Already today, over a billion people lack adequate housing, according to the UN. Two billion people lack access to safe drinking water, 3.5 billion lack adequate sanitation, and 700 million lack access to electricity.[4]

Societies and their built environments also face new forms of devastation from climate disasters and war. Rising seas and extreme weather will force cities to relocate, dams to be built, and infrastructures to be remade. Both rich and poor countries will need to expand renewable energy systems while renovating existing buildings for energy efficiency.

This implies an escalating demand for concrete and its primary ingredient: cement. Cement not only binds sand and gravel; it binds capitalist modernity through infrastructures, social relations, and imaginaries. Yet it also brings immense costs and damages. This report seeks to place cement and its problems in an historical and political context, to outline political, economic, and technological pathways to transformation, and to identify levers by which those changes can be realized.

Figure 1: Total mass accumulated by man-made materials compared to global biomass.[5]



At the heart of this study lies a central contradiction: the cement industry produces severe socio-ecological harms, yet it also appears indispensable to modern societies. It enables the construction of housing, sanitation, and transportation networks, along with many other crucial services – but how essential is cement production, really? And can it be replaced?

This report offers a systematic analysis of the costs and damages of cement and concrete, focusing especially on its carbon emissions. It also critically evaluates the industry's own proposed solutions – mainly technological fixes such as efficiency improvements and carbon sequestration. The report contrasts these with alternative measures and political levers for communities, activists, and workers – alternatives that focus instead on broader societal transformation through shifting material use and reducing unnecessary consumption. Although global in scope, the study pays particular attention to the Global North, where concrete stocks are already extensive and where the profits and other benefits from cement and concrete production have accumulated, focusing in particular on the two European multinationals: Heidelberg Materials from Germany and Holcim from Switzerland.

Analytically, the study draws from critical political ecology and examines the global social metabolism of the economy. Using material flow analysis, we explore how unequal power relations shape material flows and conflicts. Rather than treating the transformation of the cement industry as a mere technocratic process, we analyze the political and economic interests involved – showing, for instance, how dominant firms influence regulatory standards even as smaller innovators, communities, and public authorities attempt to advance alternatives.

Chapter 1 provides a primer on cement and concrete, tracing their historical development, the uneven growth of concrete stocks, and their role in unequal economic development.

Chapter 2 analyzes the socio-ecological costs and damages of the cement and concrete industry, both in production and in the use of these materials, and evaluates the industry's responses. This is complemented by ten case studies of conflicts involving the cement multinationals Heidelberg Materials and Holcim.

Chapter 3 critically examines the cement industry's response to its carbon emissions, as this is the kind of damage that is most discussed, both by the industry and activists. We scrutinize the industry's past political and technological measures, as well as its future roadmaps and communications strategies. With most of the plausible efficiency gains already won, we find that the cement industry's favoured techno-fix solution – Carbon Capture, Utilization, and Storage (CCUS) – remains in its infancy technologically and economically. Moreover, it is energy-intensive and risky, and will in all likelihood be deployed at a far too small scale and slow pace to sufficiently bend the curve of cement emissions internationally. It cannot be relied upon.

Chapter 4 surveys alternative technological and social pathways. These are structured along three different approaches. First, alternative cement production technologies are examined, with particular attention paid to industry newcomers. Second, alternative building materials are surveyed, matching the various use cases of concrete to the feasible alternatives. Third, measures to reduce the need for new construction are outlined, largely based on debates around sufficiency, and the need for different models of development in the built environment, which would allow for a convergence of social justice and fairness across the Global North and South.

Chapter 5 then outlines political levers for transformation on the basis of ongoing struggles surrounding the cement industry and the built environment sector. Adapting a framework developed by Erik Olin Wright, we classify types of transformative change as counter-hegemonic, transformative reforms, and nowtopias, and we discuss several strategies for local communities, social movements, workers, and progressive policy-makers.

In essence, we argue that cement and concrete use must be directed strictly towards meeting basic needs worldwide. All non-essential use should be phased out. The damages caused by cement and concrete production must be reduced to the greatest extent possible, and all viable alternatives to Portland cement and concrete must be pursued – while remaining attentive to real land use and resource constraints.

Endnotes

1 Zalasiewicz et al. 2019: 46.
2 IEA 2020; Krausmann et al. 2018; Wiedenhofer et al. 2021. This number includes only existing concrete structures. Demolished concrete is counted separately in the cited statistics under waste and aggregates.
3 UN DESA 2018, 2024.
4 UN 2023: 24, 26, 21.
5 Data from Elhacham et al. 2020. Projected after 2015.

1 History and development of cement and concrete

> Concrete is more than a material.
> It's about life.
> *Global Cement and Concrete Association (2025)*[1]

Concrete seems to be everywhere in the world, and in so many ways modern life appears to depend on this synthetic "liquid stone". Yet the costs and damages of cement and concrete are enormous: not least, concrete use is a major cause of greenhouse gas emissions, and a key driver of ecological destruction.

The immense ramifications of cement and concrete are largely related to the colossal quantities in which these materials are used. Why, then, is concrete so ubiquitous? How has it come to play such an exceptional role in our built environments? What is the material, what are its social and cultural characteristics, and how can these help us understand its dominant role in the metabolism of modern societies?

In this chapter, we begin by introducing some basic terminology, and we outline the basics about what cement and concrete are (1.1), before looking at their physical properties and uses (1.2). Next, we look at the "strengths" of concrete within capitalist modernity, and what we discern to be a distinct "concrete culture" (1.3). Then, we dive into the specific history and changing chemistry of cements and concrete up until the present day (1.4). We examine what the global cement industry looks like today (1.5). Finally, we interrogate some prevailing assumptions about the indispensability of widespread cement use. Specifically, we interrogate the degree to which cement and concrete are treated as essential for meeting the basic needs of the world's poor (1.6). As this study makes clear, widespread cement use today is certainly not directed where it is needed most. This needs to change.

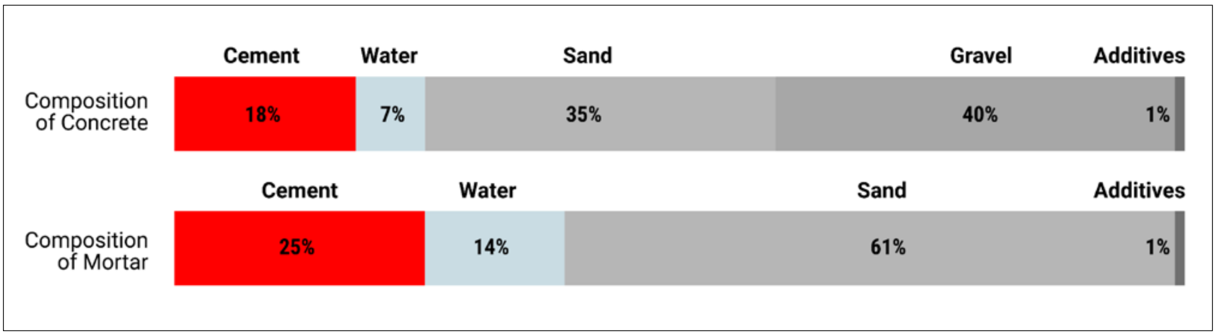
1.1 Cement! What cement?

Cement is essentially a binder, a glue holding together other materials with such strength that it can be used in buildings and infrastructure. Throughout history (see 1.4) there have been many different mixtures used as cement.

Most cement used today is so-called "Portland cement": a hydraulic cement produced in large, industrial cement plants. There, a mixture of mostly limestone, clay, and iron ore is heated above 1,450 °C to produce "clinker", an intermediary product that is ultimately milled to produce the powerful grey powder we call cement (see 1.5.1). (Throughout this study we use the word "cement" to refer specifically to Portland cement, unless otherwise noted.)

When mixed with water, cement gains its binding capacity and hardens ("cures") within one or two days, gaining further strength over time. The addition of sand ("fine aggregate") to the mixture creates mortar, which can hold together walls of bricks and rocks.[2] When gravel ("coarse aggregate") is incorporated into this mix, one can replace the stone altogether with concrete.[3] Concrete can be poured *in situ* on a construction site, into purpose-built "formwork" (usually made with timber). It can also be used to make precast elements. So-called ready-mix concrete is transported to construction sites in the form of a liquid slurry, ready to pour. Cement also has other uses besides the production of mortar and concrete – for example, it can be used to stabilize earth constructions (buildings or structures made largely from soil). However, broadly 70 % of cement is used for concrete and 30 % for mortar.[4] (We use the word concrete to refer to concrete *and* mortar, except for where the distinction between these two materials is important.)

Figure 1.1: Typical raw material mixes of mortar and concrete by weight.[5]



Much of the concrete in use today is "reinforced concrete", with steel rebar typically placed within the concrete to provide tensile strength (see 1.2) – and this hybrid material is the basis of much of the built environment today.[6] More broadly, concrete and steel together comprise the dominant "building system" globally: when not used together in the form of reinforced concrete, they frequently appear side by side – for instance, in the case of building structures made of steel, which almost always have concrete foundations, and may also have concrete elevator shafts and stairways.[7]

The composition of concrete can be varied, in order to confer physical strength or other properties. For example, supplementary materials can be added to the cement (see 3.2.2), or additives inserted into the concrete mixture. Still, the vast majority of concrete is essentially held together by Portland cement.[8]

1.2 Properties of concrete

Concrete, the final product, has several distinctive physical properties that make it particularly useful for the modern construction industry: its strength and hardness, its plasticity, its wide availability, and its homogeneity.

Like stone, concrete has high compressive strength. Once it has hardened, it is capable of withstanding very large, static, vertical loads, and this makes it incredibly useful for load-bearing structures, such as walls, foundations, or vertical columns. It is also hard and rigid: comparatively resilient to mechanical stress, comparatively impervious to water, and an effective barrier against plants and animals. These are all useful properties, for instance, when concrete is used in tunnels, or as paving. Modern forms of hygiene have often relied on the hardness of concrete, and on its relative imperviousness to water. This includes sewage systems and reservoirs, but there are millions of smaller-scale examples too, such as the widespread use of cement flooring to improve cleanliness.[9] Like stone, concrete is relatively fireproof;[10] concrete also has high "thermal mass", meaning that it nevertheless very effectively absorbs and retains heat. Used wisely, concrete is a good material for stabilizing indoor temperatures throughout the seasons.[11] However, it can also be detrimental, as we can see with the urban heat island effect (see 2.4.1).

Unlike stone, concrete begins as a liquid. Before it sets, it can be poured and easily molded into any shape. At least in principle, concrete can be set as a continuous mass in any dimension (unlike cut stone or lengths of timber, which are limited in size). It can be made into straight walls, flat floor panels, cylindrical tunnels, or any shape you care to imagine, more or less. Ease of mixture and speed of action are also crucial qualities. Huge volumes of concrete can be poured quickly and the overall pace of work is fast, meaning that the sheer volume of construction that can be achieved in a short space of time is high when compared to more labour-intensive, craft-based construction practices such as stone masonry, brick laying, and carpentry. Furthermore, concrete can still be manipulated while it hardens.[12]

Moreover, concrete's almost magical properties are only enhanced when combined with reinforcement. Concrete on its own is very strong in compression (pushing strength), but comparatively weak in tension (pulling strength).[13] Reinforcement provides the tensile strength that concrete lacks on its own, and concrete and steel combined produce a hybrid material that is strong and rigid both in compression and in tension. Like concrete, steel is cheap. The two materials are at the same time well-matched thermally, since they expand to a similar extent when heated.[14] It is therefore no surprise that this pairing of materials should be so ubiquitous in the built environment.

Another physical property is that cement and concrete are readily available throughout the world. The main ingredients of both concrete and cement (most importantly, limestone, sand, and gravel) are widely and easily available in most countries. In addition, cement powder is readily transportable, and concrete can then just be mixed, poured, and cured at normal ambient temperatures at the construction site. Cement has freed builders from narrow geographical constraints, such as the availability or otherwise of natural stone, wood, and other construction materials, or the availability of factories and fuel to fire bricks. Physical availability and "inferior" ingredients have also made concrete cheap: limestone, sand, gravel, and water are sourced with little regard for environmental boundaries and with no economic incentive to consider such limits (see 2.2).[15]

Lastly, from an engineering perspective, concrete is uniform, measurable, and predictable. Through intensive laboratory work and standardization processes, cement can be produced consistently throughout the world, making concrete and its properties highly quantifiable and controllable when fabricated correctly – factors that provide their own cost advantages. These characteristics also enable better risk quantification and lower insurance costs, since standardized material behaviour reduces uncertainty about structural performance and potential damage.

1.3 Concrete capitalism and concrete culture

All of the above factors encouraged the widespread adoption of concrete. And yet, the simple material "usefulness" of concrete is insufficient to explain how it became so ubiquitous in the built environment, and how it became the dominant man-made material on earth.

Moreover, concrete has significant downsides too, aside from its environmental impacts. One issue is that concrete is comparatively heavy in relation to how much compressive strength it provides; it is almost devoid of ductility, causing it to crack easily.[16] A major limitation is concrete's limited lifespan, especially when combined with rebar: as we discuss later (see 2.5.1), most reinforced concrete structures only last 50 to 70 years, while houses made from stone, wood, or even Roman concrete can last hundreds of years.

Above and beyond concrete's physical properties, the major reason for its historical success is that it fits so well into the social metabolism of capitalism, and the prerogatives of growth-oriented industrial societies, including the Soviet states in the twentieth century and China today.

It starts with labour. A concrete pour requires little accumulated know-how, and can be undertaken by a comparatively unskilled workforce with only basic training required. As such, concrete to an extent neutralized the monopoly on building knowledge associated with traditional "building crafts" such as stone masonry, carpentry, and brick laying – workforces prone to unionization. When concrete was mainstreamed, those workers could be replaced by comparatively unskilled labour – workers who were easier to hire quickly and just as easy to dismiss when no longer needed. At the same time, concrete depended on highly technical expertise off-site: in the laboratory, the design office, or engineering firm. This made for a steeper organizational hierarchy of labour within the construction sector (see 2.6.1).[17]

Capitalists and politicians built on these advantages. We have noted that cement freed construction from narrow geographical constraints. However, once unbound from the autonomy of labour, the malleability of concrete permitted capital and state to reshape the world in their own image, transforming geographies, landscapes, and cities to best suit the compulsion to make a profit and accumulate capital, and to build centres of power. Concrete makes it possible to construct stable, easily managed, and largely uniform built environments that are relatively independent of local natural conditions and, at least until the era of climate change, seemed to subdue and hold nature at a distance. Concrete helps capital and state to construct "abstract space" – a homogenized, standardized spatial order designed for calculation, circulation, and control – giving the built environment "something in common with the rationality of the factory".[18] This accords with the ever-more insistent creation of "abstract time" by capital, under the application of fossil fuels.[19] And as the tendency is towards uniformity, these artificial landscapes can be made to serve social fragmentation and hierarchy – one thinks, for instance, of the segregated highways of the Israeli-occupied West Bank in Palestine (see 2.6.2). They can also be built anywhere on the globe.[20] The only limit, when it comes to concrete, has been the creative imagination of the investor, statesman, engineer, or designer.

And yet, for concrete to reach this potential, it required the willing participation of people – those managing the cement industry, of land owners, engineers, architects, and politicians. Concrete required a base of professional advocacy: people who would press the need to use concrete as the universal go-to solution, spread the word about concrete's usefulness and desirability, and establish ways of externalizing the costs of production and making this material cheap to deploy.[21]

Therefore, the ubiquity of concrete today must be seen as the product of aggressively pursued economic and political interests. Concrete and cement's physical properties unto themselves, while seen as desirable, don't explain how and why these materials became hegemonic. The era of concrete did not happen for simple reasons of engineering alone; it was made by states, by capital, and by professional interests. Cement industrialists, engineers, and architects were even called "cement men" in the early twentieth century, due to their role in spreading its gospel.[22]

Besides the role played by direct economic and professional interests, there is also the significant, if more diffuse, role played by culture: a mesh of values and mores, of psychology, and of modern "ways of life" that are the partial result of the ubiquity of concrete, and that, in turn, demand ever increasing amounts of concrete to reproduce themselves. The widespread use of concrete has become normalized and suffuses the "mentality" of daily life. And this has led to the emergence of a "concrete culture" in the world at large, which has shaped our very imagination about how we might construct, and live within, built environments.[23] Most of all, concrete culture presumes the endless supply of materials, and of unbounded material possibility.[24] With concrete, the built environment can be extended anywhere, bulldozed, redesigned again and again, remade at will from a *tabula rasa*, and made disposable. There is also a widespread desire within modern societies to seal unruly nature beneath prophylactic hard surfaces. This is evidenced primarily in cities, where concrete and tarmac are frequently imposed on all corners of the built environment, leaving no space for nature to flourish. Over time, such banishments of nature can come to be seen as normal – even desirable – by subjects who have grown up and learned to feel at home in concrete societies.

Concrete, it must be said, is beloved by many the world over for its aesthetic qualities. Le Corbusier's *Unité d'Habitation* apartment building in Marseille (1947-52) was probably the most influential building of the post-war period for architects. It featured extensive use of precast concrete and of exposed concrete poured *in situ,* openly displaying the wood grain of its timber formwork molds.[25] Concrete today remains a cherished construction material among an aesthetic cognoscenti, even as environmentally-conscientious architects are becoming highly critical of its use.

On the other hand, such aesthetic sentiments are countered by the hatred that many have for concrete – with the material often associated with the brutal imposition of insensitive materials and with failures of maintenance and upkeep. In particular since the 1970s, concrete became a locus of "culture wars", a symbol of technocratic arrogance and alienating modernism, operating on the dimension of immediate experience and aesthetic sensibility.[26]

Concrete culture accelerates the costs and damages of cement that we highlight in this report, to the extent that it reinforces prevailing norms of construction, and naturalizes the widespread use of concrete. In the face of those harms, concrete culture in this sense constitutes an important cultural aspect of the "imperial mode of living" – wherein intensive resource use, high rates of consumption, and ready mobility in the Global North (and among global elites) are all enabled by and rely upon the unlimited appropriation of resources, exploitation of cheap labour from the global South, and a disproportionate claim on global and local ecosystems.[27] As such, concrete culture is one of the key societal hurdles to rebalancing the world economy to meet the needs of the many. Genuine sustainability demands changing cultural expectations about how the built environment is formed, with what materials, and for whom.

1.4 The history and chemistry of cement

The history of cement and concrete is long and fascinating. Cement has accompanied human civilization for millennia (1.4.1), with the Romans developing an early form of concrete in the late 3rd to 2nd century BCE (1.4.2). Modern, globally replicable Portland cement was finally developed in the mid-nineteenth century (1.4.3), with an exponential rise in its use following after 1945 (1.4.4).

While the specific composition of these materials changed through the ages, its central component stayed the same: calcium carbonate ($CaCO_3$), mostly found in the form of limestone.

Limestone itself is a result of natural processes, dating back hundreds of millions of years. The oldest calcium carbonate (540 million years old or more) is thought to be of inorganic origin. More recent limestone deposits, on the other hand, are mostly the product of corals, sponges, mussels, and other organisms and microorganisms, which produce $CaCO_3$ to form shells, skeletons, and reefs. As their remains piled up, so did the limestone.[28] Like fossil fuel, limestone is a fossil material – and as with fossil fuels, limestone stores carbon and CO_2 is released under combustion. In effect, nature discovered calcium carbonate as a building material millions of years ago. Man-made cement, mortar, and concrete build on this natural foundation.

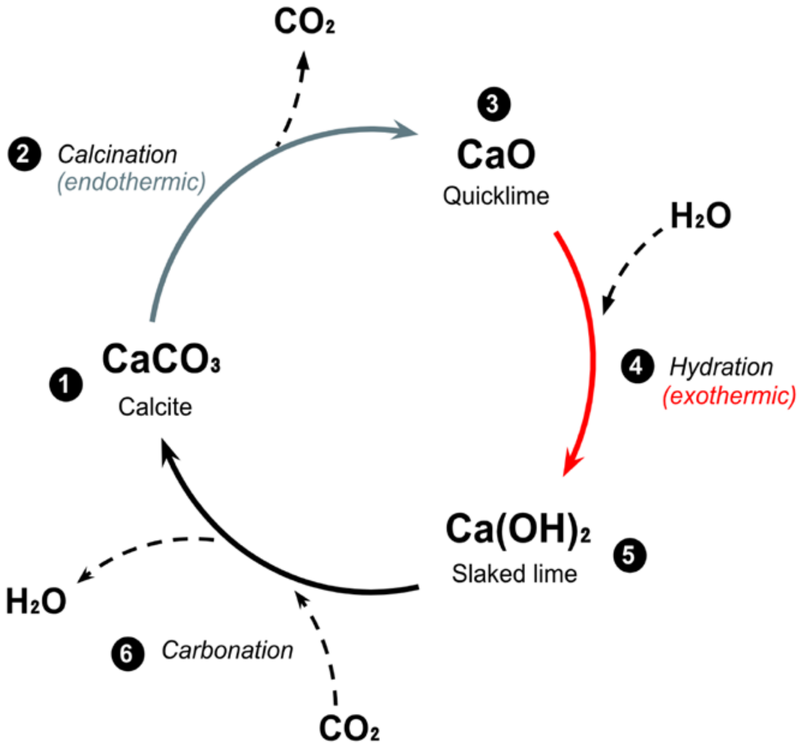
There are extensive limestone deposits around the world, with limestone covering roughly 10 % of the Earth's surface.[29] These deposits are fairly evenly distributed and widely available for mining, when compared to other minerals. There are, however, areas with fewer or smaller deposits, or deposits that are comparatively uneconomical to exploit. For instance, some parts of South America and Sub-Saharan Africa lack readily exploitable sources of limestone. For this reason, some regions (for example, in West Africa) have historically imported much of the cement and the clinker that they use.[30]

When it is exposed to the surface, limestone can produce geological landscapes called "karst", which provide unique hydrological and surface environments that are home to equally unique ecosystems. These environments and ecosystems are significantly threatened by limestone mining (see 2.2.1).

1.4.1 Early cements

The history of cement begins at least 10,000 years ago, when humans combined burnt limestone and raw clay to create floor coverings in what is now Turkey. This early form of cement was likely the first authentically man-made material synthesized via the application of heat.[31] Since then, lime-based mixtures have accompanied the emergence and growth of societies. While their exact composition and production processes have differed, the underlying chemistry remains the same, as depicted by the "lime cycle" in Figure 1.2. First, calcium carbonate (1) is heated to high temperatures, causing so-called calcination (2); carbon dioxide is emitted in the process of calcination and "quicklime" (CaO) is created (3). Next, when water is added, a highly exothermic reaction (4) causes the precipitation of "slaked lime" ($Ca(OH)_2$) (5). This can absorb atmospheric CO_2 (6), creating $CaCO_3$ once again, although now with a somewhat different structure.[32]

Figure 1.2: The lime cycle[33]



While modern Portland cements are produced by burning a mixture of ground limestone, clay, and other materials together in the kiln, these early cements ("air-curing limes") were made by burning only limestone, with any clay added after firing. Limestone was burned and calcined to form a powder (2), with the addition of water (4) subsequently forming lime putty. The addition of sand to the mix produced lime mortar. Lime mortar was used throughout different civilizations for wall rendering, ground hardening, or joining stones. Both lime putties and their derivatives harden in the carbonation phase (6), which makes them "non-hydraulic."[34]

Though air-curing limes can serve as effective basic building materials, they have major limitations. They cannot be used in wet environments. Curing additionally progresses from the outside inwards, and can be very slow. To put this in perspective, some ancient lime-based mortars still remain only partially carbonated to this day, after many centuries.[35] Finally, air-curing limes remain comparatively weak. Lime mortar does little more than fill in the gaps between the materials that provide the real structural strength, such as stone.

Lime mortars and plasters remain in widespread use across the world today, as an important part of many traditional building cultures. They are important in restoration and "heritage" contexts, and they are also favoured as a comparatively healthy and sustainable material compared to modern cement. Lime mortars are also used as binders to stabilize earth construction, and to bind together "hempcrete" – a non-structural hemp–lime composite (often called hemplime) (see Chapter 4.2 for more on all of this).

1.4.2 Roman concrete

The Phoenicians, the Greeks, and most notably the Romans discovered certain mixes that overcame the weaknesses of earlier cements.[36] Adding siliceous and aluminous materials, such as clays (before calcination) or pozzolans (after calcination), were the consistent solution throughout their successful approaches. These materials were mostly derived from volcanic sources.[37]

The incorporation of siliceous and aluminous materials allows for the creation of "hydraulic limes" ("water limes"), which harden through hydration (step 4 in Figure 1.2) instead of carbonation. These particular limes are so strong that they can be used to bind aggregates into a new kind of rock (concrete), instead of simply adhering existing stones together. While the lime cycle is still the basic underlying chemistry, the CaO is now combined with silica and alumina to create calcium silicates and calcium aluminates. When water is added to that mix, several compounds containing $Ca(OH)_2$ are created, most importantly hydrated calcium silicates (C-S-H in cement chemistry notation).[38]

The Romans were the first widespread users of concrete. Roman concrete (*"opus caementicium"*) was typically made from lime mortar combined with volcanic sand or ash, plus stone rubble. The resulting concrete structures were stronger than simple stone or brick walls, their construction was quicker, and fewer skilled masons were required.[39] Through its use in arches, barrel vaults, and other structures, Roman concrete allowed for an "architectural revolution" that impacted every facet of the built environment: from aqueducts, bridges, sea walls, military fortifications, and monuments; to bath houses, marketplaces, and temples.[40]

Figure 1.3: The Pantheon, Rome.

Source: Left: Mark Cartwright, adapted under CC BY 4.0 licence. https://www.worldhistory.org/image/8297/romes-pantheon/
right: Atibordee Kongprepan, adapted under CC BY-ND 2.0 licence. https://www.flickr.com/photos/atibordee/13995519705/

Roman concrete was quite different from modern cement. It was not poured, but laid using trowels, with the pieces of stone aggregate pressed into the lime mortar.[41] The curing of Roman concrete took time, and studies have shown that construction was phased accordingly over several seasons.[42]

However, unlike modern concrete structures, which are vulnerable to quick deterioration, many structures made of Roman concrete have proven to be more hardy. For instance, the Colosseum and the Pantheon in Rome, and the Hagia Sophia in Istanbul, are still standing today, many centuries after they were constructed – and all three were built using Roman concrete. Indeed, the dome of the Pantheon is the largest ever hemispherical dome built in unreinforced concrete, with an interior diameter of over 40 metres.[43]

In large part, the durability of Roman concrete can be attributed to the omission of rebar, which represents modern concrete's Achilles heel (see 2.5.1). But even unreinforced modern concrete seems to disintegrate quicker than Roman concrete, a major riddle that researchers have only recently begun to explain. Researchers have offered two main explanations for the durability of Roman concrete. The first is applicable only to marine structures, such as sea walls and breakwaters: the ingress of sea water into these structures, once it came into contact with the natural pozzolans in the concrete (derived from volcanic ash), might have added strength.[44]

The second explanation is applicable to *all* structures made using Roman concrete. It concerns the mode of manufacture, and the observed presence in Roman concrete of aggregate-sized lime "clasts", bright white lumps previously thought to have been the product of poor concrete preparation.[45] The new hypothesis is that Roman concrete was in fact prepared through "hot mixing" – with burnt lime mixed directly with volcanic pozzolans, aggregates, and water, "instead of, or in addition to" the use of slaked lime.[46] Present-day experiments demonstrate that the extra heat produced by the hydration reaction in these circumstances actually facilitates the generation of lime clasts, and that it does so via chemical processes that are not possible with the use of slaked lime on its own.

Moreover, these lime clasts appear to confer superior "self-healing" capacities. All forms of concrete tend to form cracks due to environmental changes or mechanical damage (freeze-thaw cycles, seismic activity). However, in recreations of Roman concrete, those cracks appear to propagate such that they intersect with the clasts. When water (for instance, rain water) then seeps through the cracks, the clasts seem to act as dormant repositories of calcium-rich hydrates, and these leach out of the clasts into the cracks and further strengthen the concrete. This self-healing process is more pronounced and effective than in modern concrete.[47]

Such effective self-healing properties could explain the impressive resilience of Roman concrete through the centuries. These properties could theoretically be revived today – with the additional benefit that Roman concrete requires lower temperatures for calcining than modern Portland cement does.[48] The successful techniques that lay behind Roman concrete were effectively lost, however, over the subsequent two thousand years.[49] In the intervening period, both air-curing limes and hydraulic limes remained in use in Europe. Even then, knowledge was fragmented, and compositions varied according to location.[50]

1.4.3 Portland cement

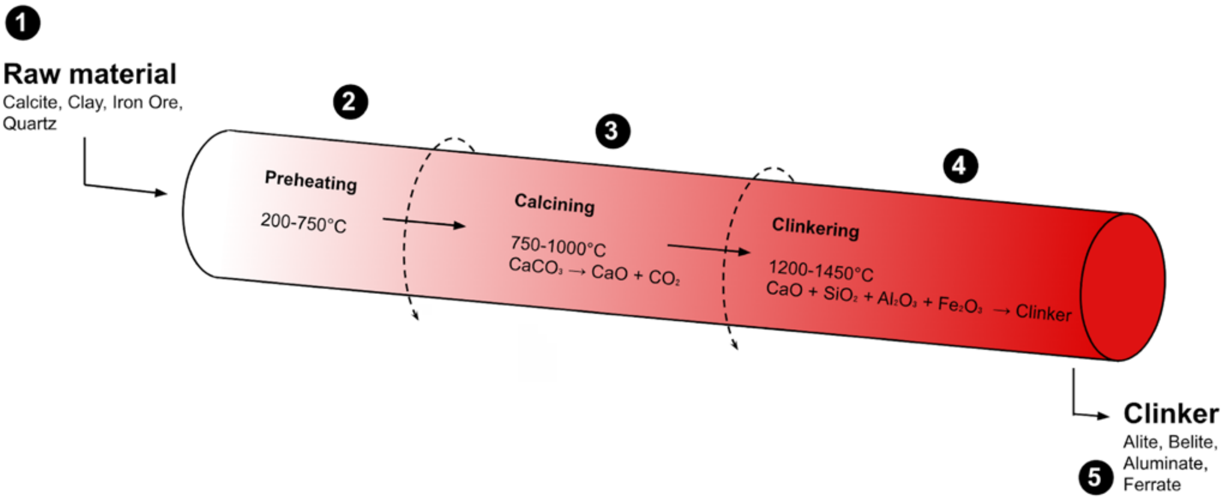
From the eighteenth century onwards, scientists of building materials in Europe devoted a lot of energy to understanding the chemistry of cement and concrete, in an effort to find superior and industrially replicable alternatives to what was available at the time.

These studies finally culminated in the creation of Portland cement sometime in the mid-nineteenth century. Widespread availability of industrial coal combustion in Western Europe meant that materials could be burned to temperatures in excess of 1,300 °C. With limestone, clay and iron ore combined together in the kiln, they produced a cement that, once hydrated, created concrete or mortar that was consistently stronger than the prevailing alternatives. The term "Portland cement" was coined by Joseph Aspdin, in a patent of 1824, because the hardened material resembled the prized building stone quarried on the Isle of Portland, a land-tied island off the south coast of England.[51]

While there now exist a variety of Portland cements, they are all based on the process depicted in Figure 1.4. A mixture with mostly limestone, clay, sand, and iron ore is put inside a rotating kiln (1). The mixture is heated to 750 °C (2), and from there to 1,000 °C (3), at which point the limestone calcines (compare Figure 1.2, Step 2), and carbon dioxide is released. The resulting quicklime then reacts with the other materials at about 1,200–1,450 °C to form clinker (4).

This clinker consists primarily of alite (tricalcium silicate), which lends the final concrete high early strength. Additional compounds are also present. Belite (dicalcium silicate) hydrates slowly and is responsible for long-term strength. Tricalcium aluminate and tetracalcium aluminoferrite speed up the hardening and lower clinkering temperatures respectively. Afterwards, gypsum is added to prevent any unwanted rapid ("flash") setting.[52] Aside from the inevitable emissions from calcination, it takes high temperatures to make Portland cement; the corresponding high energy demand and carbon emissions are the price we pay for Portland cement's rapid gain in structural strength (see 2.1).

Figure 1.4: Chemical processes within a Portland cement rotary kiln (author's illustration).[53]



This wonder material spread rapidly throughout Western Europe's emerging "fossil economy". Portland cement advanced true mass construction along with the development of the modern state and capital (see 1.3). England, France, and Germany experienced a notable concrete boom throughout the second half of the nineteenth century. For instance, between 1840 and 1860 the ports of Dieppe, Cherbourg, Le Havre, and Brest were upgraded with Portland cement. Concrete was the basis for new sewage systems and subway lines in Paris and London.[54]

It is well known that fossil fuels accelerated the production of industry and capital – and they were also intrinsic to the manufacture of cement.[55] However, Portland cement was a comparable "force multiplier" in its own right. As outlined above, the physical affordances of cured concrete (its strength, hardness, and comparative impermeability to water) are considerable. Combined with ready availability, ease of mixture, and speed of construction, all of these physical qualities help to explain why modern concrete became so prevalent so quickly in a booming fossil capitalist economy, permitting the widespread and rapid construction of buildings, infrastructure, and assorted capital assets. Moreover, as previously noted, the advantages it gave capital over labour – in the production and deployment of cement and concrete – offered significant advantages over other materials. (For more on these factors, see Chapter 2.6.)

The rapidity of construction also brought major accidents, due to poor quality implementation and cost-saving measures (see 2.5.1). Widespread standardization and regulation followed. Indeed, the German cement standard that was approved in 1878 was the first industrial standard ever, and such standards quickly spread internationally.[56]

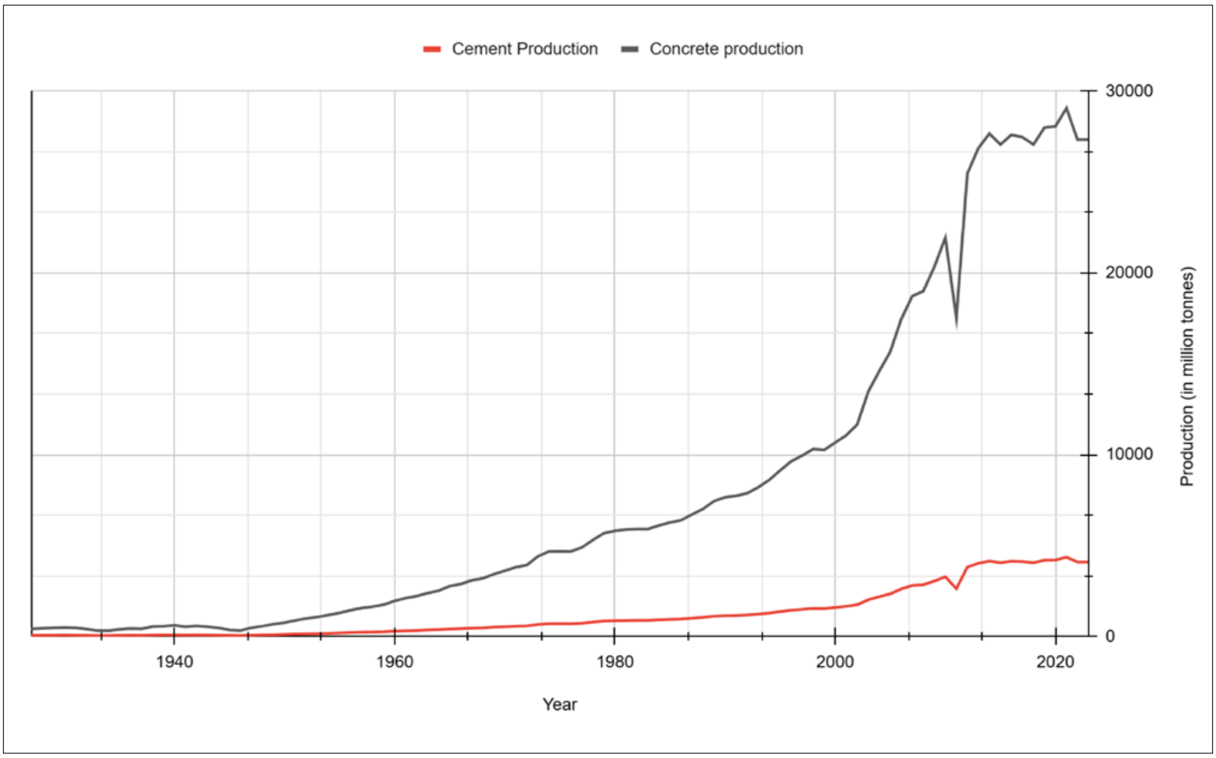
A major innovation was steel-reinforced concrete, introduced in France during the mid-19th century.[57] Further technological advancements followed, such as the rotary kiln in 1890. Small-scale vertical shaft kilns were replaced with mechanized and fully electrified "mega-machines" that brought about enormous economies of scale and had to run 24 hours a day to stay profitable (see 1.5.1). Before the advent of rotary kilns, long batch cycles prevailed, and Portland cement manufacture typically lasted several days (sometimes up to a week). Today, by contrast, cement manufacture takes a matter of minutes.[58]

Ready-mix concrete – whereby concrete is produced at a central plant and transported as a slurry to the building site – was developed in 1913, while precast lightweight concrete breeze blocks followed in the 1930s.[59] Engineers pioneered pre-tensioning and post-tensioning of concrete from the 1920s, as a way to strengthen single spans of concrete via the application of compression using steel cables (see 2.5.1). Despite the fact that concrete was increasingly paired with steel, early twentieth century architects and engineers in the United States habitually spoke of a new "Cement Age", eclipsing the previous "Steel Age".[60]

1.4.4 Global expansion

The post-1945 period saw a dramatic boom in the use of concrete (see Figure 1.5). Concrete emerged as the seemingly perfect material to solve the main challenges of the time: the development of industrial capacity; energy, transport, and sanitation infrastructure; and the provision of mass housing and other civic and commercial buildings. Many other materials – such as steel, coal, and glass – saw similarly dramatic, exponential increases in production and consumption; however, in absolute scale, the rise of concrete surpassed everything else by far, leading the way in the twentieth century's "great acceleration" in material use.[61] Global populations also expanded rapidly during the post-1945 period, with steep declines in mortality brought about chiefly by access to life-saving vaccines and antibiotics, as well as public health interventions that included improved sanitation infrastructure.[62] The proportion of concrete as a share of all man-made material stocks quickly rose from 6 % in 1900 to 12 % in 1945, and finally 40 % in 2023 – representing a higher stock than any other material (see Figure 1). Today, over 25 billion tonnes[63] of concrete are poured globally on an annual basis – or about 70 million tonnes every day (see Figure 1.5).[64]

Figure 1.5: Global production of cement and concrete from 1927 to 2023.[65]



Over this timeframe, the cement industry spread globally, driven by the adoption of a standard model of industrial development. While the poorest countries tend to have only minimal cement production and correspondingly minimal stocks of concrete in the built environment, production tends to increase as a function of material and commercial wealth, such that a country's per-capita stocks of concrete track with its level of "development" and the scale of its industrial and manufacturing output. For instance, at present Yemen has only very small stocks of concrete, whereas the amount of concrete in India is expanding at breakneck speed. Over time, as infrastructure and housing are built up, the pace of per-capita concrete stock growth tends to slow down, and the total per-capita stock level tends to eventually plateau. (For more information about the present per capita stocks of cement in low-income countries – and the mismatch in relation to underlying basic needs – see Chapter 1.5.)

This trend in the development of per-capita concrete stocks generally follows an S-shaped curve, as shown in Figure 1.6. However, the level at which concrete stocks plateau ("stock saturation") varies significantly depending on the country's material use patterns. For instance, the United States' per capita concrete stocks appear to have plateaued at a level lower than two-thirds of Germany's. China's per capita concrete stocks have, in all likelihood, now overtaken those of Germany.[66]

In some developed countries, cement production may decline slightly (as currently in Germany). However, more often than not, cement production remains robust because new construction still happens and existing concrete structures are replaced.[67] Moreover, a booming economy often will not use concrete to meet basic needs, such as the provision of housing and essential infrastructure. The prevailing model of industrial and land-use development favours first and foremost the accumulation of capital (see Chapter 1.6 and Chapter 2.6.3).

As a result of all this, while Western countries dominated cement production throughout the twentieth century, their share has declined significantly in recent decades. Today, the cement production of OECD and EU countries accounts for just 13.1 % of global output. About half of today's cement production instead happens in China (49.8 % in 2023), followed at a great distance by India (10.3 %) and Vietnam (2.7 %). (This shift is depicted in Figure 1.7.) Almost all cement is used in its country of manufacture.

Figure 1.6: Per capita concrete stocks from 1950 to 2016.[68]

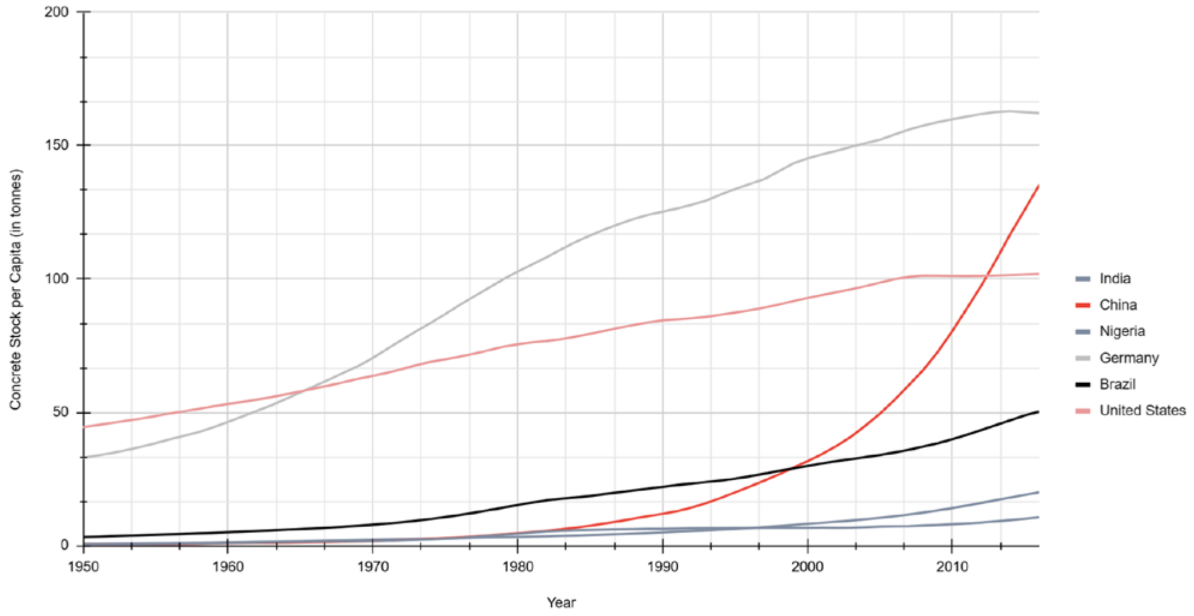
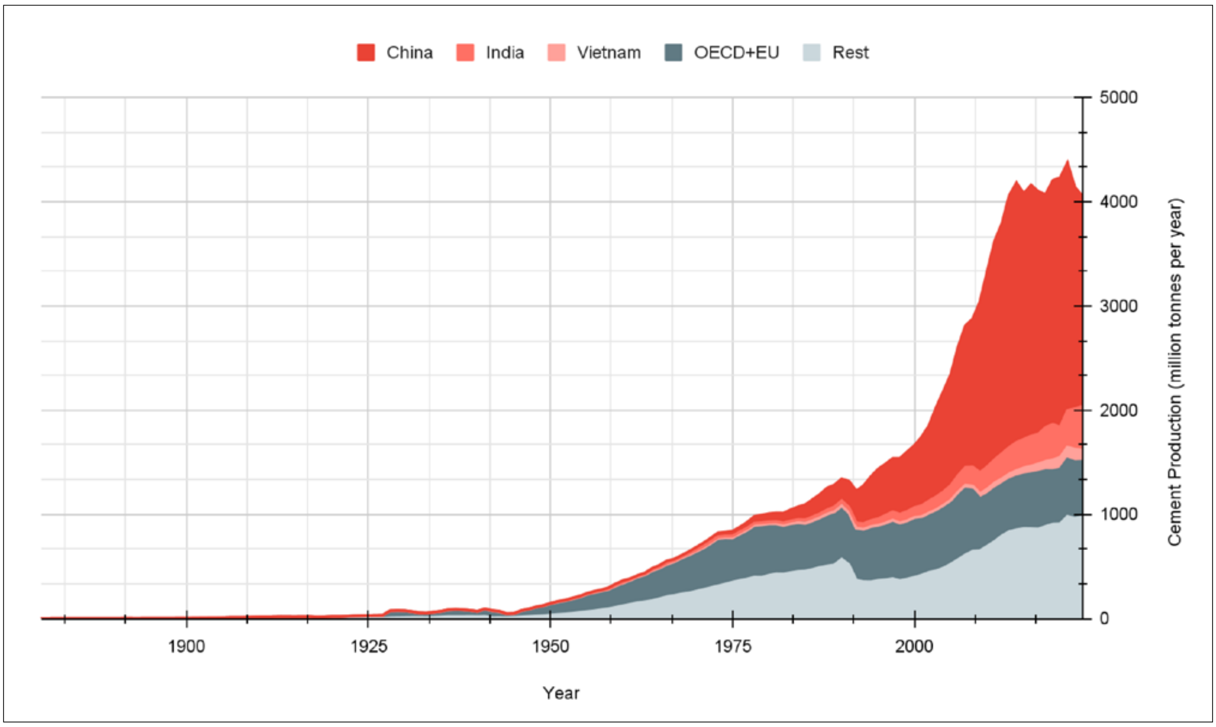


Figure 1.7: Yearly cement production of the currently biggest producers (China, India, and Vietnam) compared to the countries in the OECD and the EU as well as the rest of the world from 1880 to 2023.[69]



The tremendous scale of Chinese cement production over the last thirty years has been especially breathtaking. This reached its historic peak in 2014. China produced and consumed more cement in just three years (2011–2013) than the United States did in the entire 20th century: 6.7 billion tonnes versus 4.4 billion tonnes.[70] Since then, cement production in China appears to have plateaued and slightly declined, though still remains at an enormous 2 billion tonnes or more annually, with global cement production presently standing at about 4 billion tonnes per annum.

In the long run, China's cement production may indeed fall further. In recent years, the Chinese state has been deliberately cooling down the country's overheated construction and real estate sectors, while also trying to reduce and restructure the heavy debts of local governments, banks, and property developers.[71] But a continued push into renewable energy infrastructure – using concrete for foundations and other structures – could counter that trend.

Yet, as a result of all of these flows of concrete into China's built environment, China now has accumulated more than a third of currently-existing global concrete stocks, slightly more than that of the combined countries of the OECD and EU, whose concrete stocks add up to about 30 %. At the same time, 42 of the world's least developed countries are home to around 12 % of the world's population, but they collectively possess less than 0.002 % of the world's concrete.[72]

1.5 Today's global cement industry

We have explored how cement manufacture is primarily dependent on limestone. Limestone deposits are plentiful across the surface of the Earth, and most countries possess available resources of limestone that can be economically mined. However, limestone is heavy, and therefore expensive to transport. Cement production is also capital-intensive, and characterized by very large economies of scale. These conditions impose certain economic incentives on the physical distribution of cement manufacture globally, but also on the political economy of cement production. In the rest of this chapter, we survey the general economic characteristics of the cement manufacturing process and how they influence the location of cement plants (1.5.1). We then detail the manufacturing process itself, from quarry to crusher and beyond (1.5.2). In a dedicated section, we take a closer look at the German cement giant, Heidelberg Materials.

1.5.1 Economic characteristics

The fact that limestone is heavy means that limestone quarries and cement manufacturing will tend to be located close to one another, with other ingredients besides limestone simply transported to the same site. As such, cement plants are not often located in industrial or urban centres. However, it remains common for cement plants to be situated on the peripheries of cities. Cement plants are typically "integrated" facilities; however, "grinding" plants also exist, with clinker transported to them from elsewhere for processing.

Capital-intensity and resource-intensity favour the development of large cement works, with those facilities preferably serving a significant regional market.[73] Cement manufacture and distribution requires good transport links, and ready sources of available energy.[74] Because cement powder still has a comparatively low economic value compared to its costs of transportation, this incentivizes a wide distribution of large cement plants wherever this is economical and profitable, within a given regional market. Typically, a cement plant can economically supply a market that extends 100 km by road from the plant, or 300 km by rail.[75] Often, regional oligopolies of cement producers take shape, with companies largely shielded from international competition.[76] Attempts to set up cement cartels are a regular feature of the cement industry – as they have been from its very start in the nineteenth century.[77]

International trade in cement does occur, but in comparatively small volumes – typically just enough to balance out short-term fluctuations in supply and demand along heavily trafficked sea routes.[78] Therefore, there is also a tendency towards regional vertical integration, with the same large companies owning limestone mines while also dominating downstream markets in ready-mix concrete, precast concrete elements, and associated products.[79]

A.0 Heidelberg Materials: A global cement giant

Heidelberg Materials stands as a prime example of the multinational cement companies mentioned above. We take a closer look at this company, not only because of its exemplary role, but because the struggles by local communities and activists against this company have inspired the creation of this report and much of its contents.

Figure A1: Heidelberg Materials headquarters in Heidelberg, Germany.

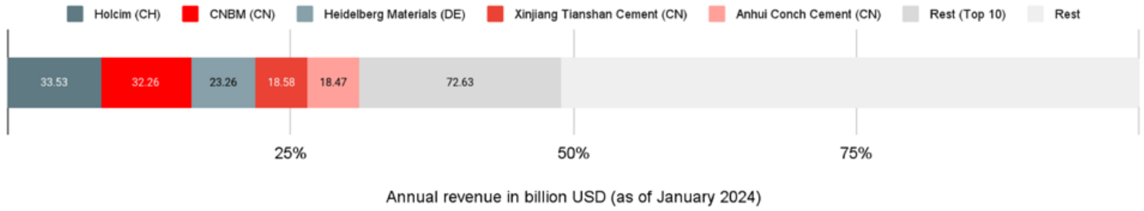
Source: CC BY-SA 4.0

pany quickly expanded throughout Germany. Its growth significantly accelerated during the National Socialist regime, with the state determining that cement was essential to its fascism. Indeed, cement proved integral to the construction of defensive walls, shelters, barracks, and highways. The post-World War II construction boom in West Germany further propelled the company's expansion.

Over the decades, Heidelberg Materials transformed from a regional cement producer into a multinational giant. Through a series of mergers, acquisitions, and investments, the company first consolidated within Germany, then expanded its operations into France and the United States, and eventually across the globe.[80] Today, Heidelberg Materials operates 130 cement plants and over 600 quarries, spanning over 50 countries and every continent except South America.[81]

Heidelberg Materials is now the third-largest cement producer worldwide, trailing only the Swiss multinational Holcim and the Chinese giant CNBM (see Figure A2). The company's operations are highly vertically integrated, encompassing major steps of the value chain. It not only operates cement plants but also controls limestone quarries, gravel and sand extraction sites, ready-mix concrete facilities, and prefabrication businesses. Additionally, Heidelberg Materials maintains a large fleet of trading vessels and trucks for global transport of raw materials and finished products.[82]

Figure A2: Global market share of major cement companies as of January 2024.[83]



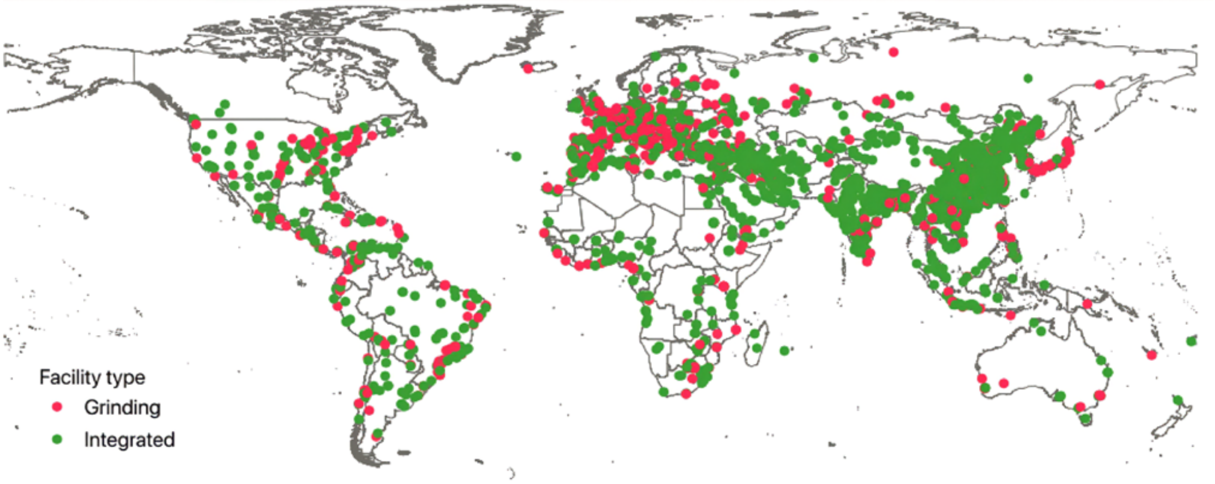
The sheer scale of Heidelberg Materials' operations generates substantial profits, much of which flows back to Europe. Ludwig Merckle, the company's largest shareholder with a 27 % stake, is among the richest people on Earth, with a net worth of USD 12 billion.[84] But while profits have accumulated, so too have the damages this giant produces.

Across the following case studies, we trace the resistance of communities and activists confronting the destructive operations of Heidelberg Materials and its subsidiaries worldwide. We have also included case studies on its largest European rival, Holcim, to highlight additional dynamics not fully reflected in the struggles against Heidelberg Materials known to us.

Although there is price competition across regions, the homogeneity of the product means that brand names have little importance. Customers generally favour buying from the nearest cement plant, but if prices there are too high, they readily switch to other producers based simply on cost – provided that onward transport costs are not too high.[85] As noted, the geographical distribution of cement production essentially follows the distribution of economic demand. Economic demand for cement, meanwhile, comes from construction. This means, finally, that the scale and extent of cement manufacture is typically driven, to a significant extent, by speculative swings in the construction industry.[86] "Bottlenecks" in the supply of cement in emerging countries are a common feature of the industry, as is overcapacity after the end of a construction boom.[87]

As a result, while the market for cement is still mostly dominated by national companies, multinational cement producers have nevertheless increasingly emerged – active across several regions globally, and more adept at buffering regional fluctuations in profits and losses. Such multinationals will, moreover, often transport cement between entire regions in fleets of boats, in order to balance out shifts in economic demand.[88]

Figure 1.8: Global distribution of cement plants.



Source: Tkachenko et al. (2023), adapted under CC BY 4.0 licence

1.5.2 The cement manufacturing process

Because limestone is heavy and thus expensive to transport, most cement production is located near limestone quarries. Figure 1.9 shows the different stages of cement and concrete production for a typical integrated facility, from limestone quarry to concrete mixer. Below, we explain each step in the manufacturing process.

Step 1: The limestone quarry
When it is mined, limestone is drilled, excavated, or (most of the time) blasted out of the earth using explosives.[89]

Step 2: The crusher
Mined limestone is loaded onto conveyor belts, trucks, or cable cars for transport to the nearby crusher and cement plant.

Modern Portland cement also requires siliceous materials (such as clay), along with further minerals (such as aluminium and iron oxide). Some of these may already be present in the limestone; others may need to be manually added to the mix. Supplementary cementitious materials (SCMs) may also be combined with the limestone at this stage to confer specific physical properties and produce non-Portland cements.

The additional ingredients are either mined nearby or transported to the crushing site, and they are combined with the limestone in a closely calculated way, since the precise proportions of the ingredients determine the physical properties of the final cement (setting speed, strength, durability, etc.).

Step 3: The kiln
The central component in an integrated cement plant is the kiln, a modern "megamachine" that needs to run around the clock to stay profitable.[90] Different kinds of heating processes and kilns exist; however, the dominant variety in use nowadays is the dry process rotary kiln. This is partitioned into three main stages: a preheater tower, a precalciner tower, and the rotary kiln itself. The preheater tower heats the crushed raw materials using exhaust gases from the main kiln; the precalciner tower then brings the temperature of the raw materials up to 1000 °C, which causes the $CaCO_3$ to break down into calcium oxide (CaO) and carbon dioxide (CO_2). Finally, the heated materials enter the end of the rotary kiln, reaching temperatures of over 1400 °C as they get closer to the combustion flame.

To reach these incredible temperatures, large amounts of fossil fuels or waste materials (see 3.2.3) are burned every day, leading to huge CO_2 emissions (see 2.1). But only in this incredibly hot environment can the calcareous, silicious, aluminous, and ferrous materials from the raw materials form the final product: semi-fused pellets of clinker.

Step 4: The mill
In the final stage of cement production, the clinker is fed into a finishing mill, where it is ground down into the fine powder we know as cement. (As above, grinding plants only contain this final step and import clinker from elsewhere.)

At this stage, more raw materials are added, such as gypsum or supplementary materials. 5 % of the final

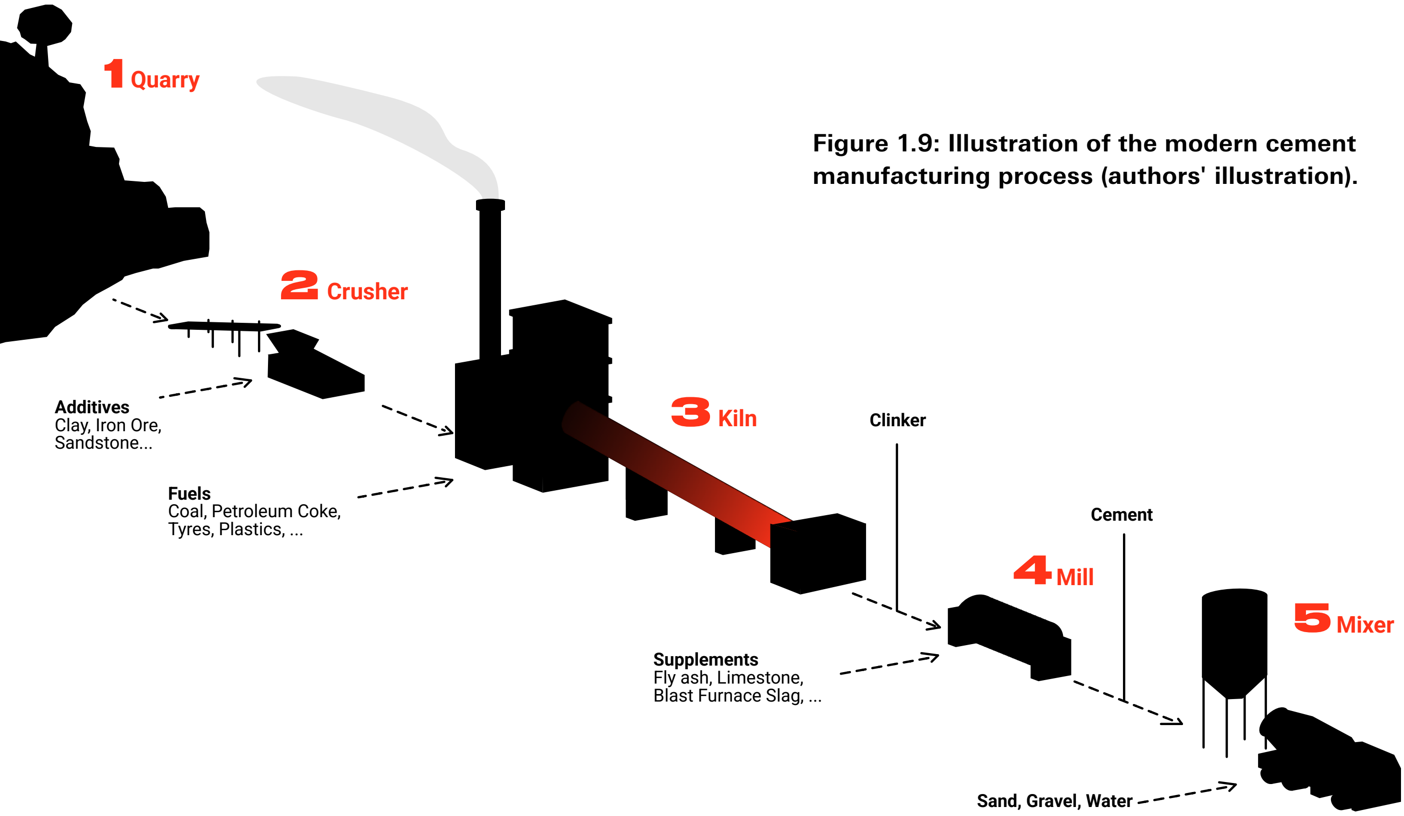


Figure 1.9: Illustration of the modern cement manufacturing process (authors' illustration).

mix of Portland cement is normally gypsum, and this prevents unwanted rapid (“flash”) setting. Adding raw limestone reduces the mass of clinker that is required for a given mass of cement. Supplementary cementitious materials such as fly ash, blast furnace slag, and natural pozzolans are also added at this stage (see 3.2.2).

Step 5: The concrete mixer
Lastly, the cement powder exits the factory either in trucks or in bags. It will be mixed with water, sand, and gravel to make concrete, and this can take place either on site, within a prefabrication factory, or in a ready-mix concrete plant, with the ready-mix concrete transported onwards via truck.

1.6 How essential is cement? Is it meeting basic needs?

Rising cement demand is often portrayed as an inevitable consequence of modern social progress. As discussed in 1.4.4, historical cement production has been observed to correlate with a country’s economic “development” – and this pattern can readily be projected onto the future as well. For instance, the International Energy Agency (IEA) predicts that cement production will remain constant in the coming decades, while the World Economic Forum (WEF) even forecasts a 45 % increase in demand by 2050, driven by “societal needs and urbanization”.[91] Such predictions are often coupled with questionable claims about where such development is needed. A more basic question is rarely asked: Whose needs are actually being met?

The scale of unmet needs is indeed vast. About one quarter of the world’s urban population – 1.1 billion people – presently live in slums or otherwise inadequate housing. Two billion people lack access to safe drinking water; 3.5 billion people lack adequate sanitation; and 700 million people lack access to electricity. One in four primary schools worldwide still have no access to basic utilities.[92] Most of these unmet needs are concentrated in Sub-Saharan Africa and India.

Meanwhile, forecast population growth broadly corresponds to areas of greatest existing unmet needs – concentrated in India, Pakistan, Nigeria, and the Democratic Republic of Congo (DRC).[93] The combined population of these four countries alone is expected to grow by almost 600 million people between now and 2050. Population growth combined with rapid urbanization will meanwhile add at least 1.9 billion additional people to cities by 2050.[94] By contrast, the population of the United States is estimated to grow by around 35 million, while China’s population is predicted to *shrink* by around 160 million.[95]

And yet, a 2017 study commissioned by the G7 group of nations – still widely cited in UN environmental and development reports – claims that the largest shares of "future investment needs" for sustainable infrastructure are in China and the United States.[96] Such claims reveal how perceived "investment need" often reflects purchasing power and capital interests, rather than basic social necessity.

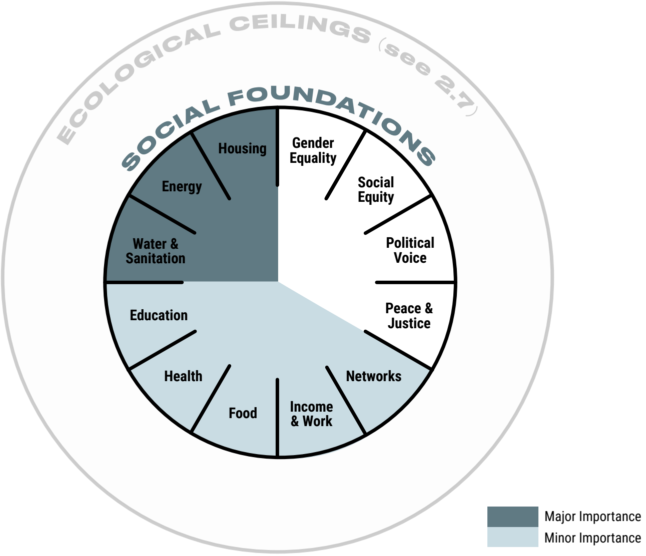
To understand future cement demand, we must distinguish *economic demand* from *social need*. And we must understand that much of what currently drives production – speculative real estate, luxury retail, and other forms of what we call "bullshit construction" (see 2.6.3) – does little to meet genuine human requirements. With the term "bullshit construction" we adapt David Graeber's notion of "bullshit jobs," which he used to describe forms of work that persist despite being socially "pointless and unnecessary" or even harmful.[97] In a similar way, "bullshit construction" refers to building activity that absorbs vast amounts of labour, capital, and materials while contributing little to collective wellbeing. It is the construction of new infrastructures that serve speculative, luxury, or otherwise non-essential purposes instead of meeting basic social needs. "Bullshit demolition," correspondingly, refers to demolition that takes place not because a building is unsafe, unusable, or socially obsolete, but because clearing a site promises higher economic returns, aesthetic marketing advantages, or short-term profit, regardless of social or environmental loss. Too much of contemporary construction is driven by these mechanisms – and thus fails to improve lives; it also deepens inequality and locks societies into resource-intensive infrastructures that promote car dependency and other forms of excessive material consumption.

We focus instead on the scale and distribution of basic needs that remain unmet or are likely to emerge in the coming decades. We focus also on how cement and concrete may help to meet those basic needs – but also, when and how these materials might be replaced with others. Our approach entails considering not only alternative materials, but also alternative models of provisioning and developing. Above all, we think that material consumption should be focused where it is needed the most.

The idea of basic human needs has been widely discussed by those who study and advocate for human development, climate change mitigation, and just transitions.[98] Crucially, human needs are considered to be "non-substitutable, satiable, cross-generational and universal". We have cited some of the most important basic needs above – housing, access to safe drinking water, sanitation, and access to electricity. Many basic needs are upheld and codified in international law.[99] They are also at the core of the UN's Sustainable Development Goals (SDG) framework.[100]

Approaches to satisfying needs will vary across different historical, geographical, and political contexts. For instance, sanitation in a modern city requires different kinds of infrastructure than sanitation in rural areas; mobility can follow a mass transit model, or it can entrench widespread car use. The provision of services to meet basic needs can be, and frequently is, informed by modern science and engineering – but such knowledge should additionally be shaped by ethical and cultural traditions, and by socio-political institutions and struggles.[101] In addition, poverty and deprivation prevent communities from advocating for their own needs.[102]

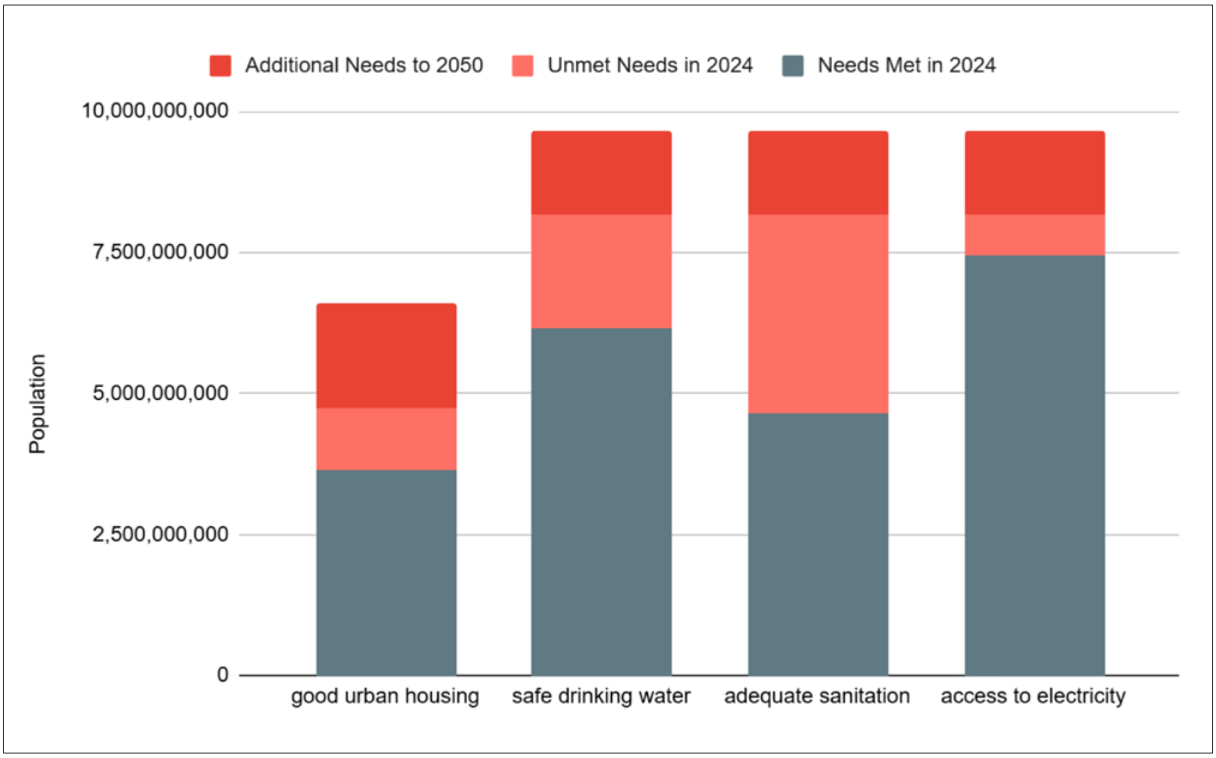
Figure 1.10: The direct and indirect importance of cement for social foundations (authors' illustration).[103] The ecological ceilings will be assessed in chapter 2.7.



We draw from Kate Raworth's so-called Doughnut Economics model, which advances twelve fundamental needs considered central to human well-being, based on the UN's Sustainable Development Goals (SDGs) (see Figure 1.10). Together, these basic needs represent a social foundation and provide the minimum conditions considered necessary for a just and livable society.[104] Among these social foundations, three stand out as being particularly cement-intensive: housing, water and sanitation, and energy.

As above, these basic needs remain unmet for billions of people worldwide. Figure 1.11 provides a rough estimate of the present scale of unmet needs (colored in salmon pink). These disparities are expected to grow further due to continuing population growth, primarily in urban areas (depicted in red in Figure 1.11). Other essential needs could also be included here, such as renewable energy deployment and climate crisis adaptation.

Figure 1.11: Scale of unmet needs in 2024, plus additional needs until 2050[105]



It is worth pausing to recognize the sheer scale of all of these unmet and future needs. By 2050, an additional 3.5 billion people will require safe drinking water – over 40 % of today's global population. Five billion people will need adequate sanitation – more than 60% of the 2024 population. And a further 2.2 billion people require electricity by 2050, if everyone is to have access to electricity – over a quarter of the world's population in 2024.[106]

The three central questions are: How should needs be met? Does meeting basic needs require cement? If it does, can cement use be reconciled with all of its costs and damages?

A recent study estimated that meeting the four basic needs listed above – using current concrete-based construction methods – has historically correlated with an average cement stock of 8 tonnes per capita.[107] That is, an average of 8 tonnes of cement per person, deployed in the built environment, has been deemed adequate to provide a sufficient level of access to basic surfaces in these four domains: urban housing, safe drinking water, sanitation, and access to electricity. If 8 tonnes of cement per person were to be deployed starting now, and targeted so as to meet present and future gaps in provision, then this would require substantial new cement output to be developed in all low-income and lower-middle-income countries.

The challenge is compounded by the mismatch between where needs are the most pressing and where cement is currently produced. The regions with the most urgent requirements for housing, water infrastructure, and energy access – particularly in Sub-Saharan Africa – account for only about 3 % of global cement production capacity.[108] India *is* already a major centre of construction – however, construction in India appears to be very poorly targeted with respect to basic needs (see examples of "bullshit construction" in 2.6.3).[109]

Meeting basic needs therefore requires that global cement output be *rebalanced* towards regions of greatest needs – and that within those regions, the production and consumption of cement is directed to where it is needed most. Our preliminary modelling suggests that, if capacities were ramped up starting tomorrow, the world's low-income and lower-middle-income countries would require a peak collective cement output of perhaps 1.5 billion tonnes per year of cement in the mid 2030s – roughly 40 % of current world production.[110] Production could then decline once sufficient per capita stock levels of concrete were reached, and once basic needs were met. Were significant volumes instead diverted to non-essential uses such as luxury housing, overall production would need to be even higher.

This outlook is undoubtedly daunting, but it must be placed into perspective. First, as noted above, the potential need for cement is significantly *lower* than current global production of 4.1 billion tonnes per year (see Figure 1.5). This indicates substantial potential to reduce and redirect cement production from non-essential to essential uses (see 4.3.1). Second, these projections assume conventional concrete-based construction. While concrete may remain indispensable for certain applications, alternatives already exist for many others – and in some cases, they are not only feasible but preferable (see 4.2).

With these considerations in mind, the following chapter examines the damages caused by the cement industry, and the measures proposed by the industry itself to address them.

Endnotes

1 GCCA 2019.

2 Xi et al. 2016. Mortar is nowadays mostly used for exterior rendering, plastering, and interior decorating; only a minority of it is used for bricklaying, plus other uses such as the maintenance and repair of concrete structures and terrazzo.

3 Typically additives are also part of the mix (see Figure 1.1).

4 Watari, Cao, et al. 2023a; Shanks et al. 2019. In the UK, just 4 % of cement is used for other purposes than mortar and concrete.

5 Data from Watari, Cao, et al. 2023. Note that the ingredients of concrete are usually combined in a given ratio according to volume.

6 Gagg 2014

7 World Steel Association 2024; Allwood & Cullen 2012: 31, 37; Jappe 2023: 18-8–19. Reinforced concrete is likely only about a quarter of all concrete used globally, though "undoubtedly" higher in "developed countries". Scrivener, John, et al. 2018. However, it must be noted that much of the reinforced concrete that is in use provides the enabling conditions for unreinforced concrete to be used plentifully elsewhere in the built environment. Roughly 42 % of global steel production is used in buildings, and 10 % in infrastructure. About half of the 52 % total is used to reinforce concrete; the rest is used structurally, in tandem to concrete (reinforced or unreinforced).

8 There are alternative cements, though their use is still very much a niche concern (see 4.1).

9 For instance, the "Piso Firme" (Firm Floor) programme in Mexico, implemented between 2000 and 2005. There, more than 300,000 low-income families benefited from the replacement of dirt floors with cement floors, which reduced the transmission of parasitic infestations, lowering the incidence of diarrhoea and anaemia. Cattaneo et al. 2009.

10 Namkung 2025. Concrete's comparative resilience to fire was widely noted in relation to the January 2025 fires in Los Angeles, which caused an unprecedented scale of destruction.

11 Berge 2009: 194.

12 Xi et al. 2016. Note, however, that cement powder has a limited shelf-life: 3-6 months on average. In a given year, 97 %-99 % of the cement produced globally is likely consumed, with the rest going to waste before it is used.

13 Gagg 2014.

14 Allwood & Cullen 2012: 31, 35, 180.

15 Constantinides 2013.

16 Designing Buildings Wiki 2023.

17 Ferro 2017; Forty 2012: 102.

18 Lefebvre 1974: 307, quoted in Malm 2015: 301. See also Lefebvre 1974: 49-65, 147-158, 285-290.

19 Malm 2015: 307-309 Arguably, capital is able to function most effectively when and where it is able to achieve a "tyranny of the abstract" across time and space.

20 Kipfer & Goonewardena 2013. "Colonial" processes are internalized into urbanization.

21 Moore, J.W. 2015; Patel & Moore 2018: 44-63. "Cheap nature", in the terms of Jason W. Moore and Raj Patel.

22 Vyta Pivo, 2021.

23 Ghosh 2016; Szeman & Diamanti 2019: 3-3–4; Szeman & Boyer 2017; Szeman 2019; Leggewie & Mauelshagen 2018. For the concept of "fossil mentalities", see Schmelzer & Büttner 2024. See the widespread literature about "energy cultures", "petrocultures", "carbon culture", and related concepts and phenomena. Amitav Ghosh writes: "culture generates desires – for vehicles and appliances, for certain kinds of gardens and dwellings – that are among the principal drivers of the carbon economy". Imre Szeman and Jeff Diamanti add: "The economic and transport infrastructures that have been generated by the ever-expanding use of fossil fuels (and which in turn support and amplify that self-same use) constitute a significant dimension of global energy culture. [But] just as significant – perhaps even more so – are the cultural desires to which Ghosh [and other writers] draw our attention."

24 Schmelzer 2016.

25 Calder 2021: 373-77. Given that concrete became the "technical foundation" of the modernist movement, perhaps this application endowed the material with an aesthetic aura that obscured some of the harms that it inflicted on the labour movement (see above and 2.6.1).

26 Bonacker 1996.

27 Brand & Wissen 2021.

28 Covington et al. 2023; Goldscheider et al. 2020; Langer 2001; Ronca et al. 2023.

29 Carrasqueira et al. 2024.

30 Harder 2021; Byiers et al. 2017; UNEP 2023: 62.

31 Crepaldi Affonso & Pernicka 2001; Aggelakopoulou et al. 2019; Rodriguez-Navarro et al. 2023. It probably predates fired pottery and the smelting of metals. Lime renders and mortars were also used in the Assyrian, Mayan, and Chinese civilizations, all before the common era.

32 Rodriguez-Navarro et al. 2023; Lanas et al. 2004.

33 Based on Scrivener, John, et al. 2018; Rodríguez-Navarro 2012.

34 Rodríguez-Navarro 2012.

35 Rodríguez-Navarro 2012; Moore, Dylan 2024.

36 Rodríguez-Navarro 2012; Moropoulou et al. 2000.

37 Natural Pozzolan Association n.d. They include volcanic ash, pumice, tuff, and perlite.

38 Jackson, M. D. et al. 2017; Moore, Dylan 2024; Rodríguez-Navarro 2012.

39 Wilson 2006: 229. "The increasing use of less skilled labour for large projects was one of the factors facilitating the political use of massive building programmes as a means of employing the urban poor [in] Rome."

40 Blagg 1983.

41 Blagg 1983: 30; DeLaine 2021; Calder 2021: 101.

42 DeLaine 2015.

43 Marder & Jones 2015: 16; Moore, David 1995.

44 Brandon et al. 2014; Jackson et al. 2017.

45 See Seymour et al. 2023.

46 Seymour et al. 2023. Ambiguities in the words chosen by Vitruvius when describing Roman concrete preparation also point in this direction.

47 Seymour et al. 2023. Note that modern concrete also self-heals in the presence of water. However, this phenomenon is limited to only very small cracks; it is also far less useful or relevant where steel rebar risks corrosion.

48 We touch on this on Chapter 4.1. However, research in this area remains in its infancy, and the outcomes of the research remain very much uncertain.

49 Moore, Dylan 2024.

50 Rodríguez-Navarro 2012; Moore, Dylan 2024. It was known, for instance, that limestones from certain geographical locations produced lime putties that set better than others, and were themselves more water-resistant. "As early as 1570, Palladio [the celebrated Italian architect], in his treatise, mentions using a hydraulic lime made from a limestone quarried near Padua."

51 Rodríguez-Navarro 2012; Moore, Dylan 2024.

52 Van Oss & Padovani 2002.

53 Based on Van Oss & Padovani 2002. Note that most modern kilns separate out the calcining and preheating stages from the rotary kiln (see 3.2.1).

54 Moore, Dylan 2024.

55 Note that the "industrial revolution" predates the widespread application of fossil fuels in Britain by at least 150 years, with a large shift of the working population out of farming and into industry occurring in the period 1600-1700, "not 1750-1850 as 100 years of scholarship has assumed" (Shaw-Taylor et al. 2024). Capitalism itself, in turn, (under almost any definition) predates this earlier period of "industrial revolution" by at least another 100 years (Brenner 2007; Banaji 2020). Coal-fired steam power meanwhile only came to dominate over industrial water power in Britain by around 1840 (Kanefsky 1979: 349, cited in Malm 2015: 80).

56 Meier 2001; VDZ 2002.

57 Jappe 2023: 24-25. Berlin´s parliament was one of the first large buildings to contain steel-reinforced concrete (1894).

58 Marta Gueidão et al 2025; Moore, Dylan 2024; Förster 2023; Jappe 2023: 23-24.

59 Zalasiewicz et al. 2019: 47.

60 Farnham 2002: 55, 63.

61 Hibbard et al. 2006; Steffen et al. 2007; McNeill & Engelke 2014.

62 Caldwell 1986; Kuhn 2010.

63 All measurements in this report are metric, and metric tonnes (1,000 kg) are used throughout.

64 Skinner et al. 2022; Gordon 2024.

65 Data of cement production from USGS 2024. The production of concrete is approximated using that on average cement makes up 15 % of concrete's mass. Compare Waters & Zalasiewicz 2017.

66 Estimate based on the data as depicted in Figure 2.5, and assuming that the share of concrete stocks in annual demolitions has not dramatically increased from the pre-2016 share.

67 Wiedenhofer et al. 2021.

68 The data until 2016 are from Wiedenhofer et al. 2024. Population data are from UN DESA 2024.

69 Data are from Andrew 2019.

70 Swanson 2015; USGS 2024.

71 He 2024.

72 Present authors' calculation, based on Wiedenhofer et al. 2024; UN DESA 2024. The UN categorizes 45 countries as Least Developed Countries (LDCs) (UN 2020). 42 of those countries are included in the MISO2 stock-flow data quoted here.

73 Ralf Löckener & Birgit Timmer 2002. In Germany, for example, the cement industry calculates a capital/worker rate of EUR 1.5 million.

74 Cook 2011: 9-11, 17, 19.

75 Scrivener, John, et al. 2018.

76 Scrivener, John, et al. 2018.

77 Marsh, A. T. M. et al. 2024.

78 Cook 2011: 12.

79 Dewald & Achternbosch 2016.

80 Cramer & Harsányi 2023.

81 Heidelberg Materials 2024a.

82 Heidelberg Materials 2024a: 99.

83 Data from Madhumitha 2024 and Fortune Business Insights 2023.

84 Forbes 2025a, 2025b, 2025c, 2025d; LaFranco et al. 2024. Merckle's wealth is surpassed by that of other cement billionaires, and these are among the world's 100 richest people. For instance, Gautam Adani's Adani Group recently bought Holcim's cement business in India, and at time of writing he has a net worth of USD 55 billion. Kumar Birla owns India's UltraTech Cement, and has a net worth of USD 20.5 billion. Aliko Dangote, the majority owner (85 %) of Dangote Cement, has a net worth of USD 11 billion, making him the richest man in Africa.

85 Marsh, A. T. M. et al. 2024.

86 Cook 2011: 7.

87 Dewald & Achternbosch 2016.

88 Cook 2011: 12.

89 The present subchapter is largely based on Van Oss & Padovani 2002.

90 Förster 2023: 240.

91 IEA 2023; WEF 2022: 44.

92 UN 2023: 24, 26, 21.

93 UN DESA 2024. By 2050, India's population is forecast to grow by 220 million (+15 %); Pakistan's by 120 million (+48 %), Nigeria's by 125 million (+54 %); and the DRC's by 110 million (+100 %).

94 UN DESA 2018, 2024. Urban population growth is the product of in-situ demographic expansion (births exceeding deaths), in-migration into cities, and densification of rural areas so that they are reclassified as urban. Regarding the case of Nigeria, for instance, see Farrell 2018.

95 UN DESA 2024. Most populations in the Global North are expected either to grow only moderately, or to shrink.

96 Global Infrastructure Hub / Oxford Economics 2017; Thacker et al. 2019, 2021; UNEP 2023b; Soriano et al. 2024a, 2024b.

97 Graeber 2019.

98 Doyal & Gough 1991; Fisch-Romito 2021; Gough 2015; IPCC 2022a: 514; Rao & Baer 2012; Shue 1993. Alternative terms in use, besides "basic needs", include "essential needs" and simply "human needs".

99 For instance, a Right to Adequate Housing is enshrined in Article 25 of the UN's Universal Declaration of Human Rights (1948) and Article 11.1 of the International Covenant on Economic, Social and Cultural Rights (1966). All states have committed themselves to this principle in one form or another (UN OHCHR 2022; UN-Habitat 2014).

100 UN DESA 2015.

101 Beyond the most basic of biological needs, there is a fundamental "historical and moral content" to what constitutes a human need (Marx 1867: 185). Needs can be opposed to the potential "limitlessness" of a want or desire; balancing the satisfaction of basic human needs against inessential wants requires some intermediary "moral evaluation" (Gough 2015). This topic has been a recurrent theme in social theory: see for instance Soper 1981, 1993; Durand et al. 2024.

102 Sen 1995: 55.

103 Based on Raworth 2017.

104 Raworth 2017. Note that Raworth also emphasizes that such needs are met in different ways across different historical, geographical, and political contexts.

105 Author's own calculation based on UN 2023: 21, 24, 26; UN DESA 2024, 2018.

106 UN DESA 2024. The UN's SDG 6.1 is for "Universal and equitable access to safe and affordable drinking water for all"; SDG 7.1 is "Universal access to affordable, reliable and modern energy services".

107 Fisch-Romito 2021. Needs here are considered met once 90 % of the population has access to the service in question ("high access" to basic services). Note that this excludes other needs, such as widespread access to transport infrastructure: that correlates to an additional 5 tonnes of cement stocks per person.

108 Authors' calculation based on Tkachenko et al. 2023; UN DESA 2024.

109 Kouamé 2024. A recent report by NITI Aayog, a government think tank, indicated an 18 % fall in multidimensional poverty in India over the last nine years; however, those claims are disputed (NITI Aayog 2024; Krishnan 2024). Moreover, the last national census in India was conducted in 2011, and there is now a paucity of data on the prevalence of urban slums and access to basic services. Under conditions of rapid urbanization, past trends, and on-the-ground observations by activists and academics, indicate that, while the share of the urban population living in slums may be in decline (World Bank 2025), the absolute numbers are likely increasing (V. Yadav et al. 2021; Killemsetty 2024).

110 Authors' estimate, based on Fisch-Romito 2021; Wiedenhofer et al. 2024; UN DESA 2024; World Bank n.d. This additionally assumes minimal demolition of cement stocks along the way.

2 Costs and damages of cement and concrete

The substantial growth of the cement and concrete industry has brought with it extensive costs and damages around the world. These encompass not only direct economic costs, but also the vast social, ecological, and cultural "hidden costs" that are externalized onto workers, communities, ecosystems, and future generations. Within this chapter, we first examine the damages caused by production, including the effects on the climate crisis (2.1), on biodiversity (2.2), and on air quality (2.3). We then look at the costs created by concrete's end use, including how cities have been left vulnerable to heating up, sinking, and being sealed off (2.4); how concrete has led to short-lived buildings and massive waste streams (2.5); and how its use is quite literally cementing power and inequality (2.6). Finally, we place these damages in the context of planetary boundaries (2.7).

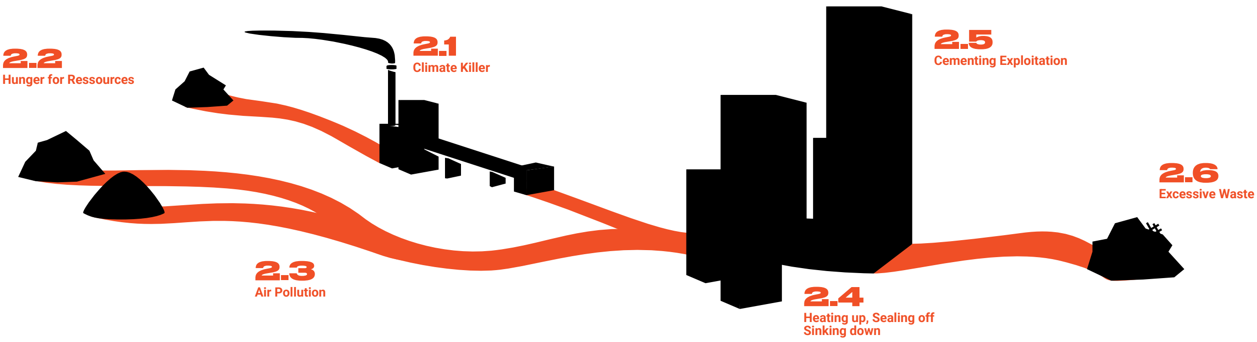
To further illustrate these damages, this chapter also includes several case studies of conflicts caused by two industry giants: Heidelberg Materials and Holcim. While most of these conflicts are local in scope and focus, some have made global headlines, such as the struggle of Indonesian farmers, the legal battles of Pacific islanders, and the actions of climate activists in Sweden and France. Together, these cases reveal the full scope of cement's environmental and social costs across the globe.

2.1 A climate killer

Globally, cement production is a major cause of greenhouse gas emissions, responsible for 7–8 % of all the CO_2 emissions from fossil fuel combustion and industry, or about 5 % of total greenhouse gas emissions. Emissions from the cement industry exceed those of aviation by a factor of three. Other sources along the production line of concrete, like the extraction of gravel, add a further 1 % of global greenhouse gas emissions.[1]

In comparison to other modern construction materials, the emissions per kilogramme of final material are not especially high for cement or for concrete. Crucially, it is the sheer scale at which concrete is used that creates a problem, and that scale has risen precipitously over the last few decades (described in Chapter 1.4.4). Still, while cement production rose

Figure 2.1: The cement and concrete industry's value chain with corresponding damages (authors' illustration).

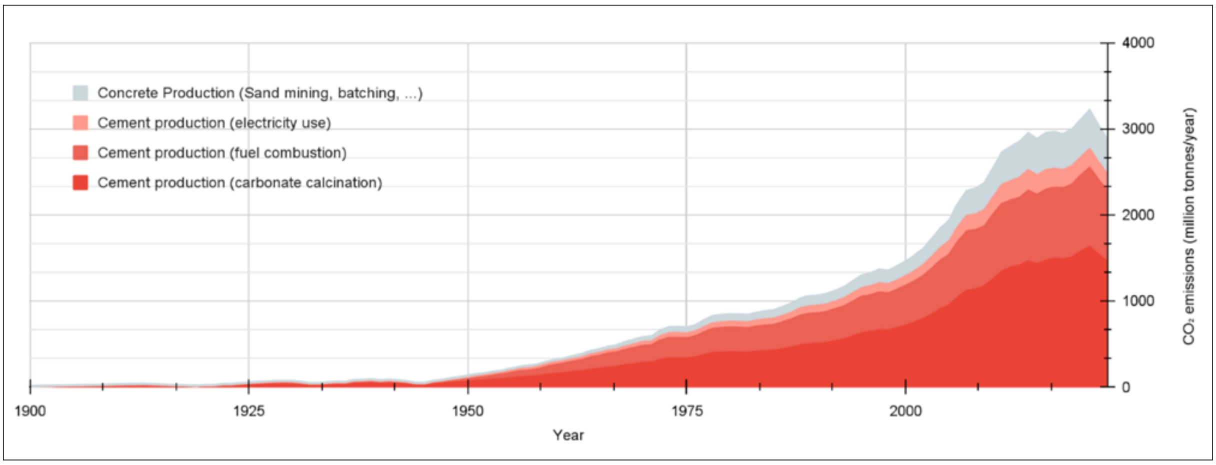


four-fold from 1990 to 2020, the resulting emissions rose only about three-fold during this time. This is a product of efficiency gains in production (see 3.2).[2] Yet the relative share of cement emissions in total CO_2 emissions globally has itself been steadily increasing from 4.2 % of all CO_2 emissions from fossil fuels and industry in 1990 to almost 8 % in 2022.[3]

Without radical decarbonization measures in this sector, the industry will continue to play a disastrous role in fuelling the climate crisis. On their own, the world's existing cement production facilities are on track to consuming nearly a third of the world's remaining global carbon budget from 2026 onwards – if the world is to remain within 1.5 °C of warming.[4]

To grasp the challenge posed by the industry's CO_2 emissions, we will first take a look at how these emissions come about (2.1.1) and how deeply the cement industry and the fossil fuel industry are intertwined (2.1.2). We then move on to discuss how the final concrete reabsorbs some CO_2 and whether it makes a significant impact or not (2.1.3).

Figure 2.2: The CO_2 emitted per year through cement and concrete production from 1940 to 2023.[5]



2.1.1 The source of emissions

What is the origin of these enormous emissions? Basically, just two aspects of the production process are responsible for the vast majority of them, and both happen directly within the kiln: calcination and fuel combustion.

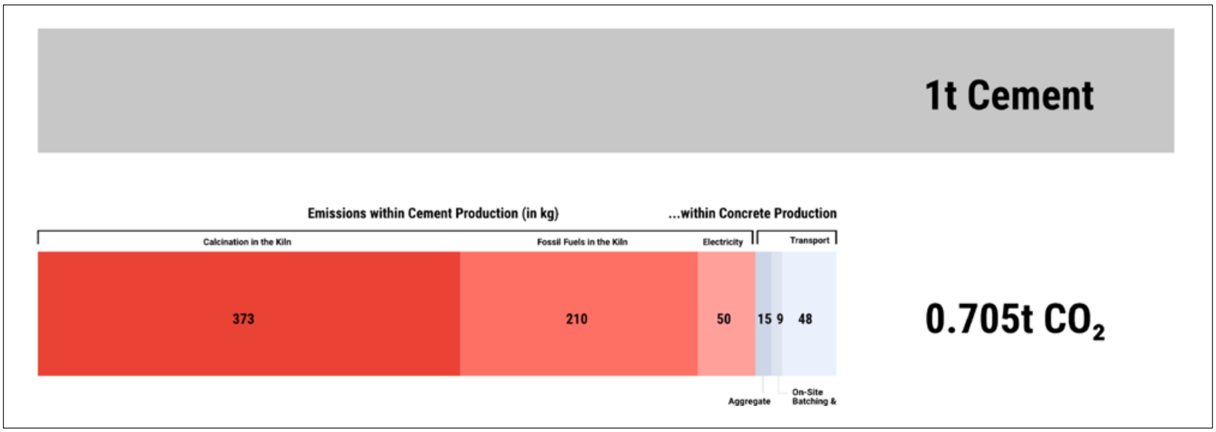
The main source of emissions is the central chemical reaction of cement manufacture, called calcination. This happens when the fossil material of limestone is split, turning it into quicklime, so that it can act as a binder (see 1.4.1). The CO_2 previously captured within the limestone is set free, resulting in so-called "process emissions" – that is, emissions that are not released through burning fossil fuels, but created instead through the process of a simple chemical reaction: $CaCO_3 \rightarrow CaO + CO_2$.

Through this chemical reaction alone, nearly half a tonne of CO_2 will be produced for every tonne of limestone put into the kiln. And with the limestone as the main input, this adds up to about 370 kg of CO_2 per tonne of cement.[6] These process emissions comprise about 60 % of cement industry emissions and cannot be avoided in any cement production based on limestone.[7]

The second main source of cement emissions is fossil fuel combustion. The production of Portland clinker requires intense heat in the kiln – 900 °C for the calcination to happen and then over 1400 °C for the formation of the final clinker (see 1.4.3). This amount of heat cannot easily be provided with electric kilns or hydrogen (see 3.2.3), so the industry depends on fossil fuels, mostly coal. Fossil fuel combustion emissions add another 210 kg of CO_2 per tonne of cement produced.[8]

On top of the process emissions and combustion emissions, finally we come to the other energy-based emissions that derive from electricity use along the production chain, especially from the milling of the raw materials and clinker. These add approximately another 50 kg of CO_2 for every tonne of cement produced.

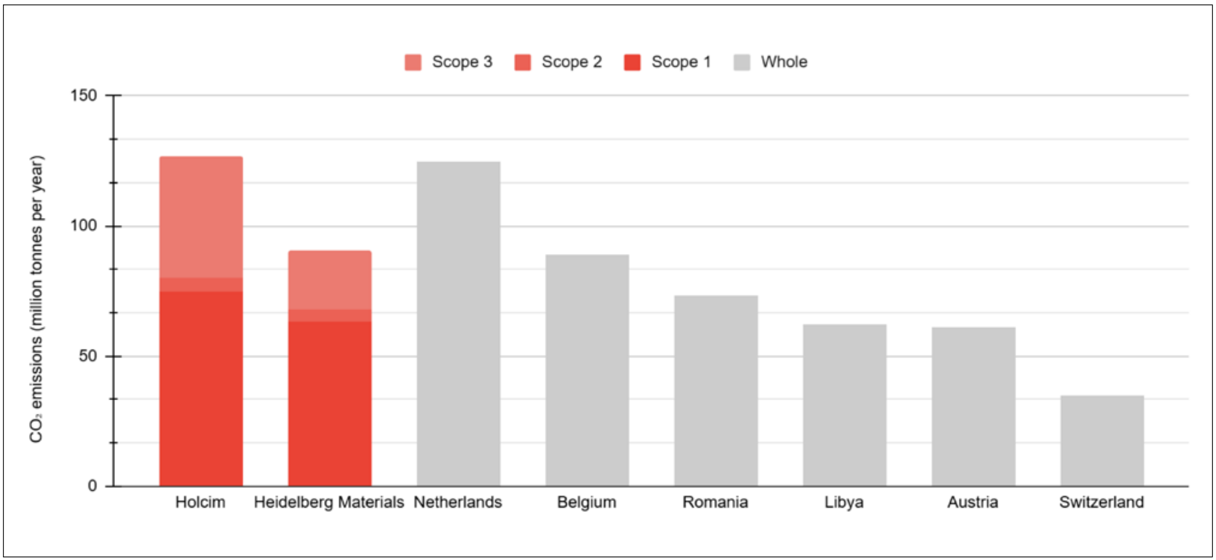
Figure 2.3: Kilograms of CO_2 emitted for every tonne of cement during its production and its final use in concrete.[9]



While these other energy-based emissions are in theory easy to curb with green electricity, both process emissions and combustion emissions are currently an inevitable part of Portland cement manufacture. Eradicating those emissions would necessitate an entirely different chemistry, including an entirely different material process, than the one that presently dominates the cement industry (see 4.1).

The global concrete industry's emissions add up to around 2,600 million tonnes (2,600 Mt) of CO_2, annually.[10] This surpasses the total emissions of every single country except for China and the United States.[11] Even the CO_2 emissions of single cement companies on their own are comparable to the emissions of whole countries. For example, the transnationally operating cement giant Holcim has a carbon footprint – which is the result of its combined global facilities – several times larger than its home country of Switzerland.[12]

Figure 2.4: CO_2 emissions of Holcim and Heidelberg Materials in 2024 compared to the emissions of several countries (Netherlands, Belgium, Romania, Libya, Austria and Switzerland) in 2023.[13]



A.1 Case study: Bringing the giant to court

Figure A3: The Indonesian island of Pari lies just above sea level.

Courtesy of zvg. Used with permission.
https://callforclimatejustice.org/en/media/

Figure A4: The 37-year-old plaintiff Edi earns a living from fishing and renting out rooms to guests.

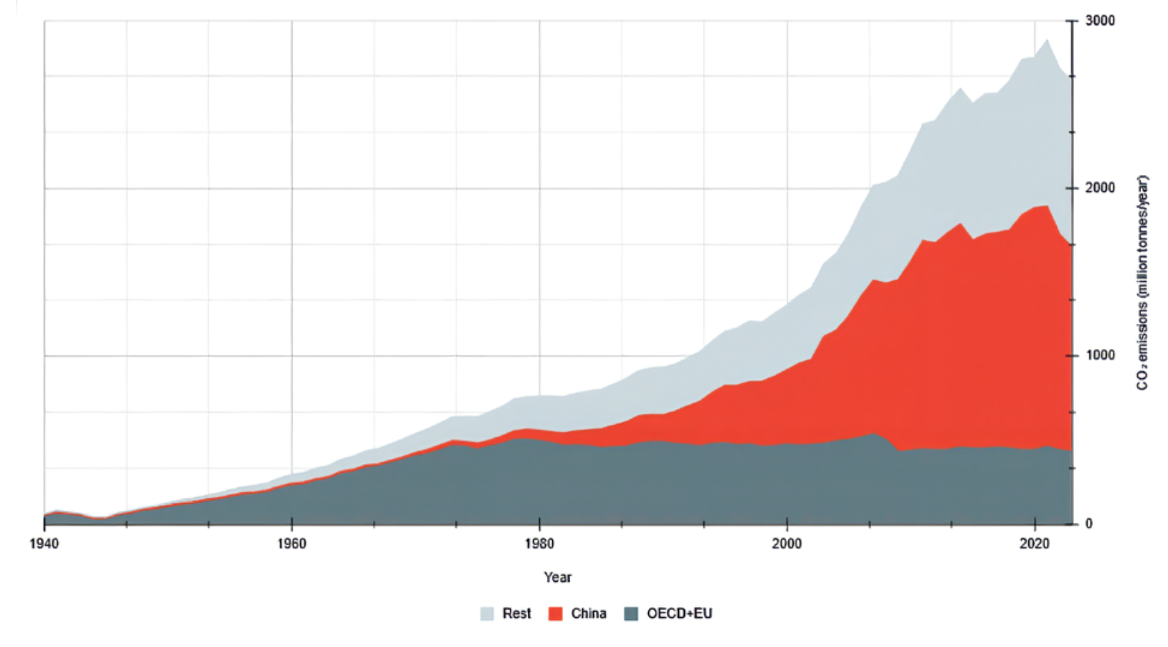
Courtesy of Abdul Baits. Used with permission.
https://callforclimatejustice.org/en/media/

Pari is a small Indonesian island, the highest point of which is just 1.5 metres above sea level. Its 1500 inhabitants will be severely impacted by climate change through flooding and severe weather, as well as the possible loss of the whole island. In a new move, in January 2023 four residents filed a civil suit against the Swiss cement major, Holcim, in Switzerland's courts, with the help of several European NGOs. They argued that the company must be held responsible for its CO_2 emissions, since Holcim has known about the consequences of its own greenhouse gas emissions for 30 years but has nevertheless permitted the scale of its emissions to increase over this timeframe. In the court case, which is still ongoing, the plaintiffs demand that Switzerland enforce a significant reduction in Holcim's CO_2 emissions, globally, provide money for flood protection measures, and provide compensation for the costs and damages incurred on the island.[14]

These emissions have been steadily increasing. Annual emissions from OECD and EU countries increased through the 1970s and have remained relatively constant since then. China now accounts for the lion's share, responsible for about half of all cement industry emissions since the 2010s. Even cumulatively, China has caught up, and both China's cement industry and that of the old industrial countries combined have each emitted over 28 billion tonnes of CO_2 in the course of their history, with cement production from all other countries combined responsible for another 24 billion tonnes.[15]

Given the growth rates of the cement industry in developing countries throughout sub-Saharan Africa, Southeast Asia, and South Asia, emissions from these regions will also likely play an increasingly important role in the future. New cement plants are being built at a massive pace in these regions, potentially locking in additional emissions. This expansion is particularly concerning given that existing cement production facilities alone are projected to consume more than a quarter of the world's remaining 1.5 °C carbon budget on a business-as-usual basis.[16]

Figure 2.5: Share of China and of the OECD+EU countries of yearly global CO_2 emissions from cement production from 1940 to 2023.[17]



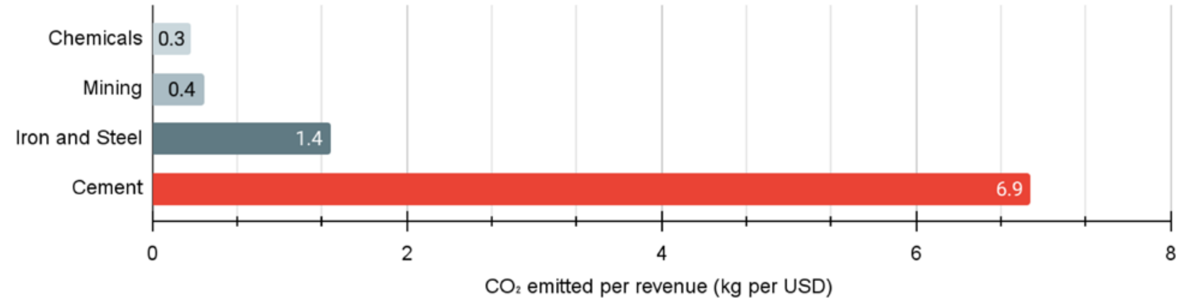
2.1.2 The fossil-fuel-cement-growth complex

The history of cement is bound up with the rise of fossil fuels, and both are central to processes of industrial growth and capitalist expansion. Wherever capital flows, concrete flows too, and the construction industry is at the heart of all major development and growth projects, from the New Deal's Hoover Dam to proposed Green New Deal green infrastructures. Concrete provides the ground and material for capitalist accumulation. As argued recently by social historian Travis J. Cook, we live in the "Second Stone Age": "The lifeblood of the modern world may very well be fossil fuels and the veins made of steel, but the body is of concrete. The modern stone is the most intensively utilized solid material on earth".[18]

The creation and historical growth of Portland cement was only made possible through the extensive use of coal from the nineteenth century onwards. This cheap source of energy created the enormous heat necessary in the kilns for burning limestone, later complemented by other fossil resources such as oil, gas, and more recently, plastic waste. On the other hand, most fossil fuel infrastructure relies heavily on concrete, namely power plants, roads, and offshore platforms. Together, fossil fuels and cement radically transformed modern societies, creating "fossil civilizations" deeply dependent on fossil fuels and fossil material – a.k.a., limestone.[19]

The production processes of fossil fuels and cement remain deeply intertwined, so much so that the cement industry's measures to salvage CO_2 are to a great extent dependent on the fossil fuel industry. Examples include the use of fly ash as a byproduct from coal plants, and the role of the fossil fuel industry in developing carbon capture and storage infrastructures – initially to more effectively extract oil (see 3.1.3). This deep reliance becomes clear when examining how much CO_2 must be emitted for every USD of revenue. At nearly 7 kg per USD, the cement industry lies far ahead of the second-highest emitter: the iron and steel industry (see Figure 2.6).

Figure 2.6: Kg of CO_2 emissions per USD of revenue of different industries compared in 2017.[20]



It's no surprise that the cement and fossil fuel industries are in a dance of mutual dependency when it comes to the end-uses of their products. Vehicle infrastructures are a case in point. Throughout the industrial world in the post-war period, the motor car and fossil fuel industries lobbied successfully to displace the development of mass transit in favour of the automobile. Concrete made highways and car-dependent suburbs a reality at scale. The mass congestion it caused then created demand for more roads, which again accelerated the expansion of car traffic and cement use.

While the emissions from the fossil fuel industry are at the centre of public discussions about decarbonization, and while they've been the object of protests for a long time, the cement industry has largely avoided the same kind of scrutiny. The industry has been able to do so precisely because cement is everywhere yet rarely seen: it disappears into the built environment, becomes part of the background of daily life, and is perceived as a neutral, technical and necessary material rather than environmentally problematic and potentially contentious. Its pollution is diffuse, complex and mediated, and it lacks the clear villains and widely visible disasters associated with oil spills, pipelines, or refineries. As a result, the cement sector has remained an infrastructural blind spot – structurally essential, environmentally destructive, but politically invisible.

A.2 Case study: Defending the Earth against Holcim

Figure A5: A Holcim concrete plant blocked by Extinction Rebellion activists.

Source: Courtesy of Extinction Rebellion. Used with permission.

Holcim's quarries and production sites have been increasingly targeted by environmental and climate activists over the last five years. Actions have included those by Extinction Rebellion, as well as several smaller grassroots groups like the French group Les Soulèvements de la Terre (Earth Uprisings). Les Soulèvements de la Terre's actions have included the occupation of quarries, such as their "ZAD de la Colline de Mormont" occupation, as well as blockades.[21] The most attention-grabbing action was arguably when 200 activists invaded Holcim's cement factory in Bouc-Bel-Air, and sabotaged the plant by destroying machinery and electrical equipment.[22] Les Soulèvements de la Terre justified their actions as responses to Holcim's ongoing environmental destruction and air pollution, but also their central role in land sealing.[23]

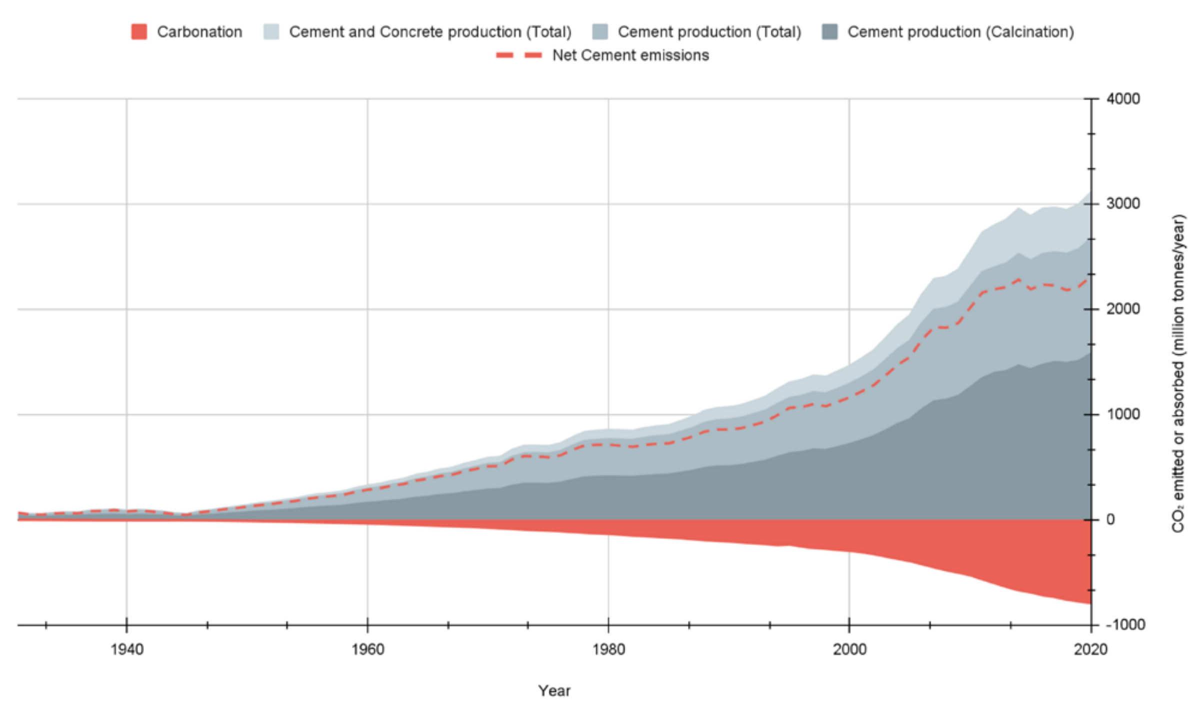
2.1.3 Concrete as a carbon sink?

The so-called "sponge effect" of cement must be mentioned in this discussion. Once the material has hardened, atmospheric CO_2 enters the pore structure of concrete. In the presence of water, it then dissolves to form carbonate ions and consequently calcite ($CaCO_3$). As such, concrete gradually absorbs atmospheric CO_2, as it progresses along the lime cycle (see 1.4.1). This sponge effect, called carbonation, is an inherent part of the cement curing process.[24]

Carbonation theoretically has the potential to fully recapture all of the "process" CO_2 emissions from cement production, so the cement industry has been very keen in recent years to champion carbonation – arguing that it significantly reduces the industry's negative impact on climate change (see 3.3.1). Indeed, it is true that cement and concrete structures can function as a carbon sink, as can demolition waste.[25]

In reality, under normal conditions carbonation is a very slow process: it happens over the course of decades (or even centuries), in contrast to the sudden release of process emissions during the manufacture of cement. Over 50 years a typical concrete structure will reabsorb merely 6 % of the total CO_2 emissions (12 % of the process CO_2 emissions) emitted in its production.[26] Only a small portion of the built concrete carbonates at a time, and surface coatings such as paint reduce that process even further.[27] Only when a structure is demolished are suitably large amounts of concrete exposed to atmospheric CO_2, and an additional 16 % of the total CO_2 emissions (30 % of the process CO_2 emissions) can be reabsorbed. However, further emissions are also likely to be incurred within the demolition process itself.[28]

Figure 2.7: Yearly CO_2 absorbed through carbonation compared to the CO_2 emitted by the industry from 1931 to 2020.[29]



Plainly, the carbonation sponge can never catch up with the emissions from calcination, unless the scale of cement manufacture plummets globally, or technological measures to enhance the speed of carbonation are employed at scale (see 3.3).[30] In the current reality, neither of those things are happening. Just 800 million tonnes (800 Mt) of CO_2 are currently reabsorbed each year through the carbonation of all of the world's stock of concrete that has been built in the past. This is equivalent to only about one quarter of all concrete-related emissions that are produced annually (see figure 2.7).[31]

Moreover, carbonation can come with dire structural consequences for buildings and infrastructure, since it can strip cement of its physical integrity, causing cracks and the corrosion of steel rebar inside reinforced concrete. Carbonation is one of the principal reasons for the short lifespan of modern concrete buildings and infrastructure (see 2.5.1). About 40 % of corrosion damage in the United States is said to be due to carbonation, adding up to estimated damages of over USD 100 billion per year.[32] If buildings and infrastructure fall down or are demolished on account of structural damage, then they also need to be rebuilt, most likely with new cement and concrete.

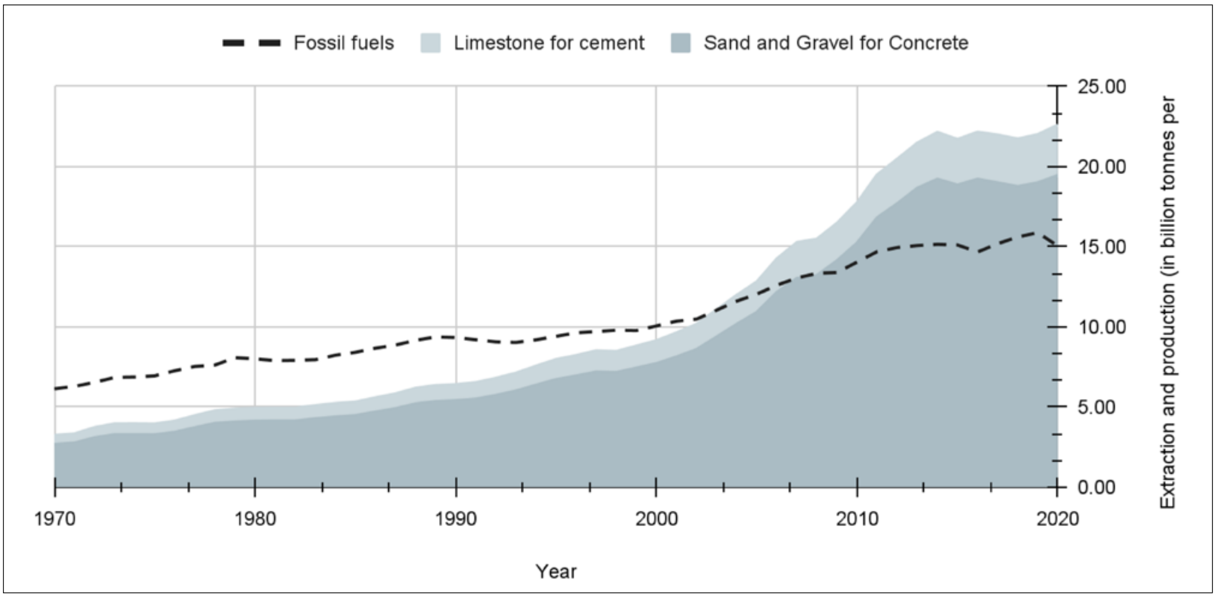
Ultimately, the extent of carbonation's utility should be viewed in relation to the immense scale of historical cement-induced emissions. While concrete does gradually reabsorb a fraction of the CO_2 released during its production, this process merely reflects – rather than compensates for – the industry's cumulative carbon footprint. The industry as such remains a major contributor to the climate crisis. Possible measures to reduce its impact are discussed further in Chapters 3 and 4.

2.2 Ecological destruction

Concrete production devours more resources than any other production process and is the single biggest "commodity frontier" of modern capitalism, leading to detrimental ecological impacts.[33]

The main ingredient of cement, limestone, is mined in vast quantities: at least 3 billion tonnes per year. More importantly, the mining of sand and gravel for concrete production has now reached about 20 billion tonnes annually, surpassing even the scale of fossil fuel extraction (see Figure 2.8).[34] Further resources are also extracted at astounding rates for the sake of cement and concrete production – for example, gypsum (200 million tonnes) and water (2 billion tonnes).[35] Simply taken on their own, limestone, sand, and gravel extraction for cement and concrete – due to the sheer scale of production – bring gargantuan damages to ecosystems and communities.

Figure 2.8: Yearly global production of sand and gravel for concrete production, as well as limestone for cement production from 1970 to 2020, compared to fossil fuels.[36]



Grasping these impacts on a global scale is a difficult challenge, since the extraction of these minerals is decentralized compared to (for instance) the extraction of most metal ores. On average, sand, gravel, and limestone quarries are much smaller than, for example, gold or tin mines, since limestone, sand, and gravel are more widely available and easier to mine.[37] Especially in countries in which extraction is largely unregulated, data on its impacts are scarce.[38] One international research team estimated conservatively that at least 24,000 animal and plant species are threatened globally due to damage caused to ecosystems by sand, gravel, and limestone extraction. The main causes of these damages are explained below.[39]

In such ways, cement and concrete production play a very large role in driving today's terrible pace of species loss . For at least some groups of species, the current speed and scale of regional population decline and global extinction are at levels unseen at any other time since the last mass extinction event (the extinction of the non-avian dinosaurs), some 66 million years ago. Whereas previous periods of such large-scale species loss were caused by volcanic or cosmic events, today's is propelled by industrial extraction, habitat destruction, and climate change. The mining of limestone, sand, and gravel for concrete lies at the heart of this process, eroding ecosystems worldwide in service of construction growth.[40]

These damaging impacts are illustrated by a closer look at the extraction of limestone (2.2.1) as well as sand and gravel (2.2.2), which is then contrasted with the measures taken by the industry to address these issues (2.2.3).

2.2.1 Destruction from limestone mining

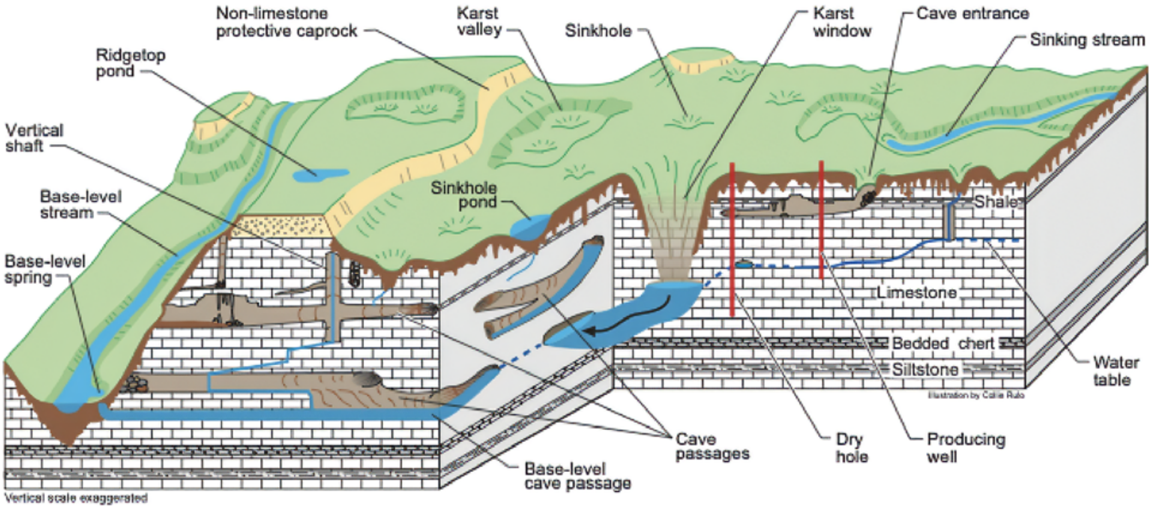
Limestone is extensively distributed throughout the globe, covering approximately 10 % of the Earth's surface. Since limestone dissolves easily – for example, when coming into contact with rainwater containing CO_2 – it creates complex water systems with equally complex environments. These sophisticated terrains are called karst areas. They include caves, sinkholes, unique rock formations, and underground rivers (see Figures 2.9, 2.10).[41]

Karst environments are home to an enormous variety of species, including rare and at-risk plant and animal species occupying sometimes very small geographical areas, both on the surface and underground.[42] Additionally, karst water systems provide about a quarter of the global population with freshwater; rainwater infiltrates the porous limestone and is stored within extensive underground aquifers before emerging at springs and wells.[43]

Figure 2.9: Karst area in Guilin, China.

Source: xiquinhosilva, adapted under CC BY 2.0 licence.
https://commons.wikimedia.org/wiki/File:Li_River_Cruise_87220-Li-River_(49040257503).jpg

Figure 2.10: Typical features of a well-developed karst terrain.



Source: Courtesy of James C. Currens, University of Kentucky, Kentucky Geological Survey. Used with permission.

Karst ecosystems can be severely damaged from the moment a quarry is set up, as vegetation and fertile soil, which took thousands of years to naturally build up, are eliminated within hours. Over decades, the drilling, excavating, and blasting severely alter the landscape and impact ecosystems far and wide through shock-waves and vibrations. They disturb nesting sites, cause permanent hearing loss to animals , and even collapse underground caves.[44]

Figure 2.11: Former limestone quarry of Heidelberg Materials in Santa Clara County, California.

Source: Dicklyon, adapted under CC BY-SA 4.0 licence. https://commons.wikimedia.org/wiki/File:Permanente_Quarry_aerial.jpg

Quarries impact karst water systems in a similar manner. They lead to damages that, again, spread far and wide beyond the quarrying site – often in unpredictable ways. Water streams can get redirected or even go dry, either because the quarry impacts underground flows or because water can no longer infiltrate the ground as easily once the topsoil is removed. Aquifers retaining water in wet seasons and releasing it in dry seasons can be impacted, making the water flows more unpredictable. Sinkholes can suddenly open up in the areas around a quarry, due to depressed groundwater levels.[45]

The overall quality of fresh water can also be degraded for a variety of reasons. Karst areas are excellent water storage reservoirs, yet limestone itself lacks water filtering properties. Once protective soils are removed through quarrying, pollutants can more easily find their way into the groundwater. Dust from quarrying can be washed into sinkholes and fissures, affecting water chemistry; it may also clog infiltration channels.[46] Oil spills from mining activities can also penetrate the soil and the aquifers beneath.[47] These harms too can spread far from the quarry site, since water streams travel great distances across bioregions and human settlements. Impacts such as these, brought about by limestone quarries, have led to the deterioration of entire ecosystems and the extinction of many species, such as the Plectostoma sciaphilum snail.[48]

Such impacts also damage humans. Karst areas are home to approximately 1.3 billion people and hold not only economical but also cultural, emotional, and spiritual value for those who inhabit them. One of the more extreme examples is the recent removal of several Taoist, Hindu, and Buddhist temples to make room for a Holcim quarry in Malaysia.[49] Flyrock from quarrying brings other risks to communities. For instance, in 2019 an Indonesian subsidiary of Heidelberg Materials accidentally crashed several boulders into homes in the town of Sukamulya, close to a quarry.[50] More widespread are the impacts on local agricultural systems, caused by changes to water systems or reductions to the overall availability of clean drinking water.[51]

Land grabbing practices by cement companies, often with the forceful help of governments, are not unusual, especially in the Global South. Local opposition against this kind of expansionism is common.[52]

A.3 Case study: Fighting for the bats

Dubbed one of the longest environmental protests in Australia, the fight against limestone mining on Mt. Etna in Queensland has lasted over 40 years, with activists using a wide range of tactics.[53] Mt. Etna has long been famous for its bat population. When an Australian cement company (Central Queensland Limited, now a joint subsidiary of Holcim and Heidelberg Materials), opened a quarry on the mountain in 1966, opposition sprung up. This mostly consisted of the local cavers associated with the Central Queensland Speleological Society (CQSS), aiming to protect the special ecosystems of the caves.

They began by writing letters, lobbying, and conducting guided tours. However, when those steps failed, they escalated in the late 1980s to non-violent direct action: namely sabotage, filling blasting holes with concrete, and finally a cave sit-in inside the caves, which received extensive media coverage. After several weeks the company agreed to a moratorium on mining, only to renege on the agreement sometime later.

In 1997, the CQSS moved to pursue legal action instead. Although this was unsuccessful, public opinion had ultimately shifted in favor of the activists and against the company, and in 1998 the company bowed to public pressure. It ceased all quarrying activities on Mt. Etna in 2004.

A.4 Case study: Those who embrace

Figure A6: Protest in front of the German Embassy in Jakarta, Indonesia against the plans of Heidelberg Materials.

Source: Save Kendeng / Dandhy Dwi Laksono, adapted under CC-BY-NC-ND 4.0 licence. https://th.boell.org/en/2023/04/24/forget-kendeng-not

On the Indonesian island of Java, farmers have been fighting back against a cement company since 2006. This resistance movement has probably attracted the most attention of any anti-cement movement worldwide.[54]

The Kendeng karst mountains situated in Java have a large water storage capacity, which allows the local population to cultivate rice easily through the constant water supply, and with comparative security of access to water. Therefore, the surrounding area has emerged as the most important rice-producing region of Indonesia.

But as infrastructure projects have emerged as a national priority, the need for concrete and cement expanded. Since 2006, two cement companies have tried to establish a cement plant with limestone quarries in the Kendeng Mountains: first the state-owned Semen Indonesia, then a subsidiary of Heidelberg Materials called Indocement.

While the cement plant project was heavily supported by political elites and government officials, local farmers organized against it; they were mostly members of the Indigenous group Sedulur Sikep ("those who embrace" in Javanese). They see themselves as deeply entwined with the Kendeng mountains, and consider its agricultural practices as a form of embrace. In order to "protect mother earth from destructive activities", they started a several decades long women-led resistance against the cement industry's plans. They used an extensive repertoire of tactics, from communications work to long marches, court filings, and finally blockades. Despite the severe repression,[55] they always stayed nonviolent. While the network of resistance has been mainly local, it has grown and included protests at the state palace, the German embassy, or at Heidelberg Materials' shareholder conference.

One peculiarly striking form of protest undertaken by activists was to publicly set their feet in concrete for a whole day to show how the factories would paralyze the community, which led to a meeting with the Indonesian president. Through several successful court filings against the company and the local government and an intervention from the Indonesian president as a result of the protests, no factory has been built to date.

Figure A7: Several women set their feet in cement in front of the State Palace, Jakarta, Indonesia.

JM-PPK, adapted under CC-BY-NC-ND 4.0 licence. https://th.boell.org/en/2023/04/24/forget-kendeng-not

2.2.2 The impacts of aggregate extraction

The amount of sand and gravel – so-called aggregates – used for concrete every year is colossal. On average, 400 tonnes of aggregates, weighing as much as about 80 elephants, are needed for a typical new single-family home, from the foundations to the roof tiles, most of it in the form of concrete.[56]

But while both sand and gravel seem abundantly available, only specific aggregates are of use. For example, most desert sand is unsuitable for use in concrete, because the grains are too rounded by the wind. Instead, the concrete industry mostly relies on aggregates from rivers, the sea, or terrestrial open pits. But extraction is happening far quicker than the existing reserves can be replenished – and in consequence some countries, such as Singapore or the Maldives, have already depleted their stocks. Even globally, readily available sand resources could be depleted as early as 2050 if we continue with current rates of production, raising fears of an impending sand crisis.[57]

Despite these enormous volumes of sand extracted annually, and despite millions of people being engaged in sand mining, it has attracted surprisingly little attention. In part, this may be because sand has relatively low value, and has historically been seen as readily available. Additionally, sand mining is not as complex technologically as most metal and other mineral mining activities. Sand extraction can be highly mechanized; however, it can also be performed with very little equipment, often at a small scale across numerous dispersed sites, and using artisanal methods with a low capital-intensity.[58]

In the Global North, where there are already tougher regulations and environmental protections in place, the extraction of sand is dominated by larger firms using capital intensive techniques, focusing on mostly terrestrial and open sea mining, as opposed to dredging at ecologically sensitive coastal sites or rivers.

By contrast, in the Global South, aggregate mining is mostly executed by small-scale miners with rudimentary tools, such as shovels and backhoes for land deposits, or suction pumps, dredging boats, or simple buckets, in rivers or coastal areas. A lot of it happens illegally and in an unregulated way. This means that the environmental impacts of such activities are spread across a huge number of smaller extraction sites that are difficult to track.[59]

In the same way that most limestone is mined near cement plants, on account of its weight, most aggregates are also mined close to where they are used. However, as some countries no longer have sufficient deposits, vast, often undocumented trading networks between countries have appeared: transferring aggregates from low- and middle-income source countries such as Myanmar and Cambodia, to high-income destination countries like the Netherlands, Singapore, Hong Kong, Qatar, and the United States. Low regulation and high demand lead to increased over-extraction in exporting states.[60] And this increased extraction impacts ecosystems severely. While the production of sand and gravel in land quarries can have similar effects to the limestone quarrying described above (especially when mined aggregates consist of limestone themselves), when mined at rivers or seas additional problems arise.[61]

A.5 Case study: Concrete exploitation

The Nahal Raba quarry, owned by the Heidelberg Materials subsidiary Hanson Israel, is located in the occupied West Bank, just across Israel's internationally recognized border with Palestine.

At the 60,000 m^2 site, the company excavates gravel for use in concrete and asphalt. When the quarry was opened in the 1980s, it was built on land that belonged to the Palestinian village of al-Zawiya, previously confiscated by the state of Israel.[62]

This has impacted profoundly on local Palestinians, since they are often not able to access the land at all. This has especially been the case since 2004, when Israel's "separation wall" was built between the quarry and al-Zawiya. Due to the location of the quarry, Palestinians are now unable to cultivate the land or have any sovereignty over the natural resources there. Complaints and petitions have fallen on deaf ears.[63] While most of the quarried gravel is produced for the Israeli market, the costs of pollution and noise mainly affect local Palestinians as well as local ecosystems, both already endangered through climate change and Israel's occupation.[64]

A further point of contention is that much of the quarried material is used in Israel's own construction projects in the Occupied Territories. With this cement, Israel and its West Bank settlers are solidifying their status as occupiers.[65]

While Heidelberg Materials denies actively supporting any Israeli settlement projects,[66] deliveries of construction materials with Hanson Israel trucks have been recorded entering West Bank settlements.[67] In addition, Palestinian quarries have been shut down and the Palestinians have been prevented from working with the natural resources themselves.[68] Heidelberg Materials bought British Hanson, the previous owner of the Nahal Raba quarry, in 2007. Since then, they have received numerous complaints over the legal status of the company's operations. Heidelberg Materials' official stance has been to claim that they do not break international law, and that they do not take any position on the status of individual territories under internal law.[69]

Since at least 2009, the company has said that they want to sell the quarry, but allegedly they haven't found a willing buyer. And yet, in the intervening period, they have continued to operate the Nahal Raba quarry. Only in November 2023 did the production come to a standstill. However, Heidelberg Materials applied for permission to extend the quarry by 10,000 m^2, enlarging it by one-sixth, into land originally belonging to another village nearby.[70] The company has stated that this expansion is necessary in order for them to sell the quarry to an unknown buyer that they found in 2019.[71]

On account of these activities in the Israeli-Occupied Territories, several blacklists have been compiled, and divestments have been undertaken by Nordic insurers and pension funds.[72] In 2020 the Nahal Raba quarry was blocked by the Israeli-Palestinian climate activist group "One Climate" for several hours, leading to increased media attention. The same group has taken legal action against the extension of the quarry, with the final decision of the courts yet to be announced at time of writing.[73]

Perhaps most notably, the controversial issue of the quarry expansion has been criticized in Israeli media. According to a 2020 opinion piece in the *Jerusalem Post,* any extension of the Nahal Raba would be "a subversion of international law." In particular, it would undermine a previous decision by the Israeli High Court that prohibited construction by Israel of new quarries in the West Bank. Any such "unilateral transformation of land beyond the Green-Line", the authors urge, would constitute an „act of environmental apartheid."[74]

In the case of rivers, where resources of sand are often the most accessible, extraction not only destroys the habitats and nesting banks of many species, but it also reduces water quality and can lead to erosion and a lowering of the overall riverbed. Mining at river deltas, such as the Vietnamese Mekong Delta, can be especially damaging, since such areas are biodiversity hotspots. After rivers, the next best source for construction-grade sands is the ocean, where beaches and the seabed also provide essential habitats. Seabeds are home to many microorganisms and cyanobacteria, which are the basis of marine life, and to many marine plants that are a major carbon sink. Coasts can be eroded through sand extraction, shoreline stability can be reduced, and suspended sediment can cause significant damage even several kilometres beyond a dredging site.[75] This impacts the livelihoods and wellbeing of nearby communities as well, particularly fishing communities, who often see their catch significantly depleted.[76]

Another consequence of dredging concerns the interruption of natural coastal and flood protections, which can lead to an increased scale and severity of floods. Especially in the face of a climate crisis that already significantly increases the risk of coastal flooding, sand extraction can undermine coastal defences for millions of people.

At the same time, dredging for sand has become a major source of income for many people. In India alone, it is estimated that 12 million people are probably involved in the artisanal and small-scale quarrying and dredging sector. As such, in India the rapid rise of sand extraction has emerged as an especially conflictual resource frontier. Even quite conservative estimates suggest a death toll in the hundreds among activists, civil servants, and villagers who are fighting against such extraction.[77] Moreover, conflicts over sand are not only increasing domestically – they are becoming geopolitical conflicts too, as when the Taiwanese Coast Guard in 2019 expelled several thousand Chinese vessels dredging for sand.[78]

2.2.3 The industry’s insufficient biodiversity measures

The cement and concrete industry emphasizes that it is already mitigating the destructive impacts of quarrying, most notably on endangered species.

And indeed, in response to local-level protests and more stringent legislation, companies are carrying out hydrological and biodiversity studies of quarrying sites in advance, inviting neighbouring communities to public hearings, designing the quarries in such a way as to mitigate harms, implementing biodiversity measures, and carrying out environmental restoration both during and after quarrying. In addition, the industry sometimes establishes separate areas to improve ecosystems and “compensate” for the destroyed biodiversity elsewhere.

Nowadays, most cement companies, especially in the Global North, solicit excessive media coverage on their biodiversity measures and even proclaim their goal to be “nature-positive” – that is, they argue that quarries are able to not only restore but even enhance local biodiversity.[79]

Though this is an honourable goal and it is true that there has been some legitimate progress, the cement industry’s impact is still a net negative – and to a massive extent. The numbers and reports on which the companies base their claims of their positive biodiversity impact contain numerous problems and biases.

The first issue is that assessing the environmental damage of mining can be difficult, if not impossible, to measure accurately. As noted above, ecosystems are complex and interconnected, especially in karst areas, such that the damage caused by quarrying can be incredibly challenging to contain and can spread far beyond the quarry site. The industry’s environmental assessments are usually not publicly available and lack independent scrutiny, and this leaves significant leeway for assessments to be skewed towards the industry’s own interests. This is especially the case when Indigenous knowledge is not acknowledged or over-ridden by authorities when it is judged not to comply with Western scientific methods. And yet such knowledge can offer detailed, long-term understanding and insight about the interdependence of local ecosystems.[80]

The second problem with industry claims is that cherry-picked examples of birds and mammals are often placed in focus and highlighted, while less “mediagenic” species like snails – whose habitats and life cycles are most intimately connected to limestone – are neglected. As nature conservationist Tony Whitten has noted, “No cement business has ever admitted the scale of the problem.” Instead, the companies “tout their biodiversity pages [on] their websites”; they publish sustainability reports “with pictures of ducks and frogs and children enjoying the wetlands created from the hills they remove. They give and receive prizes for their restoration work – but do not acknowledge what is being lost.”[81] Whitten’s words, written a decade ago, have lost none of their truth today.

Finally, the damages done through quarrying are largely irreversible, as noted above. Even with extensive reclamation plans in place, the quarry area will most likely have reduced biodiversity and nutrient cycling ability, reduced sources of food, fibre and energy, and diminished capacity for hydrological regulation.[82] Even if the environment was fully restored after reclamation, there would still be a considerable time lag during which ecosystems remained damaged and species were at worst driven to extinction.[83]

Therefore, while there has been progress and there is still potential to further minimize the impacts, claims of "nature-positive" operations should be rejected as outright greenwashing. Overall, the counter-measures of the companies amount to nothing more than cushioning the overwhelmingly detrimental impacts.

2.3 Air pollution

Producing cement and concrete leads to significant air pollution, bringing severe damage to ecosystems, workers, and nearby communities. We will first provide an overview over the causes and the nature of these damages (2.3.1), before reviewing the industry's possible counter-measures (2.3.2).

2.3.1 The causes and damages

There are three main types of air pollution from cement production: nitrogen oxides, sulphur oxides, and dust.

Nitrogen Oxides (NO_x) are a product of high-temperature reactions in the cement kiln, and originate from nitrogen compounds contained in the combustion fuels, especially coal.[84] The extent of these emissions is such that cement production is responsible for 7.8 % of nitrogen oxide emissions globally.[85] In elevated levels, these can damage people's respiratory systems and increase people's susceptibility to, and the severity of, respiratory diseases such as asthma or chronic lung disease.[86] NO_x are a major cause of acid rain, which damages plants, poisons rivers, and lakes, and speeds up the weathering of buildings, including those made of concrete.[87]

The second type of pollution is the emission of sulphur oxides (SO_x), which stem from sulphur compounds in both the raw materials that go into cement, and the combustion fuels. Similar to NO_x emissions, these can harm the respiratory system, especially in children and the elderly, and lead to acid rain.[88] Overall, the cement industry is responsible for 4.8 % of global SO_x emissions.

Figure 2.12: Dust from a Holcim plant in Figuil, Cameroon settles everywhere.

Source: Courtesy of Georg Njukeng, Greenpeace. Used with permission.

The third and most visible part of the industry's air pollution is dust. From the blasting and drilling in quarries to the milling of clinker, and from the trucks stirring up dirt roads to the batching of the final concrete, dust is created throughout every step of the production line.[89]

The harms caused by dust have several mechanistic causes. Airborne dust is not only a nuisance, but can affect ecosystems and therefore agriculture, as it settles on plants and soil, blocking out sunlight and reducing yields.[90] Particulate matter smaller than ten or even 2.5 micrometres can even enter the lungs and bloodstreams of humans and other animals, bringing severe harm.[91]

The chemical composition of dust can also be poisonous. For instance, silica dust, created by working with sand or some types of limestone, as is common in the industry, can cause silicosis, an incurable form of lung disease, as well as lung cancer, chronic obstructive pulmonary disorder, tuberculosis, and autoimmune diseases.[92] Cement powder itself, and the dust released from cement kilns, are both considered hazardous and capable of harming skin, eyes, and the respiratory system. Even single particles can sting the eye.[93] Depending on the raw materials and the fuels that are used in manufacture, cement powder and dusts released from kilns can contain high amounts of pollutants such as benzene, arsenic, and ammonia, as well as heavy metals such as chromium, nickel, cobalt, lead, and mercury (see also 3.2.3).

Any accumulation of heavy metals in soils can harm ecosystems far and wide over the long term. Airborne deposits can alter overall soil pH, affecting the availability of nutrients or increasing existing toxin levels in plants, thereby hindering plant growth. All these factors diminish food safety, biodiversity, and crop yields.[94]

In Switzerland, the cement industry made headlines when it was revealed that between 2007 and 2021 it had released about 240 tonnes of benzene, a known carcinogen, into the environment – in spite of the fact that the cement industry in Switzerland is considered to be already quite heavily regulated.[95]

A.6 Case study: Farmers vs. air pollution

Figure A8: Uroš Macerl at his farm.

Source: Courtesy of Goldman Environmental Prize.
Used with permission.

In Trbovlje, Slovenia, there had been longstanding concerns about air pollution from the local cement plant, owned by a subsidiary of Holcim. To power its kilns, the company typically burned petcoke, an oil refinery byproduct.

Locals had for a long time asserted that burning petcoke caused their drinking water to turn black, and that it reduced their agricultural yields to such an extent that farming became impossible. Local environmentalists, mainly surrounding the organization Eko Krog, organized a series of actions and protests against the company.

Things shifted gears, however, when Holcim was granted permission to incinerate waste materials at the plant in 2009.[96] The activists, led by farmer Uroš Macerl, led an extensive campaign against the company, and after several years of protests and legal action, the courts cancelled Holcim's permit to incinerate waste at the plant in Trbovlje.

Despite this, the cement company still continued with their plans, with no intervention from local authorities. It was only after the activists escalated their complaint to the European Commission that the Slovenian state did finally close the plant in 2015.[97]

Overall, the cement industry is responsible for the global emission of 5.2 % of all dust particles smaller than ten microns, and 6.4 % of all those even smaller than 2.5 microns. The industry is also responsible for causing 9 % of global mercury emissions – unsurprising, given that mercury is often contained in cement powder and dust.[98] At any specific production site, the quantity and the composition of the dust released depend heavily on the machinery, raw materials, and fuels used. Depending on the region and production method, such pollutants as volatile organic compounds, benzene, and carbon monoxide can also be emitted at significant levels.[99]

All of this adds up to considerable damages for communities near cement plants, due simply to the emission of dust. Such communities have often seen increases in cancer, preterm births, and a range of long-term health impacts manifested among children.[100] These effects are further exacerbated in two ways. First, cement and concrete production often occur adjacent to or right within cities, since such areas represent key centers of economic demand (see 1.5.2); but then the air pollution impacts more people. For example, in the smog and dust-ridden metropolis of Delhi, the sole act of batching concrete is estimated to be responsible for 10 % of all coarse air pollutants.[101] Second, cement plants, like many other industrial facilities, are often located close to low-income, disadvantaged communities, exposing them to a hugely disproportionate share of air pollution.[102] For instance, in the United States, sand mining, cement production, and concrete batching have all been shown to have a disproportionate and negative impact on low-income communities of colour, and they are most often situated in areas close to working class and disadvantaged neighbourhoods.[103]

Yet those who are most directly and intensely impacted by air pollution are the manual workers within the cement and concrete industry itself. These manual labourers are at significantly elevated risk of developing lung cancer and other lung-related diseases from the work that they do.[104] In the UK alone, it is estimated that 500 construction workers pass away every year due to silica exposure.[105]

2.3.2 The industry's counter-measures

It is possible to significantly reduce the industry's extreme air pollution. Especially in the European Union and in China, technical measures at quarries (like switching to conveyer belts and constructing windbreaks), at cement plants (like employing filters and dust-cycling systems), and at batching sites (like using ventilators or spraying water) are already increasingly employed.[106] Protective measures for workers have equally become more prevalent, including the use of respirators as well as mechanized equipment with enclosed cabs to protect the operators.[107]

As a result, most forms of air pollution from the cement industry in developed countries have been largely reduced – and it would be entirely feasible to deploy these measures globally.[108] However, that is not happening. As these measures bring additional costs to the manufacturers, they are only employed when companies are pressured to do so by authorities, which is very rare. In most cases, the legal guidelines are simply too lax or not enforced by local authorities, due to the industry's significant lobbying power. Local communities can protest for years or even decades without authorities intervening or improvements taking place.[109]

2.4 Heating, flooding, and sinking cities

Concrete is used in such high quantities that it defines many of the places we inhabit and move through: from our houses and offices to cross-country highways, dams, bridges, and tunnels. This gigantic deployment of materials is now imposing large-scale physical effects, and these are concentrated in cities that are heating up (2.4.1), sealed off from the soil (2.4.2), and sinking under the weight of construction (2.4.3).

2.4.1 Heating up

Anyone who has walked on a sunny concrete pavement can attest that concrete, like other mineral-based materials like stones and asphalt, absorbs and retains heat. On very hot days, such surfaces can even reach temperatures of up to 65 °C.[110]

In modern cities, where extensive amounts of mineral-based materials have piled up, this can significantly influence overall temperatures. When combined with increased urban sources of heat, with reduced quantities of vegetation, and the curtailment of surface water features such as ponds and streams, cities tend to warm up and retain heat more than their rural surroundings, giving rise to the so-called "urban heat island effect".[111]

The negative impacts of heat stress on comfort and human health can be extreme, with heightened risk of mortality in elderly populations and severe health impacts inflicted on children and people with disabilities. Poor and otherwise marginalized populations are more likely to be exposed to high temperatures, due to denser housing with less effective insulation or solar shading; restricted access to supplemental cooling, green spaces, and water features; and higher occupational risks of heat exposure.[112] Raised temperatures can additionally alter rainfall patterns and worsen air pollution by affecting air circulation – higher temperatures increase the amount of moisture the atmosphere can hold, intensifying evaporation and changing when and where rain falls. Higher temperatures also weaken or disrupt local wind patterns and thermal inversions, which slows the dispersal of pollutants. As a result, smog, fine particulates, and ground-level ozone accumulate more easily and persist for longer.[113]

On top of all that, global warming is increasing the frequency and severity of heatwaves. The combined risks for the future are forecast to affect roughly half of all urban populations, and they will be most pronounced in the growing mega-cities and coastal cities of Sub-Saharan Africa, South America, and India.[114] In Asia alone, roughly 3.5 billion people are forecast to be exposed to these increased risks by 2050.[115] The IPCC expresses "high confidence" that overheating in cities will heighten risks from pathogens and parasites.[116] In Europe, without steps taken to mitigate existing risks, the number of heat-related deaths could increase by a factor of fifty by 2100.[117] Meanwhile, these factors can exacerbate climate change: greater heat exposure means that more people will rely on supplemental cooling systems such as air conditioning, increasing the demand for electricity and (potentially) for fossil fuels.

Everywhere in the world, however, the solutions are similar. As we've argued and will continue to emphasize, many of the risks of extreme heat can be mitigated by reducing the amount of cement and concrete in the built environment, by using alternative materials, and by redesigning the buildings and cities that we live in (see 4.2, 4.3).

2.4.2 Sealing off

Throughout our streets, pavements, plazas, and buildings, the extensive use of concrete has sealed off large amounts of the earth's surface.[118] In 2018, the global extent of impervious surfaces was already roughly 2.5 times greater than it was in 1990, and now covers an area larger than Turkey.[119] Concrete plays a central role in this global expansion. These impermeable surfaces destroy the soil and ecosystems below and nearby; they carve walls between areas, fragmenting the landscape and its habitats, and leading to loss of biodiversity.[120]

Concrete also creates significant hydrological problems. Since concrete surfaces are largely impervious to water, they reduce water infiltration into the ground. This produces several hazards: diminished water infiltration, since water streams and runoff are redirected; soil erosion from increased and concentrated runoff; and increased risk of flooding, since excess surface water is confined in one place and channeled in large volumes. Such processes can also lead to many pollutants and biological contaminants being transported from cities into waterways, poisoning ecosystems and communities.[121]

These hazards have been heightened as a result of climate change. Increased frequency and severity of storms lead to more frequent and more destructive flash floods and coastal tidal surges, since the water has nowhere to go.[122] This can have devastating effects, directing massive streams of water with high force, high unpredictability, and an ability to quickly overwhelm areas, making these some of the deadliest kinds of natural disasters.[123] Sewer overflows are also more likely. As such, the increased incidence of urban flooding is forecast to exacerbate existing burdens of disease such as malaria, typhoid, and cholera. Those harms are likely to be compounded by damage to hospitals and interruptions to the delivery of essential medical goods, brought on by flood damage.[124]

When combined with sea level rise, the harms of impermeable surfaces are most acute in coastal cities, which face inundation from sea water. In informal settlements, which usually lack sanitation infrastructure, flooding carries even greater risk, undermining local food safety and security and disrupting livelihoods. As with overheating, all such harms are multiplied by the enlargement and concentration of urban populations, especially in the global south.[125]

Breaking up the concrete and replacing it with more porous materials or nature-based infrastructure can help with all of this. The construction industry has come up with several attempts to make more porous varieties of concrete – but these appear to be wholly unreliable, with short lifetimes of use, and requiring intensive and costly regimes of maintenance.[126] More realistically, impermeable surfaces should simply be broken up as much as possible. Urban design features such as increased greenery and sustainable urban drainage systems can reduce risks of flooding, improve stormwater management, and simultaneously mitigate the urban heat island effect (see 4.3.9). Current efforts are but a drop of water on a hot stone, as land continues to be sealed up at immense scales. In Europe alone, two square metres are still sealed off per second, while in recent years, Central Europe and Spain have experienced some of their worst floods in living memory.[127]

2.4.3 Sinking cities

The enormous volume of concrete, aggregates, and asphalt accumulated in cities is even causing coastal cities to sink under the weight of their buildings and infrastructure. With waters rising through climate change, this puts increasingly large areas at risk of inundation and flooding. When a study from the US Geological Survey examined the 48 largest coastal cities in the world, representing a fifth of the global urban population, 44 of those cities were found to have areas that are sinking faster than sea levels are rising due to increased weight, groundwater removal, and other factors.[128] This has led, for example, to Indonesia moving its entire capital city to a new purpose-built city, again involving intensive new concrete use.[129]

2.5 Excessive waste

Despite its strength and utility, the enormous volumes of concrete that exist in our built environment do not last forever. Modern concrete buildings and infrastructure have a limited lifespan (2.5.1), whether due to technical failures or elective demolitions enabled by the material's cheapness (2.5.2). Since concrete is seldom recycled (2.5.3), this has created the single largest source of human waste that the world has ever seen.

2.5.1 Cracking and corroding

Today's concrete is not as durable as it may seem. Heat, freeze-thaw cycles, carbonation (see 2.1.3) extensive vibrations, moisture, salt, and chemical exposure can all fracture and disintegrate modern concrete.[130]

However, concrete structures that predate the era of Portland cement have had exceptionally long lifespans. Perhaps the most famous examples of this are the surviving buildings of ancient Rome (see 1.4.2). Indeed, "mass" pours of modern concrete can also last a long time when implemented well. Concrete can even "self-heal" small hairline cracks since some cementitious materials always remain dormant within it and can be reactivated, provided that water is present for their hydration.[131]

But the adoption of reinforced concrete (see 1.4.3) introduced an Achilles heel into much of our built environment: rebar.[132] Rebar is almost universally made of steel, and steel corrodes when exposed to the elements. Some corrosion can actually help the concrete to adhere to the steel.[133] However, excessive corrosion degrades steel, and this impacts the concrete in which it is enclosed. Luckily, once rebar is embedded within concrete, it is substantially protected from this process due to the highly alkaline environment of the grey stone. Typically, regulations and building specifications require that concrete covers steel rebar to sufficient depth.[134] However, this protection lessens as concrete inevitably disintegrates over time: whether through carbonation, mechanical stress, or degradation due to unwanted chemicals, the protection breaks down and moisture is able to penetrate, eventually corroding the steel. Rebar can then expand as much as fourfold, causing even more cracks and eventually leaving either the tensile or compressive strength of the reinforced concrete too compromised to support the structure. The ultimate result is that the structures either get torn down or they collapse on their own, thus requiring new structures to be built.[135]

This creeping deterioration cannot be stopped but only temporarily arrested or stalled. As the historian and author Robert Courland writes:

> Almost all the concrete structures you see today are doomed to a limited life span. Hardly any of the concrete structures that now exist are capable of enduring two centuries, and many will begin disintegrating after fifty years. In short, we have built a disposable world using a short-lived material, the manufacture of which generates millions of tons [sic] of greenhouse gases. Most of the concrete structures built at the beginning of the twentieth century have begun falling apart, and most will be, or already have been, demolished.[136]

Figure 2.13: The Carolabrücke in Dresden, Germany, after a sudden collapse in 2024.

Source: SG-IMBTUDD, adapted under CC BY-SA 4.0 licence.
https://commons.wikimedia.org/wiki/File:Carolabr%C3%BCcke-Dresden-Einsturz-Br%C3%BCckenzug-C-2024-09-11-1200018_entwickelt.jpg

An additional complication is that concrete, like very many materials, is visually opaque, and this inevitably conceals from view its interior, its physical condition, and the state of its steel reinforcement. Reinforced concrete is in this sense a black box, or more literally a *grey* box.[137] This means that three additional challenges come into play.

First, the scale of damage can be more or less invisible from the outside. Unlike in bare steel structures, where rusting spots can be seen and easily maintained, the corrosion within reinforced concrete is largely hidden from view. This also makes the damage, if spotted, difficult and expensive to repair.[138]

Second, the exact composition of concrete is difficult to determine once set. Unlike bare steel, which is stamped and can be traced back to its origin, the composition of concrete can remain a mystery after construction.[139] This leaves significant room for tampering and mishandling of the material to go unnoticed, through construction mistakes, poor engineering knowledge, misspecification by the designer, or deliberate cost-cutting measures ("value-engineering") by engineers or contractors, to save on cement, steel, or other costs of construction. Such measures sometimes come at the expense of durability, but can be all but impossible to uncover in advance of a catastrophic failure.[140]

Third, even if the composition of a given mass of concrete is known, structures can deteriorate faster than expected due to historical design or engineering decisions that were flawed or based on limited knowledge. One historical example comes from the early use of high-strength cements that allowed for quicker curing, but that also ended up precipitating rapid and significant structural failures.[141] Another recent example is the scandal around reinforced autoclaved aerated concrete (RAAC) in the UK. In this case, the historical flaws of the material were already known in the 1990s, and yet successive governments failed over the course of the last two decades-plus to take sufficient steps to remedy thousands of affected buildings, most notably schools.[142]

In short, concrete structures are deteriorating, some quicker than others. Buildings with dry and temperature-controlled interiors may endure if well maintained, while structures exposed to sea water or sewage tend to last fewer than fifty years.[143] Moreover, for structures to survive even this long, they still require good levels of design, workmanship, and maintenance, all of which can be in conflict with short-term economic imperatives for low-cost construction and a care-free approach to the built environment. Even many dams, with their thick walls of concrete, are a pending risk. By 2050, more than half of the global population will live downstream from thousands of large dams near or past their intended lifespan.[144]

Globally, the economic cost of maintaining and replacing corroded buildings alone is enormous. Just in the United States, estimates suggest a bill in excess of USD 300 billion for the current stock of buildings, with a staggering 40 % of the underlying damage being the result of carbonation-induced corrosion (see 2.1.3). Worldwide costs of repairs due are estimated to exceed USD 1.8 trillion annually.[145]

The frailties too of concrete are forecast to become more acute with climate change – and as such, the costs of repair and replacement will also rise. Rising temperatures, humidity, atmospheric CO_2 concentrations, and more extreme weather will all speed up the deterioration of concrete and rebar.[146] This could generate repair and replacement costs in the EU of up to 1 % or even 9 % of GDP, if global warming rises to 2 °C or 3 °C respectively.[147]

Psychological costs have also followed, and they will continue to abound. While the great build-up of megaprojects and infrastructure may have brought a feeling of progress, their subsequent decay can invoke the feeling of being left behind and disempowered (arguably the perfect breeding place for right-wing politics).[148] And all too often, neoliberal austerity measures have led to failures in maintaining existing structures or conducting the most basic structural assessments. As this cycle of neglect persists, it can further fuel public resentment and political polarization, as communities witness the deterioration of public infrastructure without adequate government response.

If timely repair is not undertaken, or if faulty structures remain in use, then the impacts on human health and safety can be severe. The most sensational example of this is the catastrophic collapse of concrete structures without any prior notice, such as the collapse of the Koror-Babeldaob Bridge in Palau (1996), the de la Concorde overpass in Canada (2006), the Ponte Morandi in Genoa (2018), or the Carola bridge in Dresden (2024).

The construction industry has worked to mitigate all of the problems outlined above, within the limited means at its disposal. For instance, one alternative to steel rebar is noncorrosive reinforcement.[149] High (or "ultra-high") performance concrete mixtures are another solution, although they can come with larger upfront emissions during manufacture.[150] Another way to avoid steel rebar is pre- or post-tensioning (a.k.a., pre- and post-stressing), which uses steel cables ("tendons") to "squeeze" the concrete. Tensioning imparts enhanced tensile strength compared to the simple insertion of steel rebar. It reduces the risk of fracture and the quantities of concrete and steel that are required to perform a given engineering function. Pre- and post-tensioning have been around since the 1920s (see 1.4.3), and are already widespread. However, although more costly than standard rebar, both techniques could also be used more extensively. All such these mitigation strategies, moreover, only reduce the deterioration of concrete – they cannot get rid of it all together.[151]

2.5.2 Made for demolition

In reality, much concrete is wasted – not even because of structural deterioration but because functional structures are demolished and subsequently replaced. This can largely be attributed to the phenomena of throwaway architecture and throwaway construction, in which structures are often not built to last more than 50 years. The central drivers are profit maximization and superficial modernization over and above structural integrity. It is no accident that throwaway architecture is made with concrete.

First, concrete is an "abstract" material, and can be made to take on all kinds of forms (see 1.2). For this reason, it has emerged as the wonder material of modern construction, creating a sense of modernity, satisfying rapidly changing fashion trends, and fitting into the short investment cycles of so much commercial real estate.

Second, the cheapness of concrete and the reduced need for skilled labour mean that demolition and subsequent rebuilding are not as costly as they otherwise might be, permitting a throwaway attitude towards the built environment.

Finally, concrete's short lifespan is frequently not seen as a problem at all, since cycles of demolition and reconstruction move quicker than concrete's useful lifetime.

2.5.3 Downgrading and landfills

Consequently, construction and demolition waste piles up around the world. Every year about 10 billion tonnes of concrete are put to waste, totalling more than half of all waste produced around the globe.[152]

The issue here is that concrete is not readily reusable. Once it has hardened, it has transitioned from a malleable, workable material into a solid, rigid substance. The "liquid stone" has turned into veritable stone. To restore its original ability to be molded into any shape, one needs to grind it down into aggregate and then, once again, add new cement. Rebuilding with fresh, pourable concrete thereafter brings additional resource use and similarly high emissions, since the most carbon intensive step – cement production – is still needed all over again.

"Downcycling" demolition waste as aggregate in this way can save on the extraction of virgin natural resources and reduce the extent of demolition waste that goes to landfill. However, construction companies still usually prefer to use natural aggregates instead of ground-down old concrete. The main reason for this is that downcycled concrete still contains fragments of hardened cement and sand within the mix, and these make it perform worse mechanically than raw gravel.[153] Most often, old concrete is either landfilled or crushed to be used as aggregate for road foundations, filling excavated areas, or similar purposes instead.[154]

Some countries have made efforts to change their approach to concrete waste. For example, Japan has achieved a concrete recycling rate of 98 % through high-tech reprocessing plants and high fees imposed on landfilling.[155] Obviously, it would be far easier and less wasteful to just reuse hardened concrete elements, such as slabs, bricks, and walls. In reality, this is rarely done because almost none of today's buildings and infrastructures are designed for disassembly. This means that it's difficult or even impossible to detach parts without causing damage to both the component and the surrounding elements. Additionally, many concrete parts are already significantly cracked or carbonated, reducing their usefulness considerably. Finally, using old concrete elements that are often non-uniform requires more time, precision, and an ultimate "engagement with the specific building component on the scale of 1:1," standing in direct contrast to today's industrialized construction processes.[156]

Globally, the flows of concrete into landfills remain enormous, especially in countries undergoing rapid development. For instance, in Brazil, just 1 % of concrete demolition waste is reused.[157] On a global scale, a similarly negligible amount of concrete waste has been reused since 1995.[158] The result is excessive demand for land to store all that waste; copious dust; as well as preventable accidents surrounding landfills.[159] The overuse of concrete and its flagrant waste remain by far the most overt physical symptoms of a fossil economy working under the dictates of "take, make, waste".

2.6 Cementing power and exploitation

We have noted the physical properties of cement and concrete, their usefulness to society, and their usefulness to capital and state. It is no surprise, however, that concrete is associated with many systems of oppression: from walls of containment, to military encampments, and contemporary "starchitecture" for despotic regimes.

Here we begin by outlining the role of concrete in both heightening the scale and changing the nature of labour exploitation in the modern construction industry (2.6.1). After that, we look at the role of concrete in the conduct of modern warfare and occupation (2.6.2). Then we see how such principles of colonization carry forward into the mundane economic domain of property development, cementing power relations in the built environment at large (2.6.3).

2.6.1 Exploitation and subordination at the construction site

Construction, and the production of traditional construction materials, have long been sites of intense labour exploitation: think of Egypt's pyramids.[160] Today, according to the UN, construction materials (steel, glass, bricks, timber, stone, copper, iron, and minerals) are among those materials with "the highest risk of being made with forced labour".[161] From the mid-nineteenth century onwards, fossil fuels became a tremendous force multiplier for manufacturing in industrialized countries. The rise of Portland cement around the same time – and the later advent of reinforced concrete – brought further major advances in how much manufacturing and construction could be accomplished at scale (see 1.4.3).

Historically, building crafts such as stonemasonry, carpentry, and bricklaying were forms of skilled labour that retained a degree of autonomy and bargaining power. Craftspeople controlled essential construction knowledge and could collectively withhold their labour, an important source of leverage. The advent of concrete, however, began to erode this autonomy. Since modern concrete structures could be poured by largely unskilled or semi-skilled workers under centralized direction, and because these workers were not tied to any historical guild, employers and states were no longer as dependent on organized crafts.[162]

As Brazilian architect and historian Sergio Ferro has argued, capital and state used “concrete as [a] weapon” at the turn of the twentieth century to reorganize the construction process to their advantage. This “weaponization” was not militaristic but economic and social; by shifting power away from skilled workers towards managers, engineers, and contractors, concrete enabled a deeper division between mental and manual labour. The design and specification of materials was able to be done remotely by a new professional-managerial class,[163] while on-site labour was fragmented, deskilled, and rendered expendable. This transformation remains visible in the hierarchical organization of modern construction We have noted that the sheer scale of global construction activity has grown exponentially over most of the last 150 years - and the scale and pace of construction made possible by concrete has played a huge role in that. By implication, the advent of concrete has also helped drive a severalfold increase in the absolute scale of labour exploitation in the construction industry.[164]

Today, the construction industry employs roughly 160 million people internationally (7 % of the total adult labour force).165 2.8 million of those construction workers are in forced labour.[166] Many cases of forced labour in the construction industry involve migrant workers, who are trapped in such conditions as a result of extortionate recruitment fees and other unscrupulous and fraudulent practices on the part of employers and recruiting agents.[167]

One recent investigation estimated that a staggering 21,000 construction workers from Nepal, India, and Bangladesh have died since 2016 in Saudi Arabia while working on the country’s so-called “giga projects”. These are prestige projects, designed by some of the world’s leading contemporary architects.[168] Qatar’s treatment of migrant construction workers has been notorious, especially in the run-up to hosting the Football World Cup in 2022, with migrant labour comprising 99 % of Qatar’s total workforce and construction labour up to half of the total.

Far from home, hundreds of thousands are housed in “worker camps”; many have their salaries habitually withheld while building prestige projects.[169] In China, the total number of workers in construction is far greater still, with 45 million migrant workers drawn from the countryside to centers of urban development and often provided with no more than one square metre of living space per person.[170] Western countries are also culpable, with construction workers falling victim to human trafficking and a construction sector dominated by complex and opaque subcontracting systems that can fail to provide migrant workers with the same safeguards that domestic workers receive.[171]

2.6.2 The concrete-military industrial complex

Throughout its history, concrete has played a key role in military operations and occupations. We saw in Chapter 1 how concrete was used by the Romans for the construction of military fortifications. Similar uses have only multiplied in the modern era. One of the chief physical advantages of concrete is that it can be rapidly poured in place, quickly hardening to form synthetic stone. As such, it has also proven to be an ideal way to secure new “facts on the ground” in areas of dispute.[172] Once roads, settlements, or barriers are built, they transform geography into political permanence, consolidating occupation, control, and expansion, often faster than diplomacy or law can react.

A.7 Case study: Heidelberg Materials and Nazi Germany

Cement became a central material to warfare during the Second World War and was used extensively for bunkers and fortifications by Nazi Germany. The main predecessor companies of Heidelberg Materials profited greatly from the rearmament and construction programmes before and during the Holocaust. They supplied cement to build factories, autobahns, bunkers, airfields, and concentration camps.

The enormous Westwall (Siegfried Line) system of bunkers alone consumed around eight million tonnes of concrete – more than the infamous Hoover Dam in the United States. The Atlantikwall, constructed between 1942 and 1944 along the coasts of France, the Netherlands, Denmark, Norway, and Germany, consumed an estimated 12.5 million tonnes. These fortification programmes delayed the Western Allies' advance in 1944 and allowed the Soviet Union to reach Berlin first.[173] Between the pre-Nazi era and 1942, Germany´s cement output nearly tripled – from 4.5 million tonnes to between 12.5 and 13.5 million – saving Heidelberg Materials' predecessors from near-bankruptcy.[174]

Organisation Todt (OT), the Nazi regime's main construction organization, managed this vast building apparatus through forced and slave labour, involving levels of violence and murder that had previously been reserved for Europe's colonized peoples. OT employed approximately 1.4 million construction slaves, hundreds of thousands of whom perished under brutal conditions.[175] The majority were classified by the regime as "Untermenschen" ("subhumans"), largely from the Soviet Union, Poland and other parts of Eastern Europe.[176] The short period between 1939 and 1945 arguably saw the largest slave-based, industrialized construction effort in human history.[177]

In 2000, like many German corporations, Heidelberg Materials contributed an undisclosed sum to the 10 billion Deutschmark national compensation fund established for the few surviving victims of forced and slave labour, thus acknowledging some degree of responsibility for the use of forced labour.[178] Subsequently, the company published several official chronicles of its precursor firms. Each devotes only a few pages to the twelve years of Nazi rule and generally concludes that the company's collaboration was no greater than average.[179]

The directors of Heidelberg's cement works (Portland-Zementwerke Heidelberg AG) largely supported the Nazi party and Hitler's appointment as chancellor. The firm´s long-standing supervisory board chairman was Dr. Friedrich Schott; known as the "cement king" and an influential supporter of the "German people's party" *deutsche Volkspartei* (DVP), he was very conservative and anti-communist, but not a Nazi.[180] He died in 1931, before his DVP would support Hitler and vote for his dictatorship *(Ermächtigungsgesetz).* After his death his son Ehrhart, who had no party affiliation, inherited his position.[181] A recent company chronicle portrays Ehrhart as a near-opponent of Hitler, but available evidence contradicts this.[182] Schott was removed in 1933 from the company board not for political dissent but as part of an internal leadership dispute, replaced by Otto Heuer.[183] Heuer, who joined the NSDAP shortly before Schott's arrest on 1 May 1933, served as director until 1941. He was a member of the elitist "friends of the SS" *(Freundeskreis der SS)* and a leading figure in the national cement cartel *(Zementbund)*.[184]

The second "cement king" was Hermann Milke, founding member of Germany´s autobahn construction cartel STRABAG. Profits from autobahn construction enabled him to acquire a cement plant in Geseke in 1936 which went on to become one of West Germany's cement producers after the war and was partly acquired by Heidelberg Cement (Heidelberger Zement AG) in 1979.[185] Milke maintained close ties with Fritz Todt and participated in Organisation Todt projects across occupied Europe. Archival research indicates that his companies operated on *Durchgangsstraße IV* (or "Road of the SS"), a major road-building project in occupied Poland and Ukraine that relied overwhelmingly on Jewish civilians and Soviet prisoners of war working under exterminatory conditions *(Vernichtung durch Arbeit)*. Historians estimate that some 149,000 people perished along the 2,000 km route.[186] Archival and testimonial evidence indicates that Milke was involved in these work programmes and mass killings.[187]

Post-war legal proceedings in West Germany concerning the atrocities committed along *Durchgangsstraße IV* concluded after a decade without a single conviction. Many of the accused engineers, managers, and SS officers claimed to have no recollection of events, while surviving witnesses often lived in Poland or the Soviet Union and were rarely called to testify during the Cold War.[188]

Like many industrial corporations with roots in the Nazi period, Heidelberg Materials has addressed this history only in limited terms. Its public accounts acknowledge the existence of forced labour but remain largely silent on the involvement of figures such as Milke and Heuer or on the company's broader role in the rise of the Nazis to power, wartime economy or the Holocaust.

During European colonialism, concrete was both a material of domination and a symbol of "modernity." The French colonists in Algeria used concrete to extend the port of Algiers, one of the first civil engineering works made with concrete (and built by military convicts).[189] Similar ports, railways, buildings, and roads were also built throughout the French, British, Dutch, Japanese and Belgian colonies (again, by forced labourers in the millions).[190]

By the early twentieth century, the military significance of cement was already well understood. As the United States Geological Survey wrote in 1918:

> The military importance of cement can not be overestimated. It is used mostly as an ingredient in concrete, and concrete possesses great adaptability to a wide variety of uses. Besides being cheap, easily and quickly handled, sanitary, and durable, concrete is suitable for structures that are submerged as well as those in dry places, and all these characteristics taken together render it of great military importance. Among the military structures in which concrete is used are armories, barracks, roads, bridges, coast and interior fortifications, gun emplacements, trench linings, bomb-proof shelters, magazines for explosives, tunnels, retaining walls, sea walls, wharves, dry docks, water reservoirs, aqueducts, sewers, sewage-treatment works, incinerators, stables, floors, roofs, munition-factory buildings, warehouses, fuel-oil tanks, barges, ships, and structures in the interior of battleships. [191]

This enumeration captures how deeply cement had already become entwined with modern warfare, not just as a defensive material but as infrastructure for industrialized militarism itself.

More recently, military expert John Spencer argued that concrete itself is, "the most effective weapon on the modern battlefield".[192] The United States' war on Iraq (2003–2011) marked a turning point, with concrete barriers deployed widely for the protection of soldiers against improvized explosive devices. Spencer additionally describes how concrete barriers were used to interrupt the urban environment, walling in whole neighbourhoods for the purpose of dividing and containing insurgents, and limiting the movements of the population at large.[193] In Iraq, "concrete factories had to be found, built, and expanded in multiple places" across the country. "Getting concrete became as important a mission as emplacing it."[194] Today, the United States Army is actively pushing for innovation in the concrete industry, such as for the quick deployment of concrete buildings through 3D printing.[195]

Similar principles of occupation have been at work at a much larger scale in Palestine for many decades, with an extensive "architecture of occupation" built from concrete highways, settlements, and walls. Across the West Bank, ordinary elements of infrastructure function as technical tools of control and dispossession.[196] Under the guise of real estate development and the provision of amenities for settlers, land is enclosed, fragmented, and rendered inaccessible to Palestinians.[197] This is to say nothing of tactical demolitions, and of the aerial bombardment of the built environment, used against the Palestinian population.

A.8 Case study: Cementing the occupation

Previously occupied by Spain, much of Western Sahara has been occupied by Morocco since 1975, and is recognized by the UN as a non-self-governing territory that is still awaiting decolonization.[198] The Sahrawi are the Indigenous people of Western Sahara, who still comprise 30 % of the population in the Moroccan-controlled zone, and most of whom have been displaced from where they previously lived. Nevertheless, this does not prevent European cement companies from doing business in the region and providing essential materials that enable occupation infrastructures to be built and maintained.

There are three cement plants in the occupied territory of Western Sahara, all of them mills that use imported clinker. Two of the plants are majority-owned by Heidelberg Materials,[199] while one is jointly owned by Holcim and the Moroccan royal family.[200] Sahrawis have had no say in the set-up of these activities, nor do they share in any benefits. In effect, these cement plants directly facilitate the occupation: they produce the cement that allows settlement infrastructure and extractive operations to continue and expand. A recent example is Heidelberg Materials' provision of cement for the expansion of the port of Laâyoune,[201] which is essential for the large-scale export of phosphate, one of the Moroccan state's main sources of income from occupied Western Sahara.

Figure A9: Khadja Bedati from the Sahrawi youth speaks at the Heidelberg Materials shareholder’s conference.

Source: Private picture. Used with permission.

Numerous and repeated UN resolutions have asserted the right to self-determination of the people of Western Sahara and have called for a referendum on the future of the region, establishing a Mission to that end. Recent judgments by the European Court of Justice have additionally asserted the necessity of Sahrawi consent for any exploitation of the land and its resources.

However, no real change has happened. Instead, the cement giants have even expanded their business activities, with Heidelberg Materials having bought one plant in the area as recently as 2019. With renewed armed conflict ongoing since 2020 between Morocco and the Sahrawi Polisario Front, the cement giant’s stance appears to be simultaneously passive acquiescence and cynical complicity with the status quo. Heidelberg Materials has simply stated that, as a private company, it does not take a position on the status of individual territories under international law.[202]

2.6.3 Bullshit construction and demolition

A similar logic of colonization through concrete can be seen the world over. It is there wherever land is forcibly taken from one set of people and given to another, and concrete is poured in place to secure those facts on the ground. Often it goes hand in hand with sweeping demolitions and displacements to make way for construction that serves only elite interests.

Heinous examples can be found almost anywhere on the globe. Such developments are often considered to be merely “economic” in form. However, they have an acutely political nature, and constitute the conduct of warfare by other means. We term such developments “bullshit construction”. Meanwhile, the unnecessary demolitions that demolish communities, simply to make way for bullshit construction, comprise “bullshit demolition”. Each serves the role of cementing power relations and inequality in the world at large.

The Global North is replete with examples of bullshit construction and bullshit demolition, but so too is the Global South. One such place is Lagos, Nigeria, where millions live crammed into slums with few amenities. “The amount of buildable land far outstrips the state’s housing needs, and [yet] the government itself seems invested only in the housing needs of the rich,” writes Adéwálé Májà-Pearce. Wherever existing slums are deemed to be situated on prime real estate, the neighbourhoods can be demolished, their inhabitants threatened, displaced, and killed. Luxury developments are built where the poor once lived.[203]

Banana Island, an entire gated district of Lagos, and “the most expensive neighbourhood in Nigeria”, is home to the current president of Nigeria, as well as Aliko Dangote, Africa's richest man and the principal owner of Dangote Cement (Africa's largest cement company).[204] Eko-Atlantic, presently under construction, is another such mega-neighbourhood planned as a closed enclave, this time promising to provide "environmentally friendly housing" for 250,000 people, at USD 500,000 apiece for an apartment, and five times that price to buy a house.[205]

In India as a whole, meanwhile, more than 500,000 people were forcibly evicted from their homes in 2023 alone. "Slum clearance", "beautification", and removal of "encroachments" are common reasons given for such forced evictions.[206]

2.7 It all adds up

The overall damages caused by cement and concrete are immense. The cement and concrete industry is a major contributor to air pollution and biodiversity destruction, while accelerating exploitation and leading cities to sink and heat up.

One 2020 study assessed that even just the health costs from the cement industry's emissions of carbon dioxide and air pollutants amount to USD 335 billion every year. This translates into USD 20 – USD 110 per tonne of cement produced, depending on the region. In some countries, like the US, these costs even surpass the economic value of cement itself, raising the question of whether the cement industry could be considered socially bankrupt.[207]

Several further damages caused by the material should also be mentioned.

The first is the significant water consumption of the industry. Large amounts of water are needed along the production line of concrete; not only as a constituent of concrete (2 billion tonnes annually), but elsewhere in the process too. For instance, huge amounts of water are used during the production of the energy used in cement and concrete manufacture (5 billion tonnes annually) – for example, for washing fuels. Moreover, enormous quantities of water are used during the extraction of sand and gravel (7 billion tonnes annually), where water is needed for dust control and washing. Overall, the production of cement and concrete for the construction industry is responsible for about 9 % of all global industrial water withdrawal (or 1.7 % of total global water withdrawal). While conflicts surrounding this issue are currently rare, they will probably increase in the future. This is especially the case for low-income countries experiencing both booms in construction and increasing water scarcity.[208]

The second other source of significant damages from the use of cement in construction concerns impacts on cement and concrete workers' health beyond the harms caused by air pollution (outlined above, see 2.3). These harms are largely typical of such an industry, with most of them (notably musculoskeletal disorders) arising due to the manual handling of materials (for example, bags of cement), and an overall higher burden of risks associated with the use of the heavy machinery and explosives. When the Building and Wood Workers' International did a survey among the cement industry across 40 countries, they found that, across the companies surveyed, one in-work fatality happens every three days. In addition, in more than 30 % of inspected cement plants, at least one in-work fatality had happened in the last three years.[209] According to a report for the International Labour Organization (ILO), in-work risks to health are made worse by the increase in subcontracting. In the cement industry, these involve undertaking core operational activities, such as quarrying, maintenance, logistics, or cement production. Once again, this problem is especially acute in the Global South.[210]

A.9 Case study: Fishermen fighting back

When an Indonesian subsidiary of Heidelberg Materials expanded a port for its cement plant in Tarjun, excavated rock was dumped illegally in the sea nearby over a period of more than two years. Fishing nets owned by local fishermen were severely and repeatedly damaged, and this imposed heavy costs and loss of income that impacted their livelihood.

After two years, and with their complaints going nowhere, the fishermen went into action. In June 2004, together with students and activists connected to Friends of the Earth, they blocked the company's jetty for a week with a clear demand: stop dumping waste on the community's fishing grounds. The blockade was met with repression from the state, with several activists and fishermen arrested and allegedly beaten. However, it was successful: Heidelberg Materials thereafter disposed of the excavated rock elsewhere and insisted that a contracted company was to blame.[211]

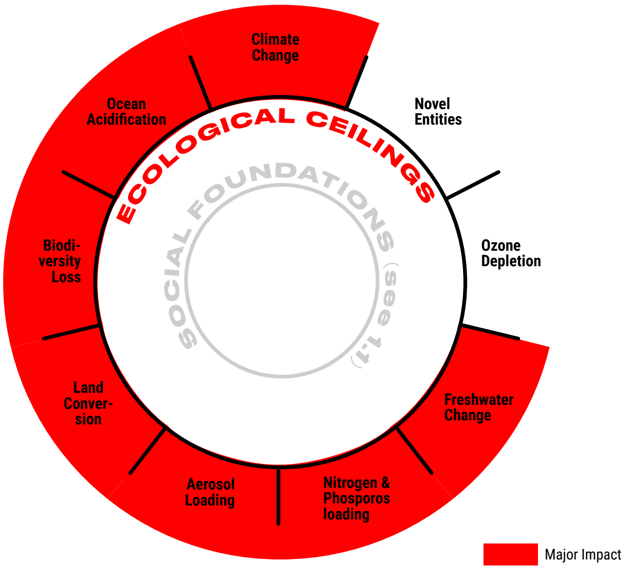
Other aspects of production include the inequality within the cement industry's workforce,[212] the impact of production noise and water pollution on surrounding communities (beyond those associated with quarrying activities – covered in 2.2.1),[213] and the problem of production wastes (besides greenhouse gas emissions, and other air pollutants – covered in 2.1 and 2.3).[214]

The cement giants have additionally faced accusations of cartel agreements, corruption, tax evasion, and even support of terrorism to keep their businesses running.[215]

Damages from the use of these materials may also include the impacts of excessive concrete within oceans.[216] Concrete affects our mental health.[217] It also causes joint problems within cities, as the hard, unforgiving surfaces lead to conditions like plantar fasciitis and other musculoskeletal issues from prolonged walking and standing.[218] Over-use of concrete (a poor insulator) has sidelined the use of passive temperature control mechanisms. Moreover, it has led to an over-reliance on supplemental heating and cooling systems (with all of the excess energy use that it necessitates), and to an over-reliance on industrially-produced thermal insulation materials.[219]

To understand how significant the damages caused by these materials' use and production are, it can be helpful to view their impact on the planetary boundaries or ecological ceilings of our modern societies. Overall, seven out of nine planetary boundaries are significantly impacted by the widespread use of cement and concrete, as shown in Figure 2.14.

Figure 2.14: The impact of cement and concrete on ecological ceilings. Their importance for social foundations has been assessed in chapter 1.1 (authors' illustration).[220]



Of course, the industry's response to these damages is limited at best. When it comes to damages from end-use, they tend to deny responsibility altogether – with prestigious and "sustainable" projects promoted extensively on their websites. Concerning production damages, the industry does employ technological measures – such as dust suppression systems, air filtration equipment, and water treatment facilities. However, they only do so to the minimum required level to comply with state guidelines or to keep protests at bay (see 2.2.3 and 2.3.2).

Climate emissions are the only area where the cement industry seems to have taken on a more proactive role, which we will critically discuss in Chapter 3.

Endnotes

1 Watari, Cao, et al. 2023; Friedlingstein et al. 2023. Total greenhouse gas emissions also include all anthropogenic emissions of for example methane, based on estimated CO2-equivalent values of 100-year global warming potential. Note that climate change is fueled not only by direct emissions, but also by other factors such as changes in land use.
2 Watari, Cao, et al. 2023.
3 Watari, Cao, et al. 2023; Friedlingstein et al. 2023.
4 Authors' calculations, based on C. Chen et al. 2022; MCC 2024.
5 Data until 2020 from Watari, Cao, et al. 2023. Authors' estimates after 2020 based on Watari, Cao, et al. 2023; Friedlingstein et al. 2023. Note that two further sources of greenhouse gas emissions are excluded here. The first are the emissions from steel rebar, which add a further 300 – 400 Mt of CO_2 per year (see Kwon et al. 2021). The second are the effective emissions caused by loss of Karst areas as carbon sinks through limestone quarrying; however, no reliable data presently exist for the extent of those losses (see Goldscheider 2019).
6 Huang et al. 2023.
7 Watari, Cao, et al. 2023.
8 Zhi et al. 2021.
9 Authors' calculations based on USGS 2022; Watari, Cao, et al. 2023.
10 Van Oss & Padovani 2002. Aside from CO_2, cement manufacture produces only negligible amounts of other greenhouse gases.
11 Friedlingstein et al. 2023.
12 Friedlingstein et al. 2023; Holcim 2024.
13 Data from Friedlingstein et al. 2023; Heidelberg Materials 2024a; Holcim 2024; Cemex 2024. Scope 1 emissions include direct emissions from calcination, the combustion of kiln fuels, and emissions from fossil-fueled company trucks. Scope 2 emissions comprise the indirect combustion emissions from purchased electricity. Scope 3 emissions are all other indirect emissions, such as from electricity transmission, bought raw materials or company investments.
14 ECCHR 2024.
15 Authors' calculations, based on Friedlingstein et al. 2023; Watari, Cao, et al. 2023.
16 C. Chen et al. 2022.
17 Authors' calculations, based on Friedlingstein et al. 2023; Watari, Cao, et al. 2023.
18 Cook 2021: 10.
19 Smil 2014.
20 Data from Czigler et al. 2020.
21 Climate Case Chart 2024.
22 Les Soulèvements de la Terre 2024.
23 EJOLT 2023; Lapuente Tiana 2024.
24 Cao et al. 2020.
25 Cao et al. 2020; Watari et al. 2022. In the case of Japan, it is estimated that in-use concrete stocks contribute 74 % of total carbonation; 22 % comes from demolition waste; 4 % comes from cement kiln dust, plus cement wasted (not used) at construction sites.
26 Van Roijen et al. 2024.
27 Van Roijen et al. 2024; Xi et al. 2016. Humidity, concrete porosity and other factors can also play a role.
28 Van Roijen et al. 2024.
29 Data from Friedlingstein et al. 2023; Goldscheider 2019; Van Roijen et al. 2024; Watari, Cao, et al. 2023.
30 Van Roijen et al. 2024.
31 Van Roijen et al. 2024; Watari, Cao, et al. 2023.
32 Peng & Steward 2016, cited after Dimova et al. 2024: 79.
33 Berg 2021.
34 Carrasqueira et al. 2024. Note that much of the gravel is limestone as well.
35 Watari, Cao, et al. 2023.
36 Data on sand, gravel and fossil fuels from Watari, Cao, et al. 2023. Data on limestone calculated using the calcination emissions from Friedlingstein et al. 2023.
37 Exemplary numbers for the mining of different materials in Brazil can be accessed in the supplementary material of Ruiz et al. 2023.
38 Cooke et al. 2024; Han et al. 2023; Torres et al. 2017.
39 IUCN 2024; Torres et al. 2022.
40 IPBES 2019; Hatfield et al. 2025. The prevailing scientific conception of "mass extinction" defines it as 75 % of species becoming extinct in less than a period of 2 million years.
41 Carrasqueira et al. 2024.
42 Goldscheider 2019.
43 Goldscheider 2019.
44 Goldscheider 2019; Langer 2001.
45 Goldscheider 2019; Langer 2001. For example in the Belgian city of Tournai about thirty sinkholes opened up along the river probably as a result of limestone quarrying connected to a cement plant that was recently acquired by Heidelberg Materials. This led not only to changing terrain but again impacted the groundwater quality, since contaminated river water could then flow into the karst aquifer.
46 Goldscheider 2019; Piccini et al. 2019.
47 Maksimovich & Khmurchik 2015.
48 Confino 2014.
49 S. L. T. Tong 2021; Whitaker 2022.
50 Sunarya 2019; Swaragita 2019.
51 Goldscheider 2019; Langer 2001.
52 Koch & Abraham 2021. For instance, Heidelberg Materials has faced serious accusations of land grabbing by communities in Togo and Indonesia.
53 This case study is based on Berrill & Vavryn 2008; Gistitin 2010.
54 This case study is based on Kunz et al. 2024 and a personal interview with Gunreto from the Sedulur Sikep.
55 Schott 2018.
56 John 2021.
57 Rentier & Cammeraat 2022; UNEP 2022.
58 Torres et al. 2017.
59 Bendixen et al. 2021.
60 Marsh, A. T. M. et al. 2024.
61 Caserini et al. 2022.
62 Abdallah & de Leeuw 2020.
63 Abdallah & de Leeuw 2020.
64 Buxbaum 2022.
65 Weizman 2007.
66 Heidelberg Materials 2023.
67 Who Profits 2023.
68 Levinson 2016.
69 Heidelberg Materials 2023.
70 Human Rights Watch 2016.
71 Poppe & Schäfer 2020.
72 AFSC Investigate n.d.
73 One Climate n.d.
74 Lubanov & Raz 2020.
75 Torres et al. 2017; UNEP 2022.
76 Bendixen et al. 2021.
77 Bisht & Gerber 2017 cited after Bendixen et al. 2021.
78 Aduda & Bolf 2024; Jensen 2020.
79 Heidelberg Materials 2024a; Holcim 2024.
80 Burman 2020; Confino 2014.
81 Confino 2014.
82 Ruiz et al. 2023.
83 Burman 2020.
84 Van Oss & Padovani 2003.
85 Miller & Moore 2020.
86 US EPA 2024.
87 Dimova et al. 2024; J. Guo et al. 2023; Hasanbeigi et al. 2022; Xie et al. 2004.
88 Hasanbeigi et al. 2022; US EPA 2023; Van Oss & Padovani 2003.
89 Koh et al. 2011.
90 Adeyanju & Okeke 2019; Iqbal et al. 2024.
91 Sairanen et al. 2018; Van Oss & Padovani 2002.
92 HSE 2024; Ronsmans & Nemery 2019.
93 Al-Bakri et al. 2022; A. T. M. Marsh et al. 2024; Wüthrich 2020.
94 Adeyanju & Okeke 2019; Iqbal et al. 2024.
95 Niederhäuser 2023.
96 Eko Krog n.d.; Zivcic 2021.
97 Cemnet 2019. Since 2019, Holcim has been seeking a new permit for the plant, but only as a grinding facility.
98 Knight et al. 2023; Miller & Moore 2020. On top come additional emissions from the end-use of cement, especially motor vehicle infrastructure.
99 Van Oss & Padovani 2003.
100 Adeyanju & Okeke 2019; Raffetti et al. 2019.
101 Safi 2017.
102 Hasanbeigi et al. 2022.
103 Marsh, A. T. M. et al. 2024.
104 Adeyanju & Okeke 2019.
105 HSE 2024.
106 Langer 2001; Yan et al. 2024.
107 BWI 2016.
108 Raffetti et al. 2019; Yan et al. 2024.
109 Leukhardt 2018; Niederhäuser 2023; Oberschelp et al. 2023; Wüthrich 2020.
110 Zafra 2023.
111 Susca & Pomponi 2020; IPCC 2022b: 922.
112 S. Chen et al. 2024; IPCC 2022a: 924.
113 S. Tong et al. 2021.
114 S. Tong et al. 2021.1.

115 IPCC 2022b: 80.

116 IPCC 2022b: 913, 2018: 9.

117 S. Tong et al. 2021.

118 Scalenghe & Marsan 2009.

119 Gong et al. 2020. Roughly 320,000km^2 in 1990, and roughly 800,000 km^2 in 2018.

120 Ibisch et al. 2016; Scalenghe & Marsan 2009.

121 Scalenghe & Marsan 2009.

122 Anees & Kapir 2024.

123 Anees & Kapir 2024.

124 IPCC 2022b: 926.

125 IPCC 2022b: 925.

126 Xie et al 2019.

127 EEA 2019; Maskell 2024; Latona 2024.

128 Parsons 2021.

129 Winkless 2023.

130 Wan-Wendner 2018.

131 Seymour et al. 2023. Cracks of up to 0.20mm can self-heal in this manner, if the perpendicular movement of the crack also remains tiny.

132 Dimova et al. 2024.

133 Fu & Chung 1996. Surface corrosion gives steel rebar its characteristic orange stain.

134 See, for instance, European Union 2004: 49–52.

135 Courland 2011: 320-321; Gagg 2014.

136 Courland 2011: 23.

137 Gross 2019.

138 Courland 2011: 321.

139 Gross 2019.

140 Langfitt 2012.

141 Courland 2011: 328-329.

142 Merritt 2024; Booth 2023.

143 Courland 2011: 321-329.

144 Perera et al. 2021.

145 Dimova et al. 2024. Note that the United States number also includes corrosion of for example cars. However, as this number is more than 20 years old the costs are more than likely to have significantly expanded.

146 Bastidas-Arteaga et al. 2022; Mishra and Sadhu 2023 cited after Miller et al. 2024.

147 Dimova et al. 2024.

148 Deppisch 2021.

149 Heber et al. 2024; Miller et al. 2024. For instance, carbon fibre-reinforced polymer bars.

150 Miller 2020; Stengel & Schießl 2014.

151 Billington 1985: 202-203; Intaç 2023; Marrey & Grote 2003; Ray 2018. With pre-tensioning, the cables are laid directly inside the concrete formwork, and stretched (put under tension) prior to the concrete being poured; once it sets, the cables are released. In the case of post-tensioning, the cables are fed through channels in concrete that has already set; once stretched and fixed in place, they "squeeze" the concrete.

152 Wiedenhofer et al. 2021.

153 Miller et al. 2024.

154 S. Griffiths et al. 2023; Tam 2009.

155 Tam 2009.

156 Stricker et al. 2021: 278-279. Translation by the authors.

157 Gross 2019.

158 Wiedenhofer et al. 2021.

159 Elinoff et al. 2017, cited after Imrie 2021: 30. One notorious example is a landslide of landfilled construction waste in Shenzhen, China, in 2015. The landslide spanned 25 acres, destroying 33 buildings and killing 73 people.

160 Allen 2005; Lewis 2016; Pasley 2019. Many monuments and buildings in Washington DC were constructed using slave labour, with slaves put to work in marble and sandstone quarries, and as skilled masons, as well as as carpenters, plasterers, joiners, painters and glazers.

161 UNEP 2023a: 41.

162 Ferro 2017.

163 Ehrenreich & Ehrenreich 1977; Walker 1979. For a study of these shifts, in the context of construction in the United States, see Slaton 2001.

164 As noted above, forced labour is widespread in construction, and in relation to the sourcing of materials for construction, whether or not concrete is involved.

165 ILO 2023; World Bank 2023. The global labour force stands at roughly 3.6 billion people, with a 61 % labour force participation rate.

166 ILO 2022: 31-34. Out of all sectors of the economy, the construction sector has the largest proportion of its workers in forced labour. The service sector, however, contains by far the greatest absolute number of workers in forced labour.

167 ILO 2022: 32.

168 Spocchia 2024.

169 Amnesty International 2023; Gulf Labor Artist Coalition 2017, 2019; WBYA? 2017. Prestige projects in Qatar include buildings by Zaha Hadid and Rem Koolhaas. See also the case of Abu Dhabi, with its programme of Western "satellite" museums, including the Louvre Abu Dhabi and Guggenheim Abu Dhabi.

170 WBYA? 2017: 29.

171 Davies et al. 2024; Deleu 2023; Ollus 2024; Assmus et al. 2024.

172 El-Haj 2001; Stolzenberg 2009; Tan 2019. The term "facts on the ground" is used to refer to potentially irreversible actions on a territory (e.g. settlement construction, military occupation) that shape the de facto status, regardless of legal or rhetorical claims.

173 Tooze 2006.

174 Tooze 2006, Cramer 2013: 64-68.

175 Gruner 2006.

176 Dick 2020: 2-8; Gogl 2020.

177 Césaire 1972: 36.

178 10 billion DM was worth roughly 5 billion USD in December 1999. Today it would be worth about 9.5 billion USD.

179 See for example Dietmar 2013: 101. See also the publications at www.heidelbergmaterials.com/en/company/heritage.

180 Birkle, Karola und Heidelbergement AG, Leben und Werk des Zementpioniers Friedrich Schott, Heidelberg 2021: 50f.

181 Birkle 2021

182 Cramer, Dietmar, Eszter Harsanyi, HeidelbergMateriasl, Die Geschichte von Heidelberb Materials, Heft 15, Heidelberg 2023: 66

183 That careerists joined the NSDAP to force out non-party members from desired posts was a rather common occurrence. However it did not mean that they were not also antisemites, racists, anti-communists, in one word, real Nazis. Many of those after the war portrayed themselves as the much lesser evil, only careerists, not ardent Nazis. They were threatened by conviction and jail. It is difficult from todays perspective to determine exactly who was a "real" Nazi and who a careerist *(mitläufer)*.

184 Cramer 2013: 91-92.

185 Harsányi & Cramer 2019: 35, 53, 67.

186 For the Holocaust by bullets in the east and also at the road building sites, see Angrick 2004. For the death number and an overview of the whole DG IV, see Sandkühler 1996 and Kunze 2022: 229 – 274. In Poland, few survived by fleeing or being transferred to less deadly sites. They were "owned" by the SS, or precicely, by the Kommissar der Polizei und SS in Poland, Prützmann in Ukraine, and Generalgouverneur Katzmann in Poland. The SS leased detained persons to the construction companies. Historical research shows that a person named Milke, very likely Hermann Milke with his road construction company, "rented" Jewish slaves from the Ghetto in Łeczna in Poland: "In August 1940, the SS arrived in consecutive weeks [in the Ghetto of Łeczna] to conscript Jewish men for labour in camps. Local ethnic Germans, led by Becker and Milke, rounded up conscripts during the first raid in which they were marched to a nearby labour camp, likely in Milejów, established for road construction work." Megargee 2009: 668. Note that, unlike in the case of Łeczna in Poland, documentation is scarce about Milke's role in Ukraine. There are few documents that allow for accountability of the atrocities to particular German officers, and construction companies´ mangers. Nevertheless, thanks to Soviet records made available recently, we now know that in 1944 survivor Raisa Pustylnik (just liberated by the Red Army), recalled precisely how 475 Jews had been transferred from Milke´s road works on second Christmas day, 26th December 1942, to their site of execution and mass burial with the help of "German cars" ("немецкие машины"). This was part of the liquidation of the Shirokoe concentration camp (Schirokoe, Schirokoje, Широкое) in district Novi Rig, south-west of Dnipro (Dnjepopetrovsk). While it is not possible to determine beyond any doubt whether these were Herman Milke's vehicles or whether he was personally involved, the evidence points to company-level participation in the system of forced labour and mass killing characteristic of Organisation Todt operations in occupied Eastern Europe. См. протокол допроса свидетеля Пустыльник Раиса Юдковна 8 февраля 1944 г. (ГАРФ, ф. 7021, оп. 149, д. 36 лл. 87-88). Quoted from Kruglov et al. 2016: 165.

187 It was indeed common practice for "many construction companies to permit the SS to use their car fleets to transport Jews to their shooting" and 475 victims suggests a lot of assistance. It was also common for companies to refuse assistance. See Sandkühler 1996: 14. In the Sofiyivka region in Ukraine a pre-war population of 130,000 Jews perished. The mass graves, mass shootings, misery of Jews and Soviet POW must have been visible most of the time to most people, as survivors like Arnolt Daghani documented beyond doubt. Milke, like all members of the companies, knew what he was doing and what was happening. See Daghani 1960 and Kruglov et al. 2016: 147-166.

188 One witness, Arnolt Daghani, lived in England and did appear in court as a witness only to be bitterly disappointed by the result: not a single sentence against any of the accused. A paucity of material evidence remaining made it furthermore difficult to connect atrocities to names, and justice was decided instead by the accused. See Daghani 1960.

189 Forty 2012: 232.

190 Salvaing 2020.

191 Quoted in Lesley et al. 1924: 182-183.

192 Spencer 2016.

193 Spencer 2016. "This reduced the ability of insurgent forces to create mass-casualty events with IEDs and disrupted their ability to move freely or resupply forces. Walling off troubled neighbourhoods became the daily mission." Spencer notes similar strategies of counter-insurgency by the French during the Battle of Algiers (they, "cordoned off the entire Casbah and its 100,000 inhabitants"); and by the British in Malaya (now Malaysia), in the 1950s.

194 Spencer 2016.

195 Aouf 2018.

196 Weizman 2007: 4-5,63,80-81. The original architects of this programme, initiated during Menachem Begin's Likud government (1977-1983), were general-turned-politician (and future prime minister of Israel) Ariel Sharon, and the (actual) architect Avraham Wachman. "Ariel Sharon's rapid, albeit not untypical, transformation from a popular military general to minister in charge of settlement activity in the first Likud government of 1977 allowed him to translate military doctrine and the principles of a dynamic battlefield into planning practices of civilian settlements".

197 Weizman 2007: 19. Palestinians are systematically separated from one another, and from their land and livelihoods, but also from ready access to wells and aquifers. Water access is further restricted via a "politics of verticality" that restricts subsoil sovereignty: "Israeli [water] pumps may reach down to the waters of the common aquifers whilst Palestinian pumps are usually restricted to a considerably shorter reach."

198 UN 2024. This case study is largely based on Zaragoza 2021.

199 Ciments du Maroc n.d.

200 LafargeHolcim Maroc 2024.

201 Ciments du Maroc n.d.

202 Heidelberg Materials 2024c; Association of Ethical Shareholders Germany 2019.

203 Májà-Pearce 2023. A notorious example is the case of Maroko, an old slum neighbourhood on Victoria Island. In 1990, evictions and demolitions were announced just a week in advance, over the radio. "When the day arrived, women and girls were raped, property was looted, and an unknown number were killed in the ensuing mayhem." Residents were told they would be rehoused in public housing, but nothing came of it. "Today, Makòko is called Victoria Island Extension, and the only poor to be seen are the servants employed in the mansions that have since sprung up."

204 Nsehe 2011.

205 Májà-Pearce 2023.

206 HLRN 2024: 10, 18.

207 Miller & Moore 2020.

208 Miller et al. 2018.

209 BWI 2016.

210 Kukathas 2024.

211 Friends Of The Earth 2004; Indocement n.d.; INSAN 2009.

212 A. T. M. Marsh et al. 2024.

213 The Greens/EFA 2021.

214 Abdul-Wahab et al. 2021.

215 Kuepper et al. 2020; Wüthrich 2020.

216 Heery et al. 2017.

217 Hanley 2019.

218 Beech 2019.

219 Jappe 2023: 82.

220 Based on Raworth 2017; Richardson et al. 2023. Both climate change and ocean acidification are impacted by the CO_2 emissions of cement manufacture (2.1). Biodiversity loss and land conversion are primarily impacted by the extraction of materials (2.2), and by the use of concrete to seal up soils (2.4). Aerosol loading is increased by the industry's emissions of small particulate matter, while atmospheric nitrogen loading is intensified by the industry's NOx Emissions (2.3). Finally, freshwater change follows from the withdrawal of water along the entire value chain of cement and concrete production (2.7), including specific impact on Karst water systems (2.2).

3 The cement industry's climate response

As global attention towards the climate crisis and its causes has risen, so has the pressure on cement companies to respond. All major cement companies and industry associations now have extensive public relations messaging about their climate achievements and have set net-zero carbon goals with roadmaps to achieving them.[1] Heidelberg Materials, for example. proclaims itself "determined to build a more sustainable future" and a pioneer the industry's advances towards net-zero emissions.[2] But decarbonizing a production process so deeply reliant on both fossil fuel combustion and the chemical transformation of a fossil material, limestone, is an enormous task – which raises important questions: how true are their claims? And what have they really done to date?

In this chapter we'll therefore take a look at how the lobbying of the industry has slowed down effective climate regulation (3.1) and how, as a result, the incremental measures that the industry has employed have been easily overwhelmed by rising production (3.2). Then, we'll examine how the industry's future roadmaps are reliant on highly uncertain and risky projections of Carbon Capture and Storage (3.3). We then discuss how the industry frames its climate mitigation efforts (3.4). Note that we focus here on the steps the industry is taking to reduce the scale of its greenhouse gas emissions – and we set aside its various other (frequently lacklustre) measures to mitigate the other harms of production (on which, see chapter 2). We show how the industry overpromises and underdelivers on greenhouse gas reductions, despite enormous subsidies. Similar to most industries, it advances highly unproven techno-fixes, in a desperate effort to shore up and retain its ecologically unsustainable production model.

3.1 Lobbying

Since the Kyoto Protocol climate policy negotiations of 1997, the cement industry has pursued a proactive public messaging strategy on emissions, through its main lobby organization, the Global Cement and Concrete Association (GCCA). This has involved officially acknowledging the challenge of climate change and claiming that the industry is doing its utmost to address it through technological measures. A Global Cement Sustainability Initiative was established, and all major companies, including Heidelberg Materials, started to produce CO_2 emission reports, voluntary emission goals, and of course excessive public relations work.[3] However, when things got serious, they lobbied vigorously against significant climate regulations.

3.1.1 Profits instead of regulation

This is exemplified first and foremost by the European Cement Association's (Cembureau) opposition to the European Emissions Trading Scheme (ETS). The ETS was the first climate legislation with the potential to significantly impact the cement industry. By establishing a carbon market while setting an emissions cap, it aimed to encourage the industry to invest in clean technology and phase out dirty technology.[4]

Despite its official endorsement of carbon pricing schemes, the Cembureau, like many other industry associations, has, since the early 2000s, successfully lobbied to nullify its impact. Benchmarks for the cement industry were set low and the European cement giants received free emission certificates far exceeding their actual emissions.[5] This ensured that there was very little financial pressure on the industry to implement changes. Instead, they were able to generate significant profits by selling their surplus certificates on the ETS market. Just between 2008 and 2014, the cement industry made over 3 billion euros from these excess certificates, more than any other industry.[6]

One of the main arguments used by the cement industry was that costly certificates would render the domestic cement industry uncompetitive, and that it would lose out to foreign companies able to export cheaper cement into Europe, unburdened by the ETS or a CO_2 price. But while a carbon border adjustment mechanism has now been introduced by the EU in 2023, the Cembureau, like other major polluting industries, still spoke out against the expiration of their free allocations.[7] Additionally, the cement industry was heavily involved in the recent corporate backlash that "fought tooth and nail against [the EU's] climate policies" and successfully watered down the EU's climate ambitions.[8] However, despite their lobbying, free allowances for the cement industry are finally coming to an end, albeit only after a drawn-out period of reduction: the cement industry will only face zero free allowances in 2038.[9]

Outside the EU as well, climate regulations directed at the cement industry are only advancing at a glacial pace, partly attributable to the sector's lobbying. For example, to this date, only 29 % of Holcim's emissions are covered by any CO_2 regulation,[10] mostly coming from the EU, but also from Kazakhstan, certain Canadian provinces, and California. This global picture might change soon. The EU is implementing its carbon border adjustment mechanism, and the Chinese cement industry, for example, is being incorporated into China's national emissions trading system.[11]

3.1.2 Killing the Competition

Second, the cement giants have not only used their lobbying power against climate regulation overall, but also to throttle the advancement of alternative cements. Alternative cements (see 4.1) could significantly curb the industry's carbon footprint. They directly attack the root cause of the cement industry's emissions: clinker production (see 2.1.1). However, since they could radically disrupt the industry to the disadvantage of dominant firms and their invested capital,[12] larger cement companies have used their political power to throttle advancement.[13]

This has mainly occured through the committees that decide on construction standards. These standards are very important, since they are referenced in regulations, guidelines and contracts and are almost always followed in the risk-averse construction industry. Newcomers usually lack the power and the resources to participate in the committees that shape regulation and standards, and such committees are disproportionately made up of representatives of the cement giants. Therefore it's no surprise that many standards still continue to be based on Portland cement, acting in many countries as a severe restriction and obstruction to the use of alternative cements.[14]

In the industry's major lobby organizations, as well, the multinational cement companies dominate, and are able to shape policy in their favour.[15] One example is the Cembureau's impact on the ETS benchmarks, which were based on clinker, not cement. This effectively created a lock-in-effect on Portland cement, based on vast amounts of clinker, and failed to create any financial pressure to phase out clinker, a state of affairs heavily criticized by NGOs as well as industry newcomers.[16] Another example is how industry associations such as the GCCA downplay the role of alternative cements in official roadmaps, creating a self-fulfilling prophecy, in which such materials have only a marginal role to play.[17]

3.1.3 Opening the Door for Carbon Storage

The third way in which the cement industry throttles climate action through its lobbying is by aggressively promoting carbon capture, utilization and storage (CCUS). As will be argued in Section 3.3, CCUS is promoted by cement giants as the most important technological fix, despite its enormous risks and uncertainties.[18] Therefore, the cement giants have begun to lobby for states to allow the technology and to provide immense public subsidies for such projects.

In this, they've joined forces with the fossil fuel industry. For example Holcim, Heidelberg Materials and the Cembureau are all part of the fossil fuel dominated Industrial Carbon Management Forum (until 2023 called CCUS Forum), while Heidelberg Materials is vice-chair of the Zero Emissions Platform (ZEP) – heavily made up of major oil giants like BP, Shell, and TotalEnergies, and described by the Corporate Europe Observatory NGO as "little more than an institutionalized fossil fuel industry lobby group".[19]

CCUS uses similar technologies as are used in oil and gas extraction, and this makes it a source of income for fossil fuel companies no matter if it delivers on its promises of capturing CO_2 or not.[20] There is reason to fear that cement companies could also inadvertently serve as a "door opener" for coal plants and other fossil fuel infrastructure to continue operating. The concern is that once expensive carbon capture infrastructure – including pipelines and storage facilities – is built specifically to handle emissions from cement plants (which are considered "hard-to-abate" because they're difficult to decarbonize), this same infrastructure could then be used to justify continued operation of fossil fuel plants. Coal and gas plants could simply connect to the existing carbon capture network as a way to extend the life of fossil fuel facilities, rather than phasing them out.[21]

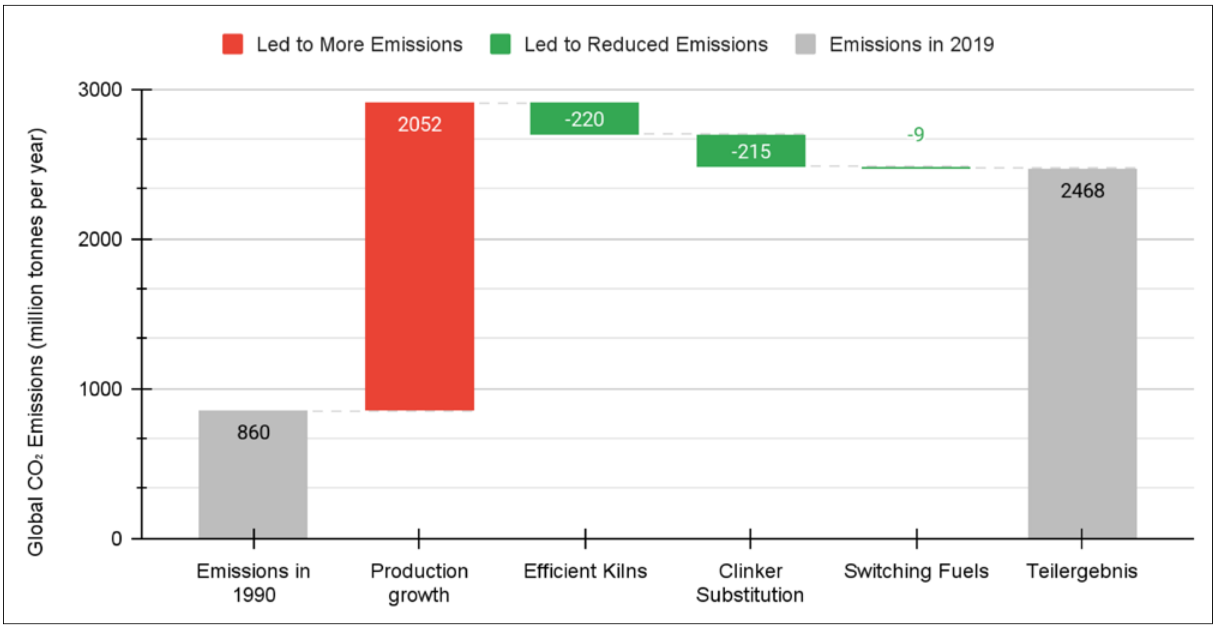
Public funding for large one-off carbon capture projects has increased rapidly. More scalable research on alternative cements and other measures (see 4.1-4.3) is urgently needed, but has yet to follow pace.[22]

3.2 Efficiency Measures

As we have seen, cement giants have in large part stymied climate regulations and potential competitors. At the same time, the dominant firms claim to be pursuing a sustainable future via the rollout of efficiency measures within cement production.[23] Such measures include: changing the kiln to more efficient designs (3.2.1), replacing some of the clinker with supplementary material (3.2.2) and switching fuels (3.2.3).

All of these efforts have already been pursued by cement manufacturers for a long time as they can save considerable production costs, and have only recently been reframed as a response to climate change.[24] These efforts have in fact, had a measurable effect on emissions. The yearly CO_2 emissions of the industry today would be about 450 million tons higher without them – roughly equivalent to 10 % of US annual emissions. However, the industry has grown so dramatically that these measures have proven largely ineffective in the aggregate (see Figure 3.1). The rebound effect – where efficiency improvements are offset by increased production volumes – has overwhelmed every technological advancement, and emissions from the industry still tripled between 1990 and 2020.[25] Despite this poor track record, the industry continues to position all three of these approaches as essential components of its future transformation towards carbon neutrality. These efficiency measures are therefore explained in detail below.

Figure 3.1: Past impacts of efficiency measures and production growth on the cement industry's CO_2 emissions between 1990 and 2019.[26]



3.2.1 Efficient Kilns

The first major emissions-saving measure has been to make kilns more efficient. This has been a primary focus of the industry, as it saves energy, one of the major cost factors in the production process. This effectively meant replacing older shaft kilns and wet-process kilns with newer dry-process kilns, mostly with separate preheater and precalciner towers that work at lower temperatures.[27] Since 95 % of all kilns globally are now dry-process kilns and 85 % include preheater and precalciner systems, this has saved considerable amounts of energy, and therefore money and emissions. This change has had a particularly pronounced effect in China, where there was previously much greater reliance on less capital-intensive but more energy-intensive shaft kilns and wet kilns (see Figure 3.1).[28]

Updating the kilns has had additional positive effects, for example by limiting the vast amounts of slurry waste created through wet kilns.[29] However, this may have also produced a rebound effect, and led to an increase in overall production.[30] This is due to several factors. First, energy costs are one of the biggest cost factors in the industry, so that measures that significantly reduce energy demand can lead to a significantly lower cost for the final product. One possible upshot of that is greater consumption. Second, these modern kilns, in contrast to older shaft kilns, are "megamachines" that process very large amounts of material at a time and need to run 24/7.[31] Their efficiency is partly dependent on vast economies of scale.[32] This means that the industry is better placed to process ever-larger volumes of extracted raw materials, and produce ever-larger volumes of cement for a booming construction industry.[33]

Furthermore, while newer, more efficient kilns have had a large impact on production, the effect of these changes is flattening out. Most kilns worldwide have now been upgraded and new cement plants use the latest technology. While in the EU and US there is still room for improvement as older kilns remain running, in China and India, for example, the practical limit has nearly been reached, and further significant gains to kiln efficiency look unlikely.[34]

3.2.2 Clinker Substitution

Clinker production is the most energy-intensive and climate-harming part of the cement value chain (see 2.1.1). As the key players are largely clinging to Portland cement (see 3.1.2, 4.1), the second major emissions-saving measure has been to reduce the amount of clinker within the final cement, the so-called clinker-to-cement ratio.

Originally, Portland cement was 95% clinker, with 5% gypsum added, to prevent flash setting. But putting additional supplementary materials, such as pozzolans (see 1.5.1), into the mix can replace some of the energy-intensive and costly clinker. This can also enhance certain physical properties of cement or concrete. Since the 1970s, cement manufacturers have increasingly used clinker substitutes to save costs or create cement with special characteristics. And although this has been a common practice for decades, these companies are now framing clinker substitution as one of their central climate measures.

The first kind of supplementary material is simply filler material, mostly just ground limestone or concrete, used to blend the cement to save costs, but non-reactive. Their use is traditionally very limited: when used at concentrations higher than 10 %, they can reduce the strength of the final concrete, although some innovations are happening in this area (see below).[35]

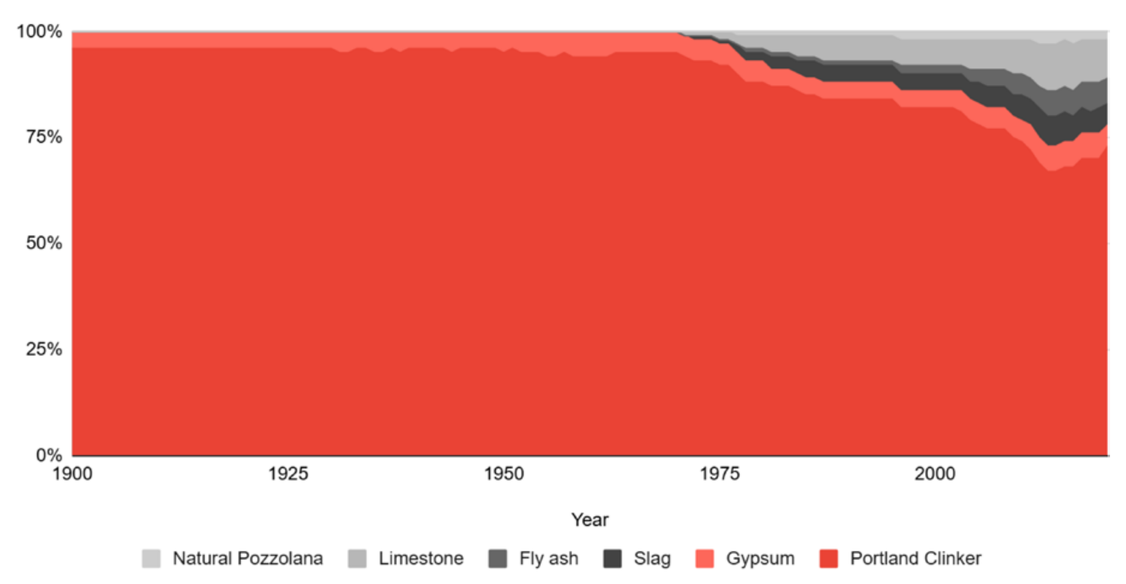
The second kind of supplementary material is reactive binders, that is, materials that after being processed also add hydraulic cementitious properties to the mix. Natural pozzolans have played a small role as reactive binders, but currently only about 75 million tonnes of these are used every year.[36] Since natural pozzolan deposits are very localized, their quality can also vary significantly and this variability in quality can lead to greater water demand and workability problems at the concrete-mixing stage.[37] The two most widely used kinds of reactive binders, however, are artificial pozzolans, by-products from other industrial processes, namely fly ash and blast furnace slag. Fly ash is a waste product of coal combustion in power plants and can easily replace 30 % of the clinker and even enhance the strength and durability of the final concrete. Around one third of fly ash's yearly production of 900 million tonnes is used in cement and concrete. While there may be some potential for further use, this faces limits, since not all of it meets the required quality standards. Blast furnace slag is a granular waste product from blast furnaces in iron and steel production.[38] Of the yearly 330 million tonnes produced, over 90 % is already used for cement and concrete, as it can replace as much as 70 % of the clinker while enhancing strength and durability.[39]

The use of these materials in cement manufacture has been a perfect match especially in cases where steel and coal plants are located close to cement plants: not only has this solved the disposal problems of the coal and steel producers, it has also helped the cement industry to save on resources and energy.[40]

The volumes of supplementary materials used in cement production have increased significantly over the last decades and the relative use of clinker (clinker-to-cement ratio) has decreased globally to average only 76 % of the final cement.[41] While this accounts for about half of all emissions savings since 1990 (see Figure 3.1), three caveats need to be mentioned.

First is that, in absolute terms, clinker production still expanded significantly, and the relative advances were quickly offset by more growth in production. Since clinker substitution often decreased costs of the final cement, part of this production growth could arguably be attributed to another rebound effect from this cost-saving efficiency measure.

Figure 3.2: Cement ingredients from 1900 to 2020.[42]



Second, while there are large regional differences, globally, the potential of prevailing artificial supplementary material is largely used up. Such potential will moreover decline as coal plants close and steel plants switch to greener production methods.[43]

Finally, it must be noted that both coal plants and fossil-fueled iron production facilities are themselves responsible for vast quantities of emissions. It is only because fly ash and blast furnace slag are considered to be waste products that those emissions are not counted on the balance sheet of the cement industry. Meanwhile, slag itself requires expensive additional processing.[44] On top of that the transport emissions alone can outweigh the carbon savings for both of these clinker substitutes.[45]

Still, clinker substitution plays a central role in the official climate strategies of the cement industry. Heidelberg Materials plans to reach a clinker-to-cement ratio of 68 % in 2030 (with 70,2 % in 2023).[46] The GCCA even projects the share of clinker to globally decrease by more than 10 % by 2050.[47]

As the supply of fly ash and slag will come to an end if coal power plants are phased out, the dominant players are also starting to rely on new supplements. This includes agricultural waste ash,[48] recycled glass powder, mining tailings,[49] or end-of-life cement paste.[50] But the most promising newcomer is arguably a mixture of calcined clay and limestone. While both materials have already been used as supplementary materials in the past, new combinations called limestone calcined clay cement (LC^3), have gained traction, since ow 50 % of the clinker can be replaced without significantly decreasing its performance. Both clay and limestone are abundantly available. Moreover, the calcination of clay occurs at temperatures of around 700-850 °C – and crucially does not release any process emissions.[51]

Despite their earlier opposition (see 3.1.2) even major players are starting to invest in the kilns required to make LC^3, albeit at a comparatively slow pace. LC^3 is especially gaining traction in West Africa, however, where cement is currently expensive.[52] And yet 50 % of clinker substitution still leaves 50% of clinker remaining. Even where the introduction of LC^3 is sped up, considerable volumes of emissions will also be left as an intrinsic part of cement manufacture. Therefore even the GCCA projects that clinker substitution will only mitigate a mere 17 % of the cement industry's emissions (see Figure 3.4).

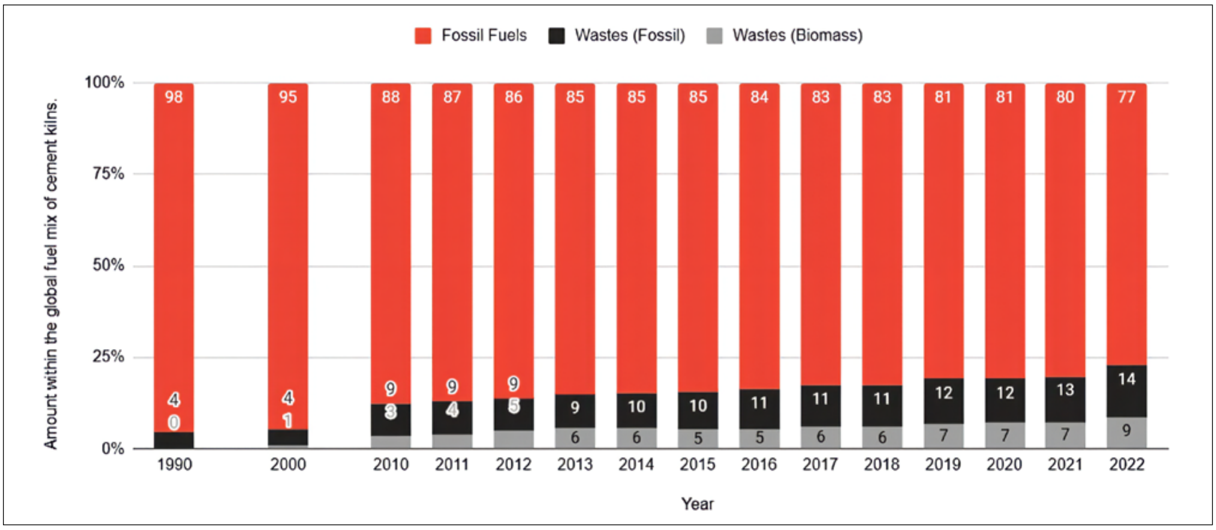
3.2.3 Switching fuels

The third major emissions-saving measure has been to change how the high temperatures within the kiln are fueled. As 40 % of all CO_2 emissions of the industry are caused through the vast amounts of fuels needed to reach these temperatures (see 2.1), the potential is significant.

But replacing fossil fuels with electricity or hydrogen is proving very difficult. While there are some innovations in, for example, electrolysis of raw feedstocks or plasma-based kilns, these are only in the developmental stage and are not likely to replace traditional kilns soon. It is likely that only a switch from Portland cement to alternative cements, which mostly need lower temperatures, could help here (see 4.1). Therefore the dominant firms, as well as most researchers and lawmakers, have accepted that fuels still need to be burned and that the important task is changing what fuel is burned.[53]

Beyond these efforts, the most effective option emerging is that of is mixing waste into the fossil fuel mix. This waste, so-called "alternative fuel", can be biomass (such as saw dust or animal meal), fossil-based (such as plastics and tyres), or some mixture of both. Nowadays, these wastes add up to a considerable share of the fuel powering cement manufacture: globally 23 % of the whole fuel mix are these so-called "alternative fuels", while fossil fuels have been reduced to 77 %.[54]

Figure 3.3: Fuel mix within the cement industry from 1990 to 2022.[55]



This, the industry argues, has not only permitted the replacement of large amounts of fossil fuels; it has also helped to tackle the enormous global challenge posed by large quantities of waste. The waste problem has been addressed in two important ways, according to the cement industry. First, they argue that these wastes would otherwise not be recycled and instead end up in landfills, using up valuable space, polluting soil and waterways, and emitting not only CO_2 but also methane, a far more potent greenhouse gas. Therefore it is better to burn waste for energy, and replace fossil fuels in the process. Moreover, since cement kilns are distributed globally, such combustion reduces the need for additional new waste incinerators to be built. Second, in contrast to other industrial processes, the temperatures required for clinkering are very high, so that many pollutants are destroyed in the kiln: instead of leaving large quantities of ash or other byproducts behind, most pollutants are captured in the clinker. Therefore, cement plants can be considered very suitable for the combustion of even very toxic waste.[56]

Indeed since waste streams often come cheap or free, and since fossil fuels would otherwise comprise the largest cost of production,[57] many cement companies already began in the 1970s to use alternative fuels.[58] Nowadays, companies will often even receive considerable payments for managing waste streams, especially when waste is toxic or harmful. Just through the waste incineration from one plant in one year alone, Holcim made over €6 million in profit. Across its entire global operations, Heidelberg Materials saw revenues of €380 million in one year alone, due to its waste incineration activities.[59]

While it is a profitable endeavour for the companies, the framing of waste combustion as a sustainable measure can nevertheless be called into question. In the end, roughly the same amount of CO_2 exits the kiln. The emissions can even be higher than with fossil fuels alone, since it is less energy efficient to burn waste.[60] And yet, by the industry's accounting, both fossil and biogenic waste combustion are considered to be carbon neutral.[61]

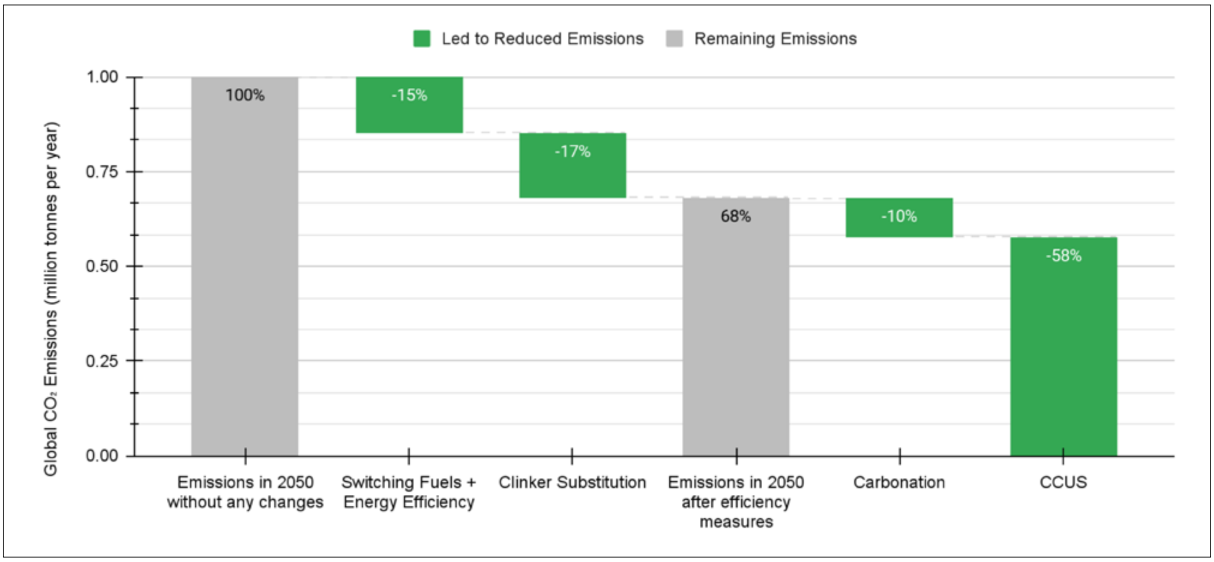
The reasoning is twofold. First, just like fly ash and slag (see 3.2.2), the argument is that these are wastes that would have piled up anyway. Second, in the case of plant biomass, it is argued that any CO_2 emissions from combustion simply return to the atmosphere whatever CO_2 was absorbed during the growing stage of the plant. This second point sets aside the fact that the combustion of woody biomass generates upfront emissions slightly greater than those produced by the combustion of coal.[62] Those are emissions that might otherwise remain locked up in the wood were another use found for it, instead of combustion.

More broadly, all of the above "quick fix" thinking ignores the potential for considerable, and hazardous, feedback effects. "If you can dump everything in a cement kiln, then why would you still care about the problem?"[63] The danger is that waste combustion decreases the incentives to reduce the creation of wastes in the first place.

A particular example of this is the vast streams of plastic waste, which presently comprise a large share of the alternative fuels used by the cement industry.[64] As things stand, Latin American countries, China, Indonesia, and others, have been the dumping ground for plastic wastes from the United States and the European Union, and the cement industries in these countries have played a large role in mopping up the global glut of waste. Yet the further potential for the cement industry to absorb additional plastic waste streams is enormous: the cement industry could, if asked, burn through all of the plastic waste currently produced every year, globally. Unsurprisingly, this has caught the eye of major plastic producers, such as Coca-Cola, Unilever and Nestle: each has begun collaborations with cement manufacturers around the world to create the sorting facilities necessary to make use of these wastes as fuel. The former are happy about the simple solution, with the hope of keeping regulation on their extensive production of plastic to a minimum; the latter are happy about the steady stream of (allegedly carbon-neutral) fuels.[65]

Air pollution remains a considerable hazard, however; and this is notwithstanding the fact that many hazardous compounds, such as heavy metals, can remain trapped in the manufactured clinker. Others, such as dioxins and furans, can be released into the atmosphere.[66] The latter such risks are often exacerbated by less stringent air pollution guidelines on cement kilns than on waste incinerators.[67]

Figure 3.4: The GCCA's forecast of how efficiency measures and carbon dioxide removal will influence global CO_2 emissions in 2050.[68]



Still, alternative fuels play a central role in the cement industry's decarbonization plans. The GCCA forecasts them to increase from the current 6 % to 22 % and 43 % by 2030 and 2050 respectively.[69] Together with the measure to make the kilns more effective, this would save another 15 % of the cement industry's CO_2 emissions (see Figure 3.4).

To sum up, even under the very optimistic forecasts of the industry, its three main efficiency measures won't add up to more than 35 % of emissions saved in 2050 (see Figure 3.4). Since the root cause of CO_2 emissions – the production of clinker – is only partially addressed, these measures are ultimately not enough.

3.3 Carbon Dioxide Removal

While the cement industry's conventional measures fall very short of achieving zero emissions, the industry argues that it can continue causing CO_2 emissions but still achieve net zero through carbon dioxide removal. This removal would take two forms: natural carbonation (3.3.1) and CCUS (3.3.2).

3.3.1 Natural Carbonation

The first measure of carbon dioxide removal advocated by the cement industry is natural concrete carbonation, but it is disputed whether this can actually be counted as such. Carbonation (see 2.1.3) happens already naturally to some extent, and the cement industry argues that this should be recognized as their own contribution to climate change mitigation. The GCCA argues that this should free them from dealing with 15 % of their remaining emissions (see Figure 3.4). The European Cement Association even argues that under certain circumstances they should receive carbon removal certifications. As this process occurs without any intent or additional work from the side of the cement industry, whether they deserve recognition and financial compensation is questionable.[70]

The discussion is different with so-called "enhanced carbonation" – when carbonation is accelerated through methods such as injecting liquid CO_2 into a concrete mix while batching.[71] While such technologies regularly gain significant media attention and could have large potential, they are still mostly in the demonstration phase, and it is highly unlikely that these techniques could be applied at the enormous scales required by the industry by 2050.[72]

3.3.2 Carbon Capture, Utilization, and Storage

The final emissions-saving measure of the cement industry is CCUS. It is claimed that this technology deals with all remaining CO_2 emissions, still more than half of the total (see Figure 3.4), by capturing these and either using them (CCU) within some chemical process or storing (CCS) them. The process includes three steps:

Stage 1: Capture

The CO_2 needs to be captured from the exhaust flue, filtered from the other gases, and finally cached at the plant. For this, large new industrial facilities must be installed at every running cement production site, nearly doubling the size of the original cement plant.[73] Capture rates are never 100 % and generally, at least 5-20 % of CO_2 is still emitted.[74]

Stage 2: Transport

Few cement plants are located close to potential CO_2 storage or utilization sites. Therefore the captured emissions need to be transported long distances via pipeline and ship and short distances by truck or rail. In Germany alone, the cement industry is planning pipelines with a combined length of almost 5,000 km, with costs of around € 14 billion. To make transportation possible, the CO_2 must either be brought to very low temperatures or contained at high pressure.[75]

Stage 3a: Utilization

One option to deal with the CO_2 would be to use it in some chemical process, for example to produce fertiliser, fuels or plastics. Another use is so-called enhanced oil recovery: injecting the gas into active oil reservoirs to enable further extraction of fossil fuels. However, the global scale of demand for chemical products that require CO_2 as a raw input is so small that even just one cement plant would be sufficient to meet any single one of these needs.[76] Additionally, in most applications carbon dioxide is still released into the atmosphere, just one step further down the value chain, leading to no atmospheric CO_2 reduction per se.[77] Indeed, probably the only utilization that could be employed on a large scale and that might store the CO_2 indefinitely would be enhanced carbonation (see 3.3.1).

Stage 3b: Storage

The other option is to store the captured CO_2 in underground geological formations. By injecting it into reservoirs of porous rock, such as depleted oil and gas reservoirs, covered by impermeable rocks, the carbon dioxide needs to be permanently stored if it is not to have a climate impact. This must happen under high pressure, with CO_2 injected to a depth of at least 800 metres below the surface.[78]

While the cement industry has talked about and worked towards CCUS for several decades, at time of writing not a single full-scale application has been completed.[79] The first full-scale project is expected to launch in late 2025 at Heidelberg Materials' cement plant in Brevik, storing about half of the plant's yearly CO_2 emissions below the North Sea.[80] The project took more than 20 years and was funded by extensive public subsidies,[81] yet will only store about 0.4 million tonnes of CO_2 per year.

The GCCA claims that from 2050 onward just the cement industry will need CCUS capacity at the scale of about 1.4 billion tonnes of CO_2 every year.[82] Reaching this would mean setting up 130 projects equal to that in Brevik every single year until 2050. This pace is absolutely not in sight and would also bring with it major damages. In the following, we list four such damages.

First, the costs of this enormous global build-up of industrial facilities would be substantial. Just the investments for the carbon capture facilities would double the costs of the original cement plant.[83] The costs for the transport infrastructure add up as well. Just within Germany, the cement industry calculates costs of around €14 billion, simply for the CO_2 pipelines.[84] Because every storage site is geologically different, each presents new challenges, making storage hard to scale and a high likelihood of runaway costs. In other words, to imagine a depleted oil reservoir as an empty bottle awaiting a new liquid is misleading – it is instead a complex geological structure, full of hidden instabilities and potential surprises, as repeated failures have made clear. [85]

Plainly CCS requires enormous capital investments. In contrast to other technologies, such as solar panels, its costs are also not declining due to innovations and technological development, as recent research at Oxford University concludes. Instead, costs may even rise.[86] As margins in the cement industry are slim, even a rising carbon price is not sufficient to prompt such investments. Instead, like in the Brevik project, any such project often depends on immense government subsidies.[87]

Second, all this new infrastructure would need large amounts of continuous energy along the entire CCUS process.[88] Just the carbon capture technology alone would increase a plant's power consumption by 50 %-300 %.[89] On top of that, there is the energy demand for the transport and injection of the CO_2, which is considerable due to the high pressures and low temperatures involved.[90] This is particularly alarming, given that renewable sources of energy generation and storage are likely to remain in limited supply for the next few decades.[91]

A.10 Case study: The green beacon?

Sweden's most important cement plant sits on the island of Gotland. It is owned by Cementa, Heidelberg Materials' Swedish subsidiary. The Slite cement facility, named after the local area, provides about 75 % of all cement consumed in Sweden[92] and is therefore also one of the largest climate killers in Sweden, responsible for roughly 1.8 million tonnes of CO_2 annually (about 4 % of national CO_2 emissions).

Enabled by excessive government subsidies, it is also the site of Heidelberg Materials' largest CCS project yet, with the company planning to capture nearly all of the plant's annual CO_2 emissions by 2030.[93]

The technological innovation and the scale of ambition on show at Slite are undeniable. They are given pride of place in the company's public messaging. More to the point, they are framed by the company as representative of its global agenda, and a clear sign of a bright climate future for the cement industry.

However, rising opposition to the Slite cement works continues to dog the company. Most notable are widespread and serious concerns over the scale of limestone quarrying on Gotland.

In 2017, Cementa successfully applied for an extension to their Gotland quarry. However, several organizations, including the Swedish Environmental Protection Agency and the local county board, appealed that decision, citing the special biodiversity of the area and risks to groundwater supply in an area that is already drought-ridden.[94]

The appeals court agreed to some of the concerns and cancelled Cementa's extension permit, prompting the company to end all of its quarrying activities on Gotland in November of the same year. This sent Cementa, the construction industry, and the government into a tailspin, with claims that the closure of the Slite plant could lead to hundreds of thousands of job losses across the country.[95]

The Swedish legislature responded by taking special steps to circumvent the decision of the judiciary. A special law was enacted to grant Cementa rights to continue with its plans to expand its limestone mining operations on Gotland, even before a new long-term permit could be granted, a move that Sweden's Council on Legislation called unconstitutional.[96]

While Heidelberg Materials was able to continue operations at Slite, opposition continued. Moreover, activists have escalated their struggle, with the activist group "Take Concrete Action" blocking the plant in August 2022.[97]

Third, CCUS leads to additional risks for ecosystems, workers and communities, as all such infrastructure would likely be at risk of accidental failure, especially if it were to be built up at large scales and in a rush. Hazardous chemicals, gases and fuels might escape from the facilities. Pipelines can leak and lead to catastrophic failures. One such event occurred in February 2020 in Satartia in Mississippi, when a CO_2 pipeline burst. Despite a very rapid emergency response, the town was enveloped in a toxic cloud and at least 45 people were hospitalized.[98] (CO_2 is both colourless and odourless, and exposure at high concentrations can lead to convulsions, coma, and death.)[99] The injection of CO_2 underground can heighten the risk of earthquakes, pollute drinking water, and degrade soils.[100] Since geological formations are difficult to assess, and since the CO_2 itself can interact with the rock,[101] leaks are also likely. These can be dangerous for ocean ecosystems and for workers at the CO_2 storage facilities, and, moreover, can allow a significant proportion of the greenhouse gas to escape.[102]

Finally, such a large-scale build-up of CCUS faces major technical challenges. Scaling up carbon storage is especially difficult, since it cannot be standardized – every project is unique, involves different geological conditions, and needs customized technical solutions, while expertise is scarce.[103] Indeed, the history of the technology has been a history of failure; most planned projects have failed, and the ones that have been completed often store far less than planned.[104]

As a result, the levels of capture, transport, storage and utilization are all far from what the cement industry deems necessary. Currently, only carbon capture projects with a capacity of about 26 Mt are planned at cement plants through 2030 – not even 2 % of the volume the industry wants by 2050.[105] Meanwhile, it's estimated that the entire global CO_2 storage capacity would not amount to more than 70-300 million tons per year in 2050.[106] Even at maximum, this represents just one fifth of the amount required by the cement industry alone. Even the industrial and banking think tank Energy Transitions Commission (ETC) calls the current progress "very disappointing."[107]

Finally, the little progress that does occur happens in the wrong geographical areas. This has led the CEO of the World Cement Association to a dismal conclusion: "If you go to China, India, Africa, the Middle East and so on, there isn't anything in place that is going to give a return on these projects yet. And developed countries only make 10 % of the total cement worldwide and there's not much happening in CCS in that 90 % yet."[108]

3.4 Vision: The techno-optimist Road to Climate Disaster

With cement companies officially working towards decarbonization for a quarter century, results are looking rather grim. As the industry's key players are fighting off alternative forms of cements and their efficiency measures are already nearing their full potential, their decarbonization roadmaps remain highly dependent on a risky, costly, energy-intensive and highly uncertain build-up of carbon capture and storage. As a result, the necessary debate about alternative measures has been pushed to the margins.

Endnotes

1 Y. Guo et al. 2024.
2 Heidelberg Materials 2025.
3 Skjærseth & Eikeland 2016.
4 Skjærseth & Eikeland 2016.
5 Carbon Market Watch 2022.
6 de Bruyn et al. 2021.
7 InfluenceMap 2016; Brad et al. 2024.
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10 Holcim 2024.
11 Alliance for Low-carbon Cement & Concrete 2023.
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13 K. Brown & Pruss 2021; Wesseling & Van Der Vooren 2017.
14 K. Brown & Pruss 2021: 17-21; Lehne & Preston 2018.
15 Wesseling & Van Der Vooren 2017.
16 Alliance for Low-carbon Cement & Concrete 2023; Carbon Market Watch 2022.
17 A. Marsh et al. 2023; Wesseling & Van Der Vooren 2017.
18 Tansey 2024: 4.
19 Tansey 2024: 11-12.
20 Martin-Roberts et al. 2021.
21 Staude 2024.
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23 GCCA 2021a.
24 Skjærseth & Eikeland 2016.
25 Watari, Cao, et al. 2023.
26 Data from C. Chen et al. 2022. Excluding indirect electricity emissions.
27 Van Oss & Padovani 2002.
28 Yan et al. 2024.
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30 Jin & Yu 2022.
31 Förster 2023.
32 Rotary kilns can process around 60 times more cement than shaft kilns. T. Brown et al. 2012.
33 Förster 2023.
34 C. Chen et al. 2022; Scrivener, John, et al. 2018; Zhi et al. 2021.
35 Scrivener, John, et al. 2018.
36 Compared to 3,000 million tonnes of clinker produced per year. Watari, Cao, et al. 2023.
37 Scrivener, John, et al. 2018.
38 In cement more specifically “granulated blast-furnace slag” (GBFS) is used. For this, the original slag needs to be quenched rapidly with additional machinery and energy. Scrivener, John, et al. 2018.
39 Scrivener, John, et al. 2018.
40 Skjærseth & Eikeland 2016.
41 Note that in some countries this substitution is done at the concrete mixing stage (at a ready mix concrete factory, or at the construction site), and not at the cement plant. Therefore a fuller metric would be the clinker-to-binder ratio, which is currently at 63 %. But robust data on this is scarce. Data from GCCA 2021a, 2024.
42 Data from Watari, Cao, et al. 2023.
43 Scrivener, John, et al. 2018.
44 Scrivener, John, et al. 2018; WBCSD 2011.
45 Nehdi et al. 2024.
46 Heidelberg Materials 2024a: 117-119; Holcim 2024: 11.
47 GCCA 2021a.
48 Martirena & Monzó 2018.
49 Nehdi et al. 2024.
50 Miller et al. 2024.
51 Scrivener, John, et al. 2018; Scrivener, Martirena, et al. 2018.
52 Boanada-Fuchs et al. 2024; Loréa et al. 2024.
53 Cao & Massanet 2021; GCCA 2021a; S. Griffiths et al. 2023.
54 GCCA 2024.
55 Data from GCCA 2024.
56 GCCA 2021a.
57 Orosz 2021.
58 Skjærseth & Eikeland 2016.
59 Orosz 2021.
60 GCCA 2021a.
61 WBCSD 2011.
62 Roughly 0.35 kgCO$_2$ per kWh of energy produced for wood combustion (“outside of scopes” emissions); versus roughly 0.33 kgCO$_2$ per kWh for coal. DESNZ 2024
63 Brock et al. 2021
64 Plastic amounts to roughly 50 % of all alternative fuels of the European Cement Industry. In Germany this even reaches about 70 %. Brock et al. 2021.
65 Brock et al. 2021.
66 Brock et al. 2021.
67 Leukhardt 2018; Niederhäuser 2023.
68 Data from GCCA 2021a. Note that first indirect electricity emissions are excluded as full decarbonization of the electricity grid is assumed by the GCCA. Second, the categories were slightly renamed for simplicity. “Switching fuels + Energy Efficiency” therefore includes the small impact of using decarbonated raw material and “Clinker Substitution” includes the small impact of using alternative cements, which is forecast to be very low by the GCCA.
69 GCCA 2021a.
70 Laugesen 2023.
71 For an overview see Astle et al. 2024; European Commission: Joint Research Centre & Marmier 2023; S. Griffiths et al. 2023.
72 Additionally there are problems with energy use, limitations in use and their long time behaviour as doubts whether the technologies’ actually are amounting to net-negative emissions. Chalmin 2020, 2024; Cousins 2023; Lehne & Preston 2018; Ravikumar et al. 2021.
73 Heidelberg Materials 2024b.
74 Cao & Massanet 2021; Schneider et al. 2023.
75 VDZ 2024.
76 Scrivener, John, et al. 2018.
77 Carbon Market Watch 2022; Chalmin 2020.
78 Bukold 2024; IEA 2021.
79 Loréa et al. 2024.
80 Bukold 2024.
81 Just the capture facility at the cement plant will have cost at least USD 350 million, while the whole project including transport, storage, and a capturing facility of a nearby waste incinerator with similar capacity, will have cost about USD 2.7 billion, two thirds of which is paid by the Norwegian Government. Falkengaard 2023; Houg 2024; Royal Norwegian Ministry of Energy 2024.
82 Without any growth of the industry, which is certainly planned by its dominant firms.
83 Menon 2023.
84 VDZ 2024.
85 Fendt et al. 2023.
86 Bacilieri et al. 2023.
87 Menon 2023.
88 Chalmin 2024.
89 Schneider et al. 2023.
90 Herzog 2024.
91 Watari, Cabrera Serrenho, et al. 2023.
92 Wadell 2022.
93 Global Cement 2024.
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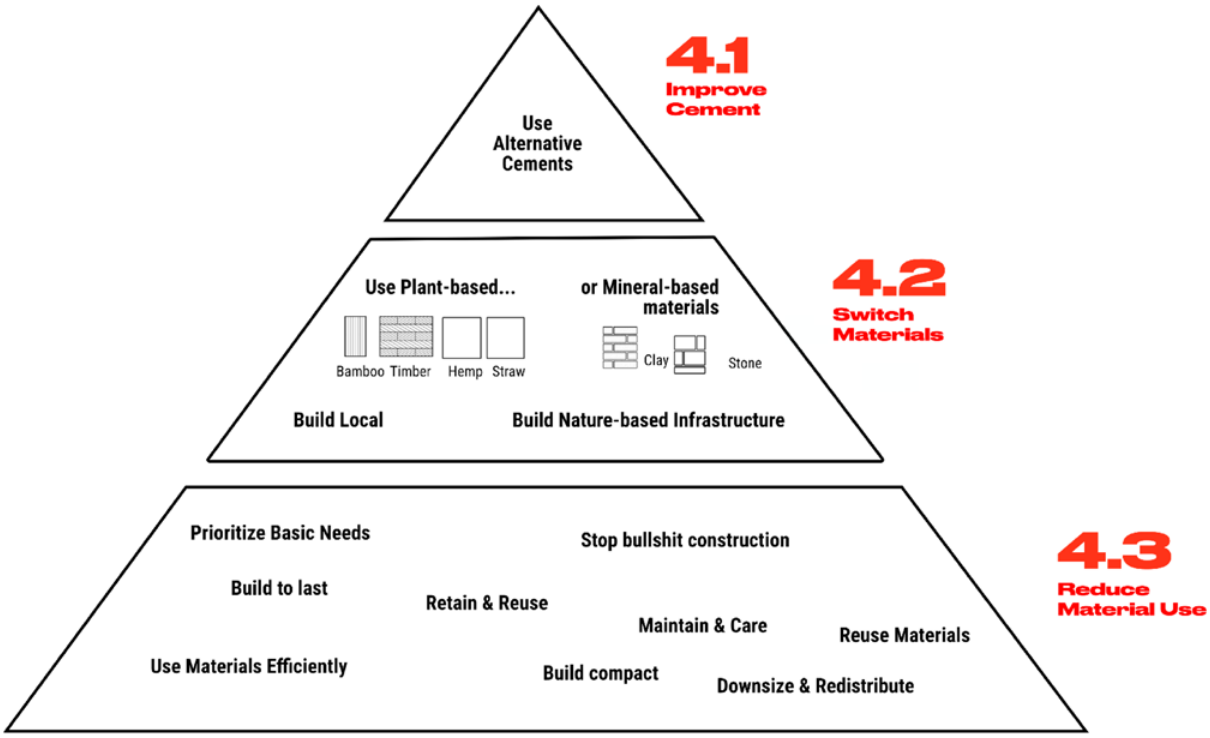
95 Fairs 2021; S. Johnson 2021.
96 Hofverberg 2021.
97 Take Concrete Action 2022.
98 Zegart 2021.
99 Permentier et al. 2017.
100 Bukold 2024.
101 Gholami et al. 2021.
102 Fendt et al. 2023.
103 Bukold 2024; Fendt et al. 2023; Watari, Cabrera Serrenho, et al. 2023.
104 Martin-Roberts et al. 2021.
105 IEA 2024; Loréa et al. 2024.
106 Martin-Roberts et al. 2021.
107 Bukold 2024.
108 Gordon 2024.

4 Alternative measures

The cement industry's climate plans are clearly not working. But there are still enormous unmet needs for basic housing and infrastructure, so we must urgently find better solutions. At the same time, the cement industry has a very limited view of what is possible. The real answers will require changes that go far beyond the cement industry's role and its proposed solutions – we need to rethink how we approach building and construction as a whole.

We highlight three categories of alternatives, and these need to be put into practice swiftly.[1] The first key measure is to improve cement, by using different production methods that go beyond Portland cement and its enormous emissions (4.1). The second measure is to switch to alternative materials wherever possible, by employing plant-based and other mineral-based construction materials (4.2). The third measure is to reduce the overall use of construction materials wherever possible, to a large part by prioritizing those most in need, reducing unnecessary demolition, and curbing "bullshit construction" that services only the wealthy and certainly cannot "trickle down" to those in need: luxury condos, luxury retail, airports, etc (4.3).

Figure 4.1: Overview of alternative measures (authors' illustration).



As depicted in Figure 4.1, these measures have a certain hierarchy. As we move from the upper parts of the pyramid to the lower parts, we move from more technological measures to more social measures. Social solutions are often severely underrepresented in discussions about material use and the challenges posed by "development", environmental degradation and climate change. Not least, this is because suitable solutions would severely impact capital interests. However, social measures have enormous, currently untapped potential, and they can bring decisive changes far quicker than mere technological innovations on their own.[2] Combined, all of the measures in this pyramid offer an alternate vision for construction: a regenerative, vernacular, and people-driven built environment (4.4).

These alternative measures are not without challenges. Economic, cultural and political structures alike are built around concrete-based modes of construction (see 1.2, 1.3). For instance, we have emphasized that cement and concrete are cheap. Amongst other factors, the cement industry is still allowed to externalize many of its environmental and human costs (see 2.7). Building regulations also tend to be geared towards concrete as a norm (see 3.1.2).

In consequence, alternative approaches to construction may be more expensive than concrete, although this is by no means a given; they may come with other practical challenges too. However, the fact that an alternative may cost more or pose practical challenges is not an argument for business as usual. Moreover, as we have also sought to emphasise, the prevailing model of political economy as it stands, and the existing construction industry, are spectacularly failing to meet everyone's basic needs (1.6). All of this suggests that alternative political and economic approaches are needed instead, and not just alternative materials. These issues are discussed in Chapter 5.

4.1 Improve cement

We have noted elsewhere the importance of removing steel reinforcement from concrete to extend its lifespan. Pre- and post-tensioning of concrete, using steel cables instead, is already fairly common, but could be used more.

With regard to cement itself, Portland cement can be replaced with alternative cements that are significantly less CO_2-intensive, while still providing the wonder-material of a liquid stone (see 1.2). This is no easy challenge, and major players have only made limited progress – and sometimes actively hindered development (see 3.1.2). Instead, it has been primarily public institutions and smaller companies that have focused on the invention of alternative cements. Five categories of alternative cements have emerged that may play an important role in the future.[3]

The first group of alternative cements are materials that are produced in a similar way to Portland cement, though with a different material mix in the kiln. Since they still require both a calcination and a clinkering stage (though sometimes with lower temperatures), they offer incremental and moderate reductions in the scale of combustion CO_2 and process CO_2 emissions. However, they also offer specific performance advantages, such as reduced requirements for maintenance and renewal. These cements include belite cement, calcium aluminate cements (CACs), and calcium sulfoaluminate (CSA) cements. Most of these already have a long history of use, due to their specific advantages in performance.[4]

The second main category of alternative cements is magnesium-limestone-based cements. These are made with magnesium carbonates or magnesium oxides as the main ingredient, instead of calcium carbonate.[5] As they are still calcined, but do not require high clinkering temperatures, they too can be produced with fewer CO_2 emissions than Portland cement.[6] There are two main downsides of magnesium-limestone-based cements. The first is cost (deep mining would likely be required to source the requisite materials in the volumes necessary to make a sizable impact – see below).[7] The other disadvantage is that they can't protect rebar from corrosion – so cannot be used with conventional steel rebar. Nevertheless, they can still be ideal for production of precast elements, and for various niche applications.[8] Sorel cements (also known as magnesium oxychloride cements) are a type of magnesium-limestone-based cement that are non-hydraulic, and therefore only suitable for dry environments (they are water-soluble, so in humid or wet conditions they decompose and lose strength).[9]

The third class of alternative cements are alkali-activated cements (AACs) or geopolymer binders, which are made entirely without the use of heat. Instead, they work via a reaction between an aluminosilicate "precursor" and an alkali "activator" (for instance, sodium silicate), added together to form a gel that hardens through a chemical reaction.[10] Precursors include blast furnace slag and fly ash, which are already used as partial substitutes in Portland cement (see 3.2.2).[11] The production of AACs can reduce CO_2 emissions by as much as 80 % compared to Portland cement, while AACs themselves tend to have higher strength and durability. However, they are best used to produce precast elements or premixed concretes, so that the activator dosage can be precisely controlled. The availability and cost of activators is a major obstacle; yet AACs are today already used in a diversity of forms and contexts.[12] A recent example of their use is in the new Silvertown Tunnel under the Thames.[13]

The fourth main option is carbonation-based cements. Unlike Portland cement, these are non-hydraulic and harden through carbonation (the uptake of CO_2 from the air) instead of via hydration (see 1.4.1). This means they have the potential to even be carbon-negative. Several companies are working in this space. While their work garners arguably the most attention of any of the alternative cements, it remains to be seen whether they can move beyond the demonstration phase. Carbonation-based cements (by definition) cannot be used under water, since they require contact with CO_2 in the air to harden.

Carbonation-based cements are, in general, not a viable option for reinforced concrete. Steel rebar depends on the concrete to protect it from moisture and maintain a high pH. Carbonation, however, requires the penetration of CO_2 into the pore structure of the concrete, and this lowers the pH, leading to corrosion (see 2.1.3, 3.3.1).[14] As such, carbonation-based cements can only be used with reinforcement if corrosion is actively addressed through additional barriers – or if non-corroding reinforcement materials are used instead.[15]

The fifth main class is biocements, created by "growing" cement-like materials biologically. This happens through fungal- and microbiologically-induced precipitation of $CaCO_3$, similar to the natural creation of corals and sponges.[16] As a result, neither high combustion temperatures or calcination are needed, and these biocements could also have the potential to be carbon-negative. There are several start-ups and research teams working on this futuristic alternative.[17] However, biocements appear to still be in the early stages of development, and a lot of questions surround the technology: for instance, biocement durability and feedstock requirements.[18] They will not be discussed further here.

Table 4.1: Overview of the most widespread alternative cements.[19]

	Hydraulic Cements			Carbonation-based Cements	Biocements
	Variations on Portland cement	Magnesium-limestone-based Cements	Alkali-Activated Cements		
Examples	Reactive belite cement, calcium aluminate cements (CACs) & sulfoaluminate cements (CSAs)	Magnesium phosphate cements, magnesium silicate cements, & caustic calcined magnesia	Clay-alkali-activated cement & slag-alkali-activated cement	Carbonatable calcium silicate cement & carbonatable magnesium oxide cement	BioZEmen, biogenic cement
Some companies involved	Brimstone, Vicat, Heidelberg Materials, & Holcim	Widespread	Zeobond, Cemfree, Earth Friendly Concrete, & Ultra High Materials	CarbiCrete, Solidia, Carbon Built & Seratech	Biomason
Major climate advantage	Less limestone needed	No clinkering needed	No calcination and no clinkering needed	CO_2 uptake needed for hardening	Produced through biological "growth"
Major challenges	Large quantities of high-alumina raw materials needed	Large quantities of magnesium needed	Large quantities of activators and precursors needed	Large quantities of carbonatable materials needed	Still in early development

The most promising short-to medium-term alternatives seem to be magnesium-limestone-based, alkali-activated, and carbonation-based cements, which all have significant potential to bring emissions down, due to a combination of reduced heat required in production, and reduced (or no) calcination or other source of process CO_2 emissions introduced: in some cases up to a 80 % or even a 90 % reduction.[20] In practice, however, there are some caveats.

First, the production of the raw materials for these alternatives can already lead to high energy emissions, or even high process emissions. For example, the magnesium needed for magnesium-limestone-based cements is primarily produced by calcining magnesium carbonates, and this itself leads to extremely high CO_2 emissions. Similar effects can be seen with the production of the sodium silicate required for clay-based AACs, or with the mining of magnesium silicates.[21]

Second, the raw materials required for alternative cements are usually far less plentiful or economically available than limestone; or they are very unevenly distributed around the globe. This could mean higher costs, or increased mining or transport emissions that would counteract any carbon saving; plus potential mining conflicts as production increases.[22]

Third, some of these alternative cements, such as slag-activated AAC, are based on industrial by-products, so the emissions they generate are often not truly factored into the emissions account (compare 3.2.2). The real-life carbon savings of alternative cements can, in such cases, be less than promised.

Moreover, while many of these alternative cements are already in use, scaling them up to a level of use commensurate to Portland cement is very difficult, for several reasons. The main reason is the giant volume of materials needed for cement production at existing scales. Most alternative materials are simply not as abundant as limestone. For instance, possibilities for CSAs are constrained by a limited global supply of high-alumina raw materials. Even if all global aluminium production were stopped and the raw materials redirected to cement production, that would not even provide 15 % of the current demand for cement. Another example is the sodium silicates for clay AACs, or wollastonite for carbonatable calcium-silicate cements. These are currently produced at a scale not even sufficient to replace even a fraction of a percent of global Portland cement. In the case of magnesium-limestone-based cements, deep mining may be required in order to manufacture volumes anywhere close to the volumes of Portland cement manufactured each year.[23]

Additional challenges loom over these three alternatives. One is a lack of confidence in long-term performance, while another is the limits to their benefits in all but very controlled settings.[24] There is a lack of transparency among researchers, who favour the sort of hype that keeps investment flowing in.[25] Prescriptive regulations that apply to Portland cement alone are additionally a hindrance. Alternative cements need performance-based standards – based on how well they perform rather than what specific materials they contain. In contrast, prescriptive regulations specify exactly which materials and processes must be used. The cement majors have a disproportionate role in developing such standards and a clear incentive to maintain the dominance of existing standards, since they support their existing products and investments (see 3.1.2).[26]

The development of regulations is slow, often taking as long as ten years; the cement industry, and the construction industry more broadly, are (for obvious reasons) conservative by nature. Against the grain, however, in recent years some states and jurisdictions (the United States, for instance) have introduced performance-based standards that make alternative cements a reasonable option for engineers and builders.

We should finally mention in brief two additional options for replacing Portland cement, which draw from history.

First, traditional lime mortars and plasters should be mentioned – since they remain in widespread use across the world today, as part of many traditional building practices and in restoration and “heritage” contexts (see 1.4.1).[27] We will not go into them here in any depth, since our focus is on structural concrete. Lime mortars are far weaker than prevailing Portland cement-based concretes; however, they still rely on high temperature calcination – albeit at lower temperatures than in the production of Portland cement – and they produce considerable (albeit fewer) process CO_2 emissions and energy-based emissions in the course of manufacture. On the other hand, traditional lime mortars and plasters undergo carbonation as they cure, and reabsorb CO_2 much more readily than standard concrete. When compared to modern cement, they also bring certain advantages in terms of comfort and health. For instance, they help to passively regulate humidity.[28]

Lime mortars are already used to stabilize raw earth in construction, and to make hempcrete (see 4.2.4 and 4.2.6 below).

Second there is Roman concrete. As noted already (see 1.4.2), ancient Roman concrete is striking for having proved so resilient over millennia – in sharp contrast to modern concretes, which degrade within generations. Researchers have only very recently proposed a mechanistic explanation for this resilience, connecting a process termed "hot-mixing" to the formation of the white lumps (lime "clasts") that are found inside Roman concrete. They hypothesise that rainwater or seawater seepage leach calcium-rich hydrates out of the clasts and that these repair cracks.[29] This makes Roman concrete's "self-healing" capabilities far superior to modern concrete based on Portland cement.

Researchers in this field suggest that hot mixing, or related methods, could now be deployed in a modern context, in order to lend modern concrete some of Roman concrete's durability. They speak, for instance, of creating more durable concrete formulations that could improve the hardiness of 3D-printed concrete.[30] Nevertheless, such research remains in its infancy. Moreover, as with traditional lime mortars, such methods would presumably still depend on the high-temperature calcination of limestone – unless combined with some of the alternative cement processes outlined above. It remains to be seen if Roman concrete could ever be made compatible with steel rebar – this would offer both tensile strength and durability. This is unlikely, however, because the very feature that gives Roman concrete its self-healing ability – its permeability to moisture – also creates conditions that accelerate rebar corrosion.

In short, none of these alternative cements can be seen as a panacea, at least for many years to come. In the words of the researcher Karen Scrivener: "There is no miracle, 'new' cement out there that can avoid the associated CO_2 emissions" – and which can also be scaled up to the volumes in which Portland cement is used today.[31]

On the other hand, when thinking at a local scale, "there is a great deal that can be achieved by the production of fit-for-purpose local cement technologies and solutions specific to the areas where the desired resources do exist."[32] For instance, clay-based AACs have been considered a main way for the UK cement industry to decarbonize, while carbonation-based cements could be important for unreinforced precast concrete parts, such as slabs and bricks.[33] This attention to context is especially true if we are willing to move away from the idea that all locations in the world can (or even should) be using the same type of cement for all applications.

4.2 Switch materials

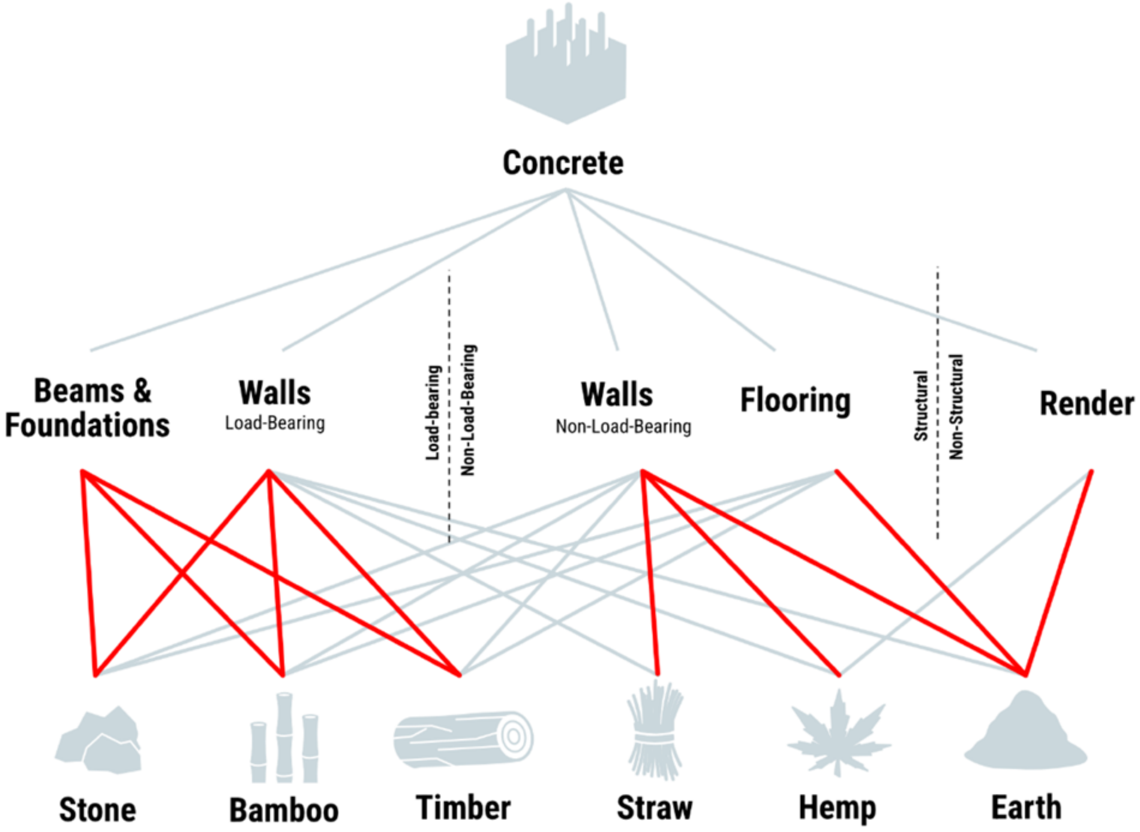
The second major alternative measure is to replace concrete wherever possible with alternative materials. Although concrete is now so ubiquitous that it appears irreplaceable, it is important to bear in mind that until very recently (see 1.4) the material played a negligible role. Instead, a diverse range of construction materials and techniques were used across different regions of the world, many of which still persist in the margins today. In this subchapter we take a look at the most important alternative materials, exploring the contexts in which they can serve as viable substitutes for concrete, as well as the limitations that must be considered.[34] Largely, these can be divided into two main categories: plant-based and mineral-based alternatives.

Plant-based (or biogenic) materials include timber (4.2.1), bamboo (4.2.2), and agricultural products such as straw (4.2.3) and hemp (4.2.4). These alternatives are not only renewable, but also actively sequester CO_2 during their growth, storing it as "biogenic carbon" for as long as the materials are conserved – as well as drawing down additional CO_2 into the soil during the growth phase. As a result, they have the potential to not only replace a CO_2-intensive material but to also serve as a significant carbon sink.

Mineral-based (or geogenic) materials include stone (4.2.4) and earth (4.2.5).[35] Unlike plant-based materials, these are non-renewable, but often incredibly abundant. These too tend to lead to fewer greenhouse gas emissions than concrete.

These six alternative materials have already been the most important construction materials since prehistoric times up until the 18th century, when concrete and steel took over.[36] None of them can entirely replace concrete as the "one size fits all" material of the modern construction industry. Instead, as illustrated in Figure 4.2, each material is suitable for specific applications, and in combination, they can in many instances replace concrete.[37]

Figure 4.2: Overview of alternative materials with their most important applications marked in red (authors' illustration).



For compressive strength, stone, bamboo, and timber are the main candidates to replace concrete, even, for instance, in the walls of high-rise buildings. Bamboo and timber can additionally provide tensile strength to rival steel or reinforced concrete; so too can stone, when implemented skillfully. Meanwhile, earth and straw can provide compressive strength for low- and mid-rise buildings. Earth and hemp (processed into "hempcrete") can additionally function as alternative exterior and interior rendering material, to replace the use of cement-based and traditional lime-based renders.

Options for replacing concrete in foundations may be limited. Timber or bamboo piles can be used, and are a common feature of many traditional buildings; however, they are vulnerable to water, and have restricted applications in many modern contexts. Trenches of compacted aggregate can work well, but they cannot provide the same "anchoring" function of conventional concrete foundations.[38] Traditionally, cut stone has been used as foundations for earthen walls, and that function could be revived and extended today, with the application of modern technology and engineering knowledge.[39] It has been argued that large masses of granite could be used to provide foundations for on- and off-shore wind farms, and similar applications.[40]

Several additional factors need to be addressed at the outset. First, switching materials is not as simple as replacing one block of concrete with a block of something else. Each construction material necessitates distinct building techniques, manufacturing capacities, and skill sets within the construction workforce. As noted in 1.3, concrete has replaced other materials to a very large extent in large part because it fit so well into the ascending capitalist system. Therefore we must discuss how these materials might fit into today's socio-technological systems of construction, and to what extent they might also help to remake existing systems (see 4.2.7).

Second, and as noted above, "prescriptive" regulations are a hindrance for alternative cements, and this is also the case for alternative materials in general. They too will require instead "performance-based" standards and regulatory frameworks.

Third, the availability of alternative materials varies across regions. Most notably, the supply of plant-based materials is constrained by biological and land-use limits: where plants can grow, how fast, and whether cultivation competes with food production or forest conservation. An alternative material is only a viable alternative where it is available in sufficient quantities to meet social needs while also conserving planetary boundaries. In general, fast-growing species such as bamboo, straw, and hemp, alongside a more limited use of sustainably managed timber, represent the most promising alternatives in this regard.[41] Bamboo, in particular, can reach maturity within three to four years and can sequester carbon several times faster than most tree species, making it especially suitable for the Global South, where construction needs are greatest.[42] In contrast, timber grows slowly and is best suited to the Global North, where forest resources are greater. However, large-scale use of plant-based materials will require careful investment in cultivation and processing, as well as strict ecological safeguards to protect biodiversity and prevent deforestation.

Fourth is the issue of greenhouse gas emissions. Replacing concrete with an alternative material does not inherently result in reduced emissions. Rather, the resulting emissions rest on a balance of forces. In the first instance, the emissions required to extract, process, and use different construction materials varies; in the second instance, the whole life cycle emissions of a material, building, or piece of infrastructure, depend on what happens to those materials at the end of their lifetime of use. In the case of plant-based materials, there is sequestered biogenic carbon (in the material itself, and in the soil) that lessens the net emissions impact of such materials. However, a key issue when assessing the emissions footprint of different materials is weight: the sheer mass of different materials that is required to accomplish a given task. Instead of comparing emissions per unit weight, it is therefore far better to compare materials based on units of end-use performance. Various kinds of timber, including engineered timbers (see 4.2.1) appear to come out best, in that assessment, and far ahead of concrete-based forms of construction.

4.2.1 Timber

One of the most promising alternative materials is timber. Forests cover about one third of the Earth's land area and are found on every continent.[43] Yet trees mature only over decades (widely used pine trees, for example, reach maturity only after 25-30 years) so wood supply cannot expand rapidly to meet near-term global construction needs.[44]

As a building material, timber can provide both compressive and tensile strength; and it can be used in many different ways: to make structural frames, flooring, non-structural walls, and roofs, not to mention window frames and furniture.[45] Timber piles also serve as a foundation in many traditional buildings.[46]

When used to construct load-bearing frames, timber can be either used directly in the form of sawn logs (the traditional way), or nowadays it can be processed into various forms of industrially-produced "engineered timber" (or "mass timber"): a very promising class of plant-based construction materials that can, in many instances, replace reinforced concrete and structural steel.[47] While historically, timber could only be used to construct low-rise buildings, highrise buildings can now be built with engineered timbers.

One example of engineered timber is cross-laminated timber (CLT). This has very high levels of structural rigidity, and it is similar in strength to reinforced concrete. It consists of different layers of sawn timber, glued together at right angles to form structural panels, and these can come in varying size and thickness. Adhesives containing natural resins can also be used. Glue-laminated timber (GLT/glulam) consists of wood laminations (lams) glued together in the same direction. Because the wood runs in the same direction, glulam can be manufactured into very long lengths and used to make wide-span structural beams.[48] Dowel laminated timber (DLT) uses dowels (wooden plugs) to fix layers of timber together, and therefore forgoes the use of adhesives. This reduces potential toxicity, while also further reducing the embodied emissions of manufacture. Engineered joists are also common. These products are highly fire resistant, especially when deliberately oversized, because when they burn, the outer layer chars, forming a fire-retarding layer for the layers below. Together, these materials can provide structural strength (both compressive and tensile) for wide spaces, with much higher load-bearing capacity than allowed by traditional sawn timber. Structurally insulated panels (SIPs) are prefabricated units based on CLT, GLT or DLT: structural, pre-insulated "cassettes" that can be assembled together to form walls or floors as part of an integrated system.[49]

Figure 4.3: The Mjøstårnet tower at its opening in March 2019.

Source: Nina Rundsveen, adapted under CC BY-SA 4.0 licence. https://commons.wikimedia.org/wiki/File:Mj%C3%B8st%C3%A5rnet.jpg

A notable recent use of engineered timber is Mjøstårnet, an 18-floor tower in Norway completed in 2019.[50] Though much of it is constructed with timber, it still relies heavily on concrete for foundational and structural support – standing on a large concrete slab at ground level with many floors also made of concrete.[51] Another example is Ascent, a 25-story residential building in Wisconsin, USA, completed in 2022. That building also uses a concrete base, plus concrete elevator shafts and stairwells.[52]

Both traditional timber and engineered timber have the potential to replace concrete to a large extent. While a mere 20 % of buildings in Europe are made of timber, about 90 % of residential homes in North America and Japan are made from wood.[53] As an industrial alternative to concrete, engineered timber can be integrated quite easily into the prevailing construction paradigm and cause relatively little disruption.[54] Unlike some other traditional construction materials, engineered timber does not require a more labour-intensive construction site (see also 4.2.7).[55]

The crucial limitation for the widespread use of timber, however, is that wood grows very slowly. Forests take decades to mature, and forest loss is already an extreme problem globally, especially in the Global South. Expanding timber plantations at scale would likely drive further loss of old-growth and biodiverse forests, replacing them with monocultures.[56] Land competition with food production further limits the scope for global expansion. Nonetheless, in the Global North, where managed forests are comparatively abundant, timber remains a viable low-carbon alternative to concrete, provided that harvesting is sustainable and long-term carbon storage is secured through long lifetimes of use.

4.2.2 Bamboo

Bamboo has the distinction of being incredibly fast growing (4-10 times faster than timber), and therefore offers far greater biological and land-use efficiency. Bamboo is technically not a wood but a grass, and bamboo forests are widespread across tropical and subtropical regions. Raw bamboo is already incredibly prevalent as a traditional building material for homes in rural settings, and the plant sits at the centre of many traditional myths and cultural practices across Asia.[57] Twenty years ago it was estimated that an astonishing one billion people worldwide lived in homes made of bamboo: that number is likely to have declined markedly since then, due to a combination of economic and cultural factors.[58] Raw bamboo is, by many, considered crude (the “poor man’s timber”), and its use in urban settings remains rare; however, it is very widely used to construct scaffolding.[59]

Bamboo could replace concrete in many instances, as it is incredibly strong. Its compressive strength can be double that of standard concrete; its tensile strength can approach that of steel.[60] Bamboo can be used to make structural walls, trusses, roofs, and flooring, and, like timber, it has some limited uses as a foundation material. Fire risk is an issue, however, as is vulnerability to humidity, which requires mitigation through, for example, building design and use of coatings – though such coatings have the disadvantages of introducing additional synthetic compounds and limiting options for later reuse (see 4.3.6).[61]

Those downsides borne in mind, bamboo can be used in its comparatively raw state. A good example of this is provided by the recent pioneering work of the Pakistani architect, Yasmeen Lari, in which she deploys locally available materials in scalable and widely replicable designs – for instance, combining bamboo frames with earth (see 4.2.6), combined with thatch or reed roofs.[62] Low-impact architecture such as this reduces dependency on external sources of materials and know-how – and this makes Lari's approach an especially valuable one for meeting basic needs for housing globally, or rehousing people in crisis-afflicted zones.

Bamboo can be processed into prefabricated structural units – something that has also been explored by Lari.[63] Alternatively, bamboo can be manufactured into "engineered bamboo", which is similar to engineered timber. One example of engineered bamboo is laminated bamboo lumber (LBL). Unlike engineered timbers, however, LBL manufacture is a net producer of greenhouse gas emissions – far greater than concrete on a per-kilogram basis. This results largely from the energy-intensive, high-temperature air-drying process and other manufacturing inputs.[64]

Yet LBL also requires less mass to perform a comparable structural role. When assessed per unit of built floor area, an engineered bamboo structure therefore produces roughly half the greenhouse gas emissions of a comparable reinforced-concrete structure.[65]

From the point of view of emissions alone, the best way to use bamboo is likely in its unprocessed form: cut, or else assembled into simple panels with minimal use of glues and other treatments. However, mass construction programmes in urban contexts are more likely to favour engineered bamboo. Available evidence indicates that engineered bamboo would remain preferable to reinforced concrete (or indeed steel), on the basis of greenhouse gas emissions.

Aside from the emissions benefits, bamboo can also deliver improvements to soil health. As a grass, it has a shallow root system, which helps to hold together soils, preventing soil erosion and landslides, while also acting to remediate polluted soils.[66]

4.2.3 Straw

Straw, another important alternative material, is generally regarded as a by-product of agriculture. It consists of the stalks of cereal plants (such as wheat, rice, barley, oats and rye) that remain after their grains and chaff have been removed.[67]

By weight, straw makes up about half the yield from cereal farming. It is fast-growing (with cereals harvested once or twice each year), and it is a considerable repository of biogenic carbon, which comprises about 40 % of its dry-weight.[68] There is presently an excess of waste straw in most of Europe. That makes it an enormously plentiful and cheap building material.[69]

Straw has been used for millennia in traditional building practices, as roofing and insulation, and in combination with clay in half-timbered buildings as infill and as a wall render (protective seal and finish). Straw is an excellent insulator, and also good for acoustic isolation. It is comparatively fire-resistant and weather-resilient, when used in the right way. In the form of straw bales, straw can provide load-bearing structural strength for buildings, with bales assembled together like large bricks to make whole walls that are capable of supporting a roof made of timber or some other material.[70]

The most promising use for straw, though, appears to be as an insulator, not as a structural replacement for concrete. Countries the world over face an enormous challenge in retrofitting existing homes and other buildings to make them more thermally efficient, and thereby reduce energy consumption and increase energy security. According to recent research, the EU's annual excess of straw production is enough to provide additional insulation to the 97 % of European buildings that need it (see 4.3.4).[71] One example of the use of straw for insulation is a housing development in Schwerin in East Germany. Straw bales were added to the exterior of historic brick brewery buildings and concrete buildings constructed under the German Democratic Republic (GDR) - forming an external insulating layer, with all the straw sourced locally.[72]

In summary: though it can be used structurally for low-rise buildings, the best use for straw is as insulation. The excess straw harvest from Europe's agriculture could provide the continent with virtually all of the insulation that it needs, in order to become climate resilient for the future.

Figure 4.4: A straw bale house in the "Sieben Linden" ecovillage in Germany.

Source: Ökodorf Sieben Linden. Used with permission.

4.2.4 Hemp

Hemp is another important plant-based material. Hemp is widely cultivable, and grows in a wide diversity of climates.[73] It has been used in construction for over 1,500 years.[74] However, it remains illegal in many places due to its relationship to cannabis.[75]

Like bamboo and straw, hemp grows incredibly fast. It can be harvested within just a few weeks.[76] Its rapid growth phase allows for enormous carbon-sequestering capacities and a rapid rate of throughput from atmospheric CO_2 to a stockpile of biogenic carbon.[77] Crucially, it is also excellent at rejuvenating degraded and polluted soils. It can be grown in untilled soils, and can be used in rotation as a "break crop", thereby helping to boost subsequent crop yields, while also providing another source of income for growers.[78]

Like straw, hemp can be used in its raw state as a form of insulation. However, "hempcrete" can also be produced by combining the inner core of hemp stalks with water and a binder such as quicklime (see 1.4.1). Hempcrete is a bit of a wonder material. It cannot, on its own, be used structurally to make walls, columns or beams, or for concrete foundations, since it lacks sufficient strength. However, it can be used as a non-structural element in walls. Mixed on-site, hempcrete can be readily molded into large, lightweight bricks, or it can be applied as a surface render. It can also be manufactured into prefabricated wall panels with very little expenditure of energy.[79]

Figure 4.5: Hempcrete wall being built.

Source: Romancito77, adapted under CC BY-SA 4.0 licence.
https://commons.wikimedia.org/wiki/File:Mauer_6.jpg

Hempcrete has excellent thermal inertia, is highly fire retardant, resistant to pests and mold, and biodegradable. It is also breathable, meaning that it naturally regulates a building's temperature and humidity, maintaining thermal comfort.

Hempcrete has about 5 % of the compressive strength of residential grade concrete. However, it weighs only about one-seventh as much as concrete, which is an advantage for minimizing the use of structural materials (see 4.3).[80] It is highly resistant to fracture under movement, and therefore well suited to construction in areas at risk of seismic activity. Hempcrete can also be reused if it is milled down and then rehydrated. On the downside, it is very good at retaining water: if waterlogged, and in the absence of sufficient ventilation, it becomes vulnerable to structural degradation, reduced durability and/or decay.[81]

Another downside of hempcrete is that CO_2 emissions are produced during the production of the quicklime binder (both energy-based and process emissions) if alternative cements are not used instead. Though not as high as the emissions from Portland cement, they are still considerable – far greater than those of the final concrete on a per-kilogram basis (since a given mass of binder holds together a very low mass of hemp). On the other hand, what hempcrete has, and cement lacks, is biogenic carbon. Once that is borne in mind, then hempcrete is a net-absorber of atmospheric CO_2.[82] On top of that, hempcrete also (like lime plaster) absorbs CO_2 during the remainder of its life cycle through carbonation (see 2.1.3).[83]

4.2.5 Stone

Stone can be found underneath everyone's feet, and there are few physical constraints to the availability of stone globally. The challenges are practical and ecological. Depending on the availability (and cost) of suitable stone, it can replace concrete and steel's capacity for load-bearing, in part or in full. It is the "natural concrete".[84]

"Prime cuts" of rare or beautiful stone, such as marble and onyx, have long been synonymous with expense and luxury.[85] Yet history also suggests that more widely available and generic sources of cut stone need not imply a cost premium over other materials. Traditional stone buildings are ubiquitous in many rural areas of Europe, indicating that stone can often be economical, compared to timber. Aberdeen, in Scotland, was almost entirely reconstructed in granite during the 18th and 19th centuries – such was the local availability of skilled labour, materials, and new fossil-powered machinery to assist with construction.[86] Cut stone, in the form of traditional paving slabs and similar objects, has also been widely used across Europe.

Stone lacks the portability and immediate convenience of the ingredients that make up concrete.[87] And yet, modern machinery can make light work of transporting cut stone, and modern saws make extraction much easier and more economical than in earlier times. Much of the stone that is used in rich countries is imported from quarries halfway around the world, meaning that if it weren't exported, it could be made widely available locally.[88]

Stone is fire-resistant, resilient to mechanical erosion, and resilient in the face of the elements (including water). It does not decompose, and it is invulnerable to pests and mold.[89] Thermally, it behaves similarly to concrete, and provides a good "heat sink" and storage medium for thermal energy. However, it is a poor insulator.[90]

"Post"-tensioning, as with concrete (see 2.5.1), uses additional steel cables (tendons), to "squeeze" the rock and add tensile strength, so that it can perform like reinforced concrete (albeit with the added greenhouse gas emissions of steel).[91] However, traditional stone masonry provides us with plentiful examples of stone used structurally without steel. Europe's historical churches make it clear that arches, vaults and domes can be formed simply by redirecting the compressive load.

As mentioned above, stone could once again be used more widely in foundations. For instance, advocates of stone suggest that it could be used instead of reinforced concrete to provide foundations for on- and off-shore windfarms.[92] As we see from history, stone can be used together with timber to make hybrid buildings. Today, that might consist of stone columns, assembled from blocks, combined with engineered timber or bamboo beams and floor slabs.[93]

In the past, one challenge of stone was quality assurance, since one could not look within the stone to see what it was like on the inside. However, ultrasound tomography now allows for checking individual pieces of stone for flaws and then grading them for use. The diversity of natural stone could also be embraced; costly finishing (widespread when it is used as facing in luxury architecture) is not necessary.[94] The growth in prefabricated housing can also help to mainstream the use of structural stone in construction. Digital design and CNC cutting technologies additionally offer more precision and intricate design options and can minimize waste. For instance, stone bricks could be fashioned for assembly, with or without a binding mortar.[95] Much of this, however, is capital-intensive.

Figure 4.6: The 15 Clerkenwell Close building in London.

Source: No Swan So Fine, adapted under CC BY-SA 4.0 licence. https://commons.wikimedia.org/wiki/File:15_Clerkenwell_Close,_Clerkenwell,_March_2022.jpg

Stone has now been widely trialed as a structural material for prestige architecture. One such example is 15 Clerkenwell Close in London, a seven-storey building that features 100 m^3 of limestone used as a stone exoskeleton supporting the interior of the building.[96] That building's embodied emissions are apparently 10 % of what they would have been if steel and concrete had been used instead. It has all the appearance of luxury; however, the stone was cheap: the cost of the outer shell and core was about half of what it would have been had concrete and steel been used. The basement and the upper floor slab were made with concrete, however, the architects realized belatedly that they could have used CLT instead, and that would have cut the construction time by eight months, while reducing emissions further as well as the cost.[97]

Finally, stone is easily and readily reused. On the whole, it is most viable when minimally cut and with few additional fixtures in place.[98] When it comes to reuse, "Any stone building is a quarry", a treasure trove of stones that can be dismantled and used in a cyclical fashion, at the end of a building's life.[99]

4.2.6 Earth

Lastly, earth is also an important alternative construction material. Earthen subsoil is a "virtually infinite resource on the planet", and raw earth-based construction has also been around for thousands of years.[100] Earth can be used structurally or for internal and external renders – protective and decorative coatings applied to walls. The clay content in earth acts as a binder that holds the material together and makes it workable when wet.[101] The oldest surviving earth-based building is the Ramesseum in Egypt (3,300 years old), and earthen construction can also be seen in the Great Wall of China, the Potala Palace in Tibet, and the Spanish-Muslim Alhambra in Spain.[102]

Earth-based buildings remain widespread internationally as a traditional form of construction, primarily in small domestic settings and agricultural buildings.[103] Methods like adobe, mud bricks, wattle and daub, and rammed earth (pisé, Stampflehm, tapial) use raw earth to construct buildings and other structures.[104] As these historical examples make clear, earth-based masonry can in fact be used to make multi-storey load-bearing walls, replacing the use of cast concrete or precast breeze block construction.[105] Fired clay bricks are made from earth as well, however they require kiln temperatures of around 900 °C and thus generate notable greenhouse gas emissions – though they are long-lasting, often reusable, and can be produced with lower emissions when fired in electric or low-carbon kilns.[106]

A recent estimate suggests that around 8-10 % of the global population live in earthen buildings, with the proportion rising to 20-25 % in "developing" countries.[107] Depending on the site, one notable advantage of earthen structures is that earth can be sourced at-site or from very close by. Ideally, local samples of earth would be lab tested for compressive strength, workability, resistance to erosion, and other factors.[108] However, the main advantage of earth is cheapness, and this is the main reason for its prevalence: earth is far cheaper than wood, fired clay bricks, cement and steel, all of which are unaffordable for many. The easiest way to build with earth is to simply add water and let the resulting mixture dry in the sun. Earth-based construction is usually performed by homeowners themselves, without technical assistance.[109]

Figure 4.7: Historical rammed earth tower houses in Sana'a, Yemen.

Source: twiga_swala, adapted under CC BY-SA 2.0 licence. https://commons.wikimedia.org/wiki/File:Buildings_of_Old_Sana%27a_(%D8%B5%D9%86%D8%B9%D8%A7%D8%A1_%D8%A7%D9%84%D9%82%D8%AF%D9%8A%D9%85%D8%A9)_(2286029999).jpg

Earth has very high thermal mass, meaning that it provides excellent protection from the sun while also effectively retaining heat once warmed up – beneficial for thermal comfort and reducing the need for supplemental heating or cooling.[110] Earth also has excellent acoustic qualities.[111] Unfired earthen materials can be readily retouched in place, reused, or returned to their original location.[112] However, earthen structures are unfortunately highly vulnerable to earthquakes and similar mechanical stresses. This is because they are heavy but brittle with poor tensile strength, making them prone to fracturing and collapsing during earthquakes.[113] Moreover, many societies with a tradition of earth-based construction are located in areas prone to seismic activity, which can bring enormous loss of life.[114]

Urgent steps are therefore required in order to structurally retrofit existing earthen buildings wherever necessary, and to implement suitable reinforcement wherever new earth-based construction takes place in regions vulnerable to seismic activity. Retrofits can use external wood, cane, wire mesh, polyester straps, or plate steel; externally applied plastic mesh is cheap and has shown effectiveness in preventing collapse.[115] Internal timber reinforcement at point of construction, while costly compared to earth on its own, is hugely effective and a long-standing traditional method of construction that is recommended in various national and international construction standards.[116]

Aside from seismic vulnerability, poor resistance to water can also be a problem. Poorly sited buildings and poor cross-ventilation add inefficiencies in thermal performance. However, these downsides can be reduced or eliminated through good design and skilled construction.[117]

Additives and stabilisers also enhance load-bearing strength and water resistance. Historically, quicklime was used (as in the Alhambra), and lime remains widely used for this purpose today, although cement is more common.[118] However, Portland cement has been found to bring very minor gains in strength, while delivering enormously increased embodied emissions – far worse even than if Portland cement-based concrete had been used in the first place.[119] Today, fly ash is widely used as a stabiliser, as are natural pozzolanic clays, various plant-based resins, gums, plant extracts and animal dungs.[120] Addition of banana leaves is a recent development, as is the use of a biopolymer extracted from brown seaweeds.[121]

4.2.7 Building local

Shifting to alternative construction materials is not simply a technical matter, but also brings profound implications for socio-technological systems of construction.[122] Perhaps the most significant change implied by a shift in materials, away from cement, stems from the fact that limestone is widely available internationally, and that concrete similarly permits construction to proceed everywhere on a similar technical basis. The same cannot be said about the alternative materials mentioned here, since their availability and their properties can vary according to location. This is particularly true for plant-based materials.

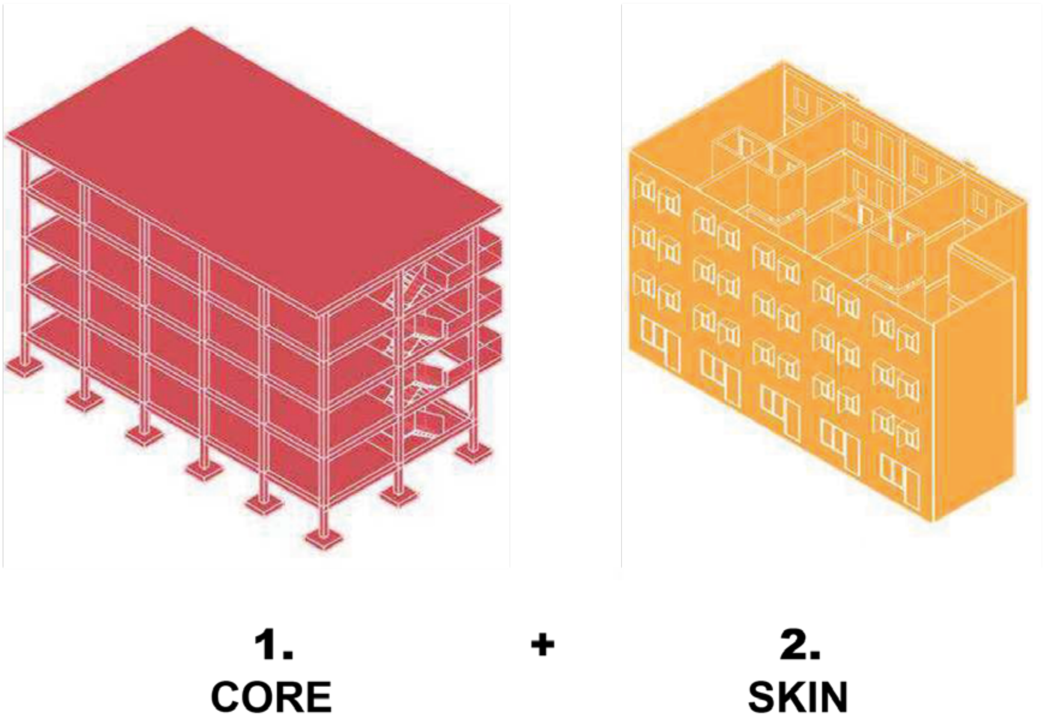
There are multiple ways to address this challenge. One approach is to incorporate alternative materials into the existing industrialized construction model. For instance, in the case of timber and bamboo (as explained above), this can involve focusing on intensive processing to create engineered, standardized materials; pairing these with heavy machinery and prefabrication, and with capital-intensive forms of manufacture and assembly.[123]

An alternative approach is to embrace the distinct properties of alternative materials (their non-homogeneity, “imperfection”, regional availability, and fluctuating supply), and work with these traits proactively. This was, in fact, the norm before the advent of concrete and steel, when construction relied exclusively on local resources and labour. As a result, traditional architecture was – and still is, where it is practised – highly diverse across the globe, evolving organically to local requirements. Many use the term “vernacular architecture” to refer to non-professional, locally rooted building traditions.[124] Arguably, traditional approaches to the design of buildings and settlements may also reveal timeless, and more humane, approaches to the organization of interior space and the wider built environment: homes and neighbourhoods laid out and developed organically in response to day-to-day needs (practical, psychological, spiritual).[125] The histories (plural) of vernacular construction offer much accumulated wisdom for the world about how to build sustainably and regeneratively, while also carrying forward and developing the world’s cultural heritage.[126] One important example of this is “bioclimatic design”: the principle by which buildings are designed to work “passively” with local environmental conditions and to take advantage of whatever natural daylight, heating, cooling, and ventilation effects are available.[127] For instance, Mediterranean courtyard houses create a microclimate that encourages shade, airflow, and evaporative cooling. Thick masonry walls (stone or adobe) provide thermal mass, moderating daily temperature swings; and they use blind walls or small windows on outer façades to minimize heat gain. Good examples of this style of construction include the *riad* houses of Fes or Marrakech in Morocco; also Greek and Italian rural homes.

Switching towards traditional materials and building practices in this way also implies shifting back to the local: local labour, local resources, local supply chains, and a more hand-crafted construction process. This could potentially reverse some of the professionalization and hierarchies of construction labour, and could also foster greater worker autonomy, turning design and construction into sites of education, where skills are passed down and construction cultures revitalized. Equally importantly, paying local workers directly, rather than funneling costs through large corporations, can ensure that economic benefits circulate within local economies. As such, to build locally can be understood as a remarkably resilient way to create green jobs, with great potential for positive social impact (see also chapter 5.5).[128]

Ultimately, both approaches (adapting alternative materials to modern techniques and embracing traditional methods), are not mutually exclusive, and they can be adapted and combined in hybrid fashion, according to construction needs and the distribution of suitable materials, know-how, and labour. One useful example is a building concept advanced in a recent report for the UN’s “One Planet” initiative.[129] It outlines how timber, bamboo, hemp, straw, earth, clays, and stone could all be deployed alongside some structural steel, some concrete, and glass windows, in order to provide mass-scale, mid-rise housing modeled after downtown Paris and Cairo. The concept is directed at an urbanizing Africa; however, when adapted, it could be applied anywhere in the world.

Figure 4.8: The UN's "One Planet" hybrid building concept combines industrial construction materials for load-bearing and glazing, with traditional materials and methods used for wall renderings and finishing.



Source: Figure adopted from Westerholm 2023. Courtesy of Sustainable Buildings and Construction Programme 2021. Used with acknowledgment.

This typology also suggests a division of labour according to capital- and labour- intensity. The load-bearing and the more structural elements of a building, the report suggests, would benefit from more industrially-coordinated, capital-intensive methods of construction (engineered bamboo, engineered timber, or concrete and steel). Similarly, building services would tend to be connected by a utility firm or large outside contractor. On the other hand, all internal walls, non-load-bearing structures, services, and finishing could be provided by non-industrial and traditional methods. Modern construction norms would have a role to play, but they would not dictate the overall programme of construction. This strategy would enable mass-scale, mid-rise housing to be constructed swiftly and efficiently, while supporting local labour, local supply chains, and alternative material economies.[130]

The challenges of scaling up local construction are significant. Less industrialized methods require more skilled local labour, and this must be nurtured and developed, especially given the widespread loss of traditional building knowledge. Local supply chains for construction materials must also be coaxed into existence and professional and regulatory standards changed.[131] The cultural preference for architectures of excess over more frugal and sustainable approaches to design and construction must also be addressed. Much of this is explored in chapter 5.5.

4.3 Reduce material use

The third major alternative measure is to reduce the overall use of construction materials wherever possible. This is not merely a technical challenge, but requires primarily social, cultural and economic changes.

A key concept in this direction is sufficiency. This entails a holistic approach that ensures everyone's basic needs are met within ecological limits, while curbing excessive consumption by those who have more than enough.[132] It requires non-technical, social, political and economic change.

The largest sufficiency impacts on material use are likely to involve the most large-scale social interventions. For instance, remaking the global economy – such that it would be oriented around meeting basic needs, instead of directing profit towards shareholders – would constitute a large-scale, non-technical social intervention. It would accomplish more than most other conceivable strategies for curbing excessive material consumption and instead direct materials and services towards those that need them most.[133]

When applied early in the process of industrial development, sufficiency measures can also help to ensure that countries and communities do not "lock in" high levels of resource consumption for the future. One example of such a lock-in effect is when settlements are designed in such a way that they create car dependency.[134] Large roads require regular maintenance and renewal – and this entails the consumption of needlessly large volumes of resources (aggregates and bitumen). Regular road maintenance is also very expensive – and can be fiscally bankrupting for car-dependent municipalities.[135] Reducing car dependency can be an especially impactful sufficiency measure, and will tend to reduce inequality so long as practical and affordable alternatives to private vehicles are widely available.

Sufficiency measures combine with efficiency measures: largely technical interventions that result in fewer material inputs being required per unit of useful output. One example, for instance, is to reduce unnecessary waste during manufacturing.

Here we focus on reducing material use by: prioritizing basic needs (4.3.1); stopping bullshit demolition, including needless demolition in war (4.3.2); building to last (4.3.3); retaining and reusing existing buildings and infrastructure (4.3.4), which in turn entails maintenance, care, repair and renovation (4.3.5); reusing materials (4.3.6); using materials efficiently (4.3.7); building nature-based infrastructure (4.3.8); building compact, nature-infused cities (4.3.9); and redistributing and sharing the existing built environment (4.3.10).

4.3.1 Prioritize basic needs

There are two core sufficiency approaches that are necessary for constraining material use in the built environment: (1) direct materials to where they are needed most; and (2) actively constrain material use for socially unnecessary ends.

Directing materials to where they are needed most means prioritizing the satisfaction of basic needs internationally – now and in the future. As noted in Chapter 1.6, basic needs consist, at a minimum, of good quality, secure housing for all, access to clean drinking water and sanitation, and access to electricity. These are the social foundation of a just and equitable world. Under an ethos of sufficiency, all of the materials that are needed to satisfy the world's basic needs would be directed to wherever those basic needs exist.

As indicated in chapter 4.2, the mobilization of alternative materials, and particularly plant-based materials, is contingent on natural availability: a function of biology, geology, and competing claims on land use. Prioritizing basic needs, among other things, therefore means sourcing suitable materials based on the geography and distribution of needs. The priority should be using alternative materials – bamboo, timber, stone, or earth – wherever they can meet basic needs within planetary boundaries, and this would also require establishing adequate supply chains. Where concrete and other industrial materials remain necessary, adequate manufacturing capacity must be established in those locations. Still, doing so should follow the sufficiency approach, producing only what is needed to meet basic needs rather than excess driven by profit or speculation. Moreover, where inadequate economic "demand" already exists, capable of meeting basic needs, then such demand would have to be put in place by states instead, using all tools at their disposal at a national and international level.

Constraining material use for socially unnecessary ends means simultaneously and severely constraining what we have termed "bullshit construction", a form of over-consumption conducted by, and on behalf of, the wealthy (see 2.6.3). Frequently, such construction occurs simply as a tool of financial speculation or solely for purposes of elite consumption.

As we noted previously, "bullshit construction" is widespread across the Global North and the Global South. We highlighted the example of Lagos in Nigeria, where millions live crammed in slums and with few amenities, where "the amount of buildable land far outstrips the state's housing needs," and yet, "the government itself seems invested only in the housing needs of the rich."[136] The poor are frequently displaced to make way for new luxury developments. Resources should be directed instead at upgrading or replacing the homes of the poor and providing those communities with the amenities that they need.

Prevailing economic and political structures are designed to benefit the wealthy. Decades of neoliberal policy and ideology have reinforced the belief that the state's primary role is to serve private capital, rather than to guarantee social and ecological well-being.[137] Overcoming this logic requires confronting the financial and institutional arrangements that sustain it – for instance, the dependence of public investment on private borrowing, rather than on direct monetary creation through central banks.[138] In the case of poor countries with very few external currency revenues flowing in, some external assistance will arguably always be necessary for building the necessary housing and infrastructure to meet their basic needs. Such support can, and should, be provided by the rich states, and without the imposition of debilitating loan conditions. It would require, however, a suitable international financial architecture to be put in place.[139] That is a key requirement for meeting the basic needs of all, and delivering on an ethos of sufficiency internationally.

4.3.2 Stop bullshit demolition

The second measure towards reduced material use builds on the first: it is to stop "bullshit demolitions". Bullshit demolition is the sort of unnecessary demolition that makes way for bullshit construction. Buildings and infrastructure are far too often demolished despite being physically in good shape. The decision to demolish reflects simply the changing structures of economic demand, or changes in surrounding land use.[140] Bullshit demolition is not brought about by physical deterioration. It is driven by political and economic decisions. A building may cease to be economically productive or cost-effective for the landlord, due to changing land values or gentrification. Perfectly habitable buildings are torn down to be replaced with new ones, in order to extract the most value out of real estate and create investment flows and opportunities.[141] We have cited forced displacements in Lagos in Nigeria, where slums may be deemed to be situated on prime real estate. We have also cited forced evictions in India, where in excess of 500,000 people were forcibly evicted from their homes in 2023 alone, in the name of "slum clearance", "beautification", and the removal of "encroachments" (see 2.6.3).[142] In rich countries too, gentrification remains a dominant dynamic within urban development. Often, perfectly viable buildings may be demolished simply on account of some ill-defined urge for something more "modern": for reasons of prestige, for the city, developer, neighbourhood and so on. A sufficiency approach to material use would tend to regard all such bullshit demolitions as a tremendous waste of resources. In the words of Carl Elefante, former president of the American Institute of Architects: the greenest building is the one that already exists.[143] All such bullshit demolitions should cease, if we are to sustain and reproduce our built environments with respect for the balance of basic human needs and ecological limits.

Where slums are concerned, such neighbourhoods require instead what the UN terms a "participatory slum upgrading approach": moving people out of slum-like conditions, while keeping communities together, and dramatically improving the quality of homes and access to amenities.[144]

As with buildings, so too in the case of infrastructure: a structure may become "obsolete" simply because planners and property owners decide to reorganize other aspects of the built environment.[145] Premature obsolescence of this sort is not physical but structural ("system obsolescence").[146] It is most prevalent in regions undergoing rapid economic development, but it is also widespread throughout rich economies.[147] To avoid this, owners of buildings and infrastructure, and the public at large, instead need to prioritize longevity. An approach to planning that is ecologically sustainable and efficient in its use of resources involves resisting dramatic rearrangements of the built environment, in favour of a flexible approach to what already exists.

Warfare is an additional cause of deliberate and needless demolition. More than "bullshit", the use of artillery to intentionally destroy buildings and infrastructure is a moral abomination, bringing death, famine, and disease. Addressing the UN's General Assembly on 27 September 2024, speaking about Russia's assault on Ukraine and Israel's decimation of Gaza and its people, Mia Amor Mottley, the prime minister of Barbados, highlighted war's waste of resources: "We cannot afford the distraction of war. We need a reset."[148] War is a mass waste of human life and the built environment. This is accomplished through ammunition and explosives that cost thousands or millions of dollars. Measured against people's enormous urgent and unmet needs, and our multiple environmental crises, such material waste and intentional destruction are unforgivable.

4.3.3 Build to last

Beyond the purely social prerogatives of bullshit demolition, however, curtailing needless demolition also means ensuring that buildings and infrastructure are built to last. Building to last means that the physical structure itself has the longest possible lifespan. This starts at the level of design, with all elements of a structure designed for longevity and minimal maintenance and cleaning. It continues through construction, with good workmanship, appropriate use of materials, and no corners cut in the name of profit.

In the case of concrete stocks, we have argued that the widespread use of steel rebar in reinforced concrete is already an Achilles' heel that begins at the design stage and shortens the lifetime of buildings and infrastructure (2.5.1). We have indicated the longevity advantages of curbing the use of steel rebar. Another route to increased longevity can come through the use of alternative cements in niche applications. For instance, calcium aluminate cements (CACs) possess a chemistry that helps to inhibit bacterial growth and thereby reduce damage, useful in sewers and similar infrastructure.[149]

With regard to minimizing physical maintenance, "self-finishing" materials are preferable wherever practical. These are materials that require no additional finishes or coats of paint that have to be sporadically reapplied.[150] Ceramic tiles are self-finishing; wood or earth-based surfaces can be, or can require only minimal treatment; stone, earth, brick, concrete, and metals can all be self-finishing on exterior surfaces; so too are metals that don't rust like aluminium, copper, brass, and bronze. Non-self-finishing materials include plasterboard (drywall), and exterior metal work vulnerable to corrosion. An absence of additional finishes or paint also permits easier disassembly and reuse of materials (4.3.6).[151]

Moreover, materials can be chosen on the basis that they wear well and retain their function physically, while also looking good through years of intensive use or exposure to the elements. Indeed, the built environment can be entirely designed, built and used with an assiduous respect for the natural qualities and life cycles of its materials and their ageing. For instance, different timbers weather in a variety of ways over time, in relation to whatever climate they are exposed to – while remaining structurally sound. These changes in appearance can be embraced within building design. Such choices amount to an alternative ethics of material use: "observing the full bio-geophysical circumstances that influence how something exists or appears in the world."[152] This implies an ethics of care as well as minimizing unnecessary repairs (see 4.3.5. below).

Building to last, however, must not mean that buildings and infrastructure should remain stubbornly resistant to modification or to partial or complete disassembly. Architects and engineers can plan for flexible use and adaptations in use (4.3.4), and design for disassembly (4.3.6), in order to ensure an effective delivery of services through an efficient and sufficient use of materials.

4.3.4 Retain, reuse and retrofit

A fourth way to reduce material use is to retain existing structures as much as possible and for as long as possible. A recent study that looked at the United States suggested that, over the entire period 1900 to 2015, a 50 % elongation of the lifetime of all concrete stocks could have reduced US concrete use by 14 %, with a commensurate decrease in the production of greenhouse gas emissions.[153] Once again, "the greenest building is the one that already exists", and the same principle also applies to infrastructure. On the other hand, decrepit structures must not be used beyond their physical limits, and beyond the scope of repair. While we can plan to retain existing structures for as long as possible, a structure rendered useless is a wasted structure.[154] The emphasis here is on actively modifying, adapting and renovating existing structures in such a way as to extend their reasonable lifetime of use. It additionally requires that structures are cared for, maintained, and repaired as necessary (4.3.5).

Moreover, when needs change, the function of a structure can be changed too, leveraging its functions for a new life. This is called adaptive reuse. Adaptive reuse can be fruitfully applied to buildings and infrastructure. It is particularly useful for ensuring the continued productive use, and preservation, of heritage buildings.[155] Moreover, structures can also be extended or their interiors rearranged.

In most circumstances, renovating and adapting an existing building will impose fewer environmental and social burdens than demolition. An excellent example of such renovations is the work of the architect duo Anne Lacaton and Jean-Philippe Vassal, which are spatially generous, beautiful, retrofitted expansions of existing social housing blocks. In one instance in Bordeaux, for example, the architects added glazed "wintergardens" and balconies onto the side of existing apartments – providing more space, more natural light, improved views, and greater fluidity of use.[156] Lacaton and Vassal's retrofits also significantly improve buildings' thermal performance, with minimal embodied emissions.[157]

We have mentioned the importance of retrofit to strengthen earthen buildings in areas of seismic risk. An additional factor for extending the service life of buildings is that most buildings that are standing today offer scant protection from heat and cold, and therefore require intensive use of supplemental heating and cooling.

According to the Buildings Performance Institute Europe, about 97 % of the EU's buildings require "deep" retrofits to add significant insulation, so that comfort and energy security can be guaranteed for their occupants, and so that the EU will meet its emissions-reduction goals.[158] According to recent research, the EU's annual excess of straw production is more than sufficient to provide adequate insulation materials (see 4.2.3).[159] To this end, construction workers could be redeployed out of bullshit construction and into retrofitting.

It should be noted, however, that such renovations must come with certain protections for tenants, if "ecological gentrification" is to be avoided: the costs of retrofit passed on to tenants in the form of higher rents, with the inevitable evictions that would follow.[160]

4.3.5 Care and repair

If buildings and infrastructure are to last, another essential sufficiency measure is that they be cared for and repaired adequately. Greater physical durability can be specified at the design stage and through good construction; an effective choice of materials can furthermore ensure fewer maintenance requirements. However, all structures nevertheless require care and maintenance if they are to survive into old age.

Key here is to design structures that inspire the care of their users. Structures that are designed to care for people will tend to inspire those people to care for them in turn.Maintenance and care can preserve a structure for many years, but eventually every building requires repair. Repair, in this sense, is simply care taken one step further. At times, genuine care involves larger acts of renewal – refurbishment or renovation that restore both function and meaning. Where parts of the built environment become degraded over time, a sufficiency approach requires that they be fixed. Renovations that extend building lifespans and reduce environmental burdens should also be pursued, following sufficiency principles.

We have noted that some materials are easier to repair than others. The surface of concrete can be patched up with mortar; however, reinforced concrete is a nightmare to repair if it suffers structural degradation (see 2.5.1). Earth-based masonry and renders can be seamlessly retouched at the surface.[161] Plant-based materials such as timber can be vulnerable to pests, and may in some circumstances require remedial action.[162] Poor ventilation and humidity can negatively affect many materials. A holistic approach to design will seek to minimize such risks; yet care for buildings and infrastructure will often require vigilance on the part of owners and users.

There is an important aesthetic component in all such "reparative" activities. All materials exhibit wear and tear over time, given sufficient exposure to the elements or intensive use. The "look" of a building or piece of infrastructure can be important to its users; and sometimes the look of something depends on an aesthetics of newness or of cleanliness. Yet, as noted above (4.3.3), wear and tear need not degrade the essential functionality of a structure; aging materials can also look good. Given an alternative ethics of material use that simply respects how materials age, repair may indeed not be necessary, and needless additional material consumption and expenditure of time and energy can be avoided. However, the users (and maintainers) of buildings also need to be on board with the cultural precepts and aesthetics of the designer, so that they do not try to "fix" something that doesn't need fixing, and in the process perhaps do more harm than good.[163]

4.3.6 Reuse materials

Another important measure to reduce the need for construction materials is simply to recycle and reuse materials that are already in the built environment. This practice is nothing new. For most of human civilization, reusing building materials was standard practice, for simple economic reasons. For instance, there is a Latin word for stone taken from an old structure and repurposed on a new one: *spolia.* However, reusing materials has become a negligible part of construction today.[164] This reflects changes in the economics of construction: materials, especially cement and concrete, have become cheap compared to the costs of labour and machinery, leading to wasteful practices which must be overturned.

Creating more of a circular economy for construction materials could have enormous potential for stemming the flow of construction materials into landfills, and could turn cities into "urban mines".[165] And yet, the reuse of whole components tends nowadays to be a very labour-intensive and time-consuming process.[166] It is no surprise that this happens only rarely, and often focuses on single, highly valuable components – for instance, copper pipes and roofing materials. The majority of materials are sent to waste.

At the same time, there are already numerous examples of how the construction industry repurposes industrial and household waste, such as using fly ash in cement or manufacturing "plastic bricks" by melting sand and waste plastics at around 220 °C. These bricks are low-energy to produce, divert plastic from landfill, and can even outperform traditional clay bricks in strength.[167] Nature-based materials are likewise particularly amenable to reuse and recycling. Wood from a building can be repurposed as furniture. As we have seen, earth and hempcrete are both readily reusable, although in a manner that requires their partial destruction and reconstitution. Modular components can also be removed and redeployed. This is as true for precast concrete elements or steel structures as it is for CLT components or other natural materials.

More than that, there is enormous scope for all new buildings and infrastructure to be designed from the start with ease of disassembly in mind – called "design for disassembly". Here, bolts and dowels are used instead of glues; paints are avoided, and "self-finishing" materials are used instead, among other strategies (4.3.3).[168] Technological innovations could also help here, such as through digital design platforms like Autodesk Revit and ArchiCAD, which can itemize every component in a given design (if necessary, down to every screw).[169] "Material passports" are an IT-based tool for keeping inventory of all the materials in a structure, so that they can be effectively harvested in the future. These take the form of a digital document (or dataset) that is held by the owner of a building or piece of infrastructure. It can be updated during renovations; and it can be made available at any time to help plan for the salvage and reuse of materials.[170] One middle-ground proposition that seems promising and scalable comes from the Brussels-based cooperative RotorDC, which operates a waste database and marketplace, an eBay of sorts for recycled materials.[171]

4.3.7 Use materials efficiently

Aside from sufficiency measures, efficiency measures are another, though often more marginal, way to reduce the overall use of materials in the built environment.

Efficiency measures allow for more material "outputs" per unit of material "input". This might involve the more efficient transfer of energy, for instance. As we saw in chapter 3, in relation to cement production, improvements to the efficiency of manufacturing usually consist of marginal technological refinements applied to existing processes.[172]

Beyond the manufacture of cement, there are important efficiency measures that could be brought to bear on the production and use of concrete and of the various alternative materials outlined in chapter 4.2. We focus here on efficiencies in the use of materials, but touch briefly on wider issues of energy efficiency insofar as they impact material use in the built environment. All such efficiency improvements are welcome, whether they are applied to the manufacture of cement, concrete, products made of timber or bamboo, or any other nature-based material.

Before going on, it is important to note that significant risks stem from the so-called "rebound effect". As mentioned already, this states that, as efficiency gains are made, greater material use often ensues – usually because the product becomes cheaper and economic demand for it is "elastic".[173] All of the sufficiency measures enumerated here comprise an essential set of tools for constraining the rebound effect, by constraining material throughput at point of use.[174] However, sufficiency measures applied in one area of society may themselves also lead to rebound effects in another area, without a broad-based approach to sufficiency.

As in any area of production, however, with construction, efficiency gains can accumulate once applied across the whole value chain of material production, design, and assembly. Moreover, these holistic changes can amplify the benefits. Changes of this kind essentially combine both efficiency and sufficiency measures.

An important credo for efficient construction is building light. Building elements can be specified to be less heavy and require less structural support. This reduces the need for supporting materials, and it also reduces the dependence on high-energy materials (such as steel or reinforced concrete).[175]

In addition, "material-efficient design" and "lean design" (also lean architecture) aim to maximize the effective material outputs per unit input by minimizing waste. They range from eliminating rounding margins for cut materials (reducing the number of offcuts), to more accurate modelling of building physics, or better thermal modelling.[176] Better modelling helps to prevent over-specifying materials for performance, or over-engineering a design. For instance, if you only need to support 1 tonne of vertical load, then there is no need to specify materials or engineer a structure that can withstand 100 tonnes of load. Similarly, if a building is very thermally efficient and requires very little supplemental heating or cooling (and the designer knows this in advance), then there is no need for the designer to specify for a highly energy-intensive heating or cooling system, with capabilities (and costs) far in excess of what is required.

Building light and material-efficient design can be applied to all materials and building methods (although digital design tools help). Where concrete or reinforced concrete are used, material efficiencies can come, for instance, from downsized components, or from not over-specifying for the strength or durability of concrete.[177] Over-use of steel rebar simply due to ease of installation typically can, according to one study, lead to 15-30 % more steel being used than is necessary.[178] Use of precast elements can increase precision, while permitting marginal efficiency gains in manufacture and reducing waste. As noted above (2.5.1), pre- and post-tensioning, in place of steel reinforcement, minimises the use of steel.

On the other hand, rammed earth- and stone-based construction are intrinsically heavy if those materials take on load-bearing responsibilities. That should not disqualify them from use, however. Rather, good design sense implies that heavy materials should be minimized wherever they impose load-bearing responsibilities on the materials below them.

It should be noted, however, that lean design also comes with its risks, since close margins leave less room for error or for unforeseen events. Unforeseen seismic shocks are one example.[179] Extreme weather events, such as tropical storms, ice rain, heavy snowfall and flooding, are another, and these are only forecast to become more frequent. Optimized design also depends on good modelling from the engineers, precise implementation of the design, and a highly qualified and skilled workforce to carry out the construction work.[180] Many of these principles can be eroded through efforts to “value engineer” the costs of construction to maximise profit, often resulting in lower quality materials and construction. With all such factors in mind, some over-specifying can be seen as a “good” adherence to the precautionary principle.

Finally, it should be mentioned that many forms of material and energy efficiency in the economy at large can help to reduce the quantity of materials that are required in the built environment. Two examples stand out. Good insulation in buildings can significantly reduce the amount of energy that is required to heat or cool homes. Similarly, electric heat pumps and electric motors in vehicles bring large end-to-end energy efficiency savings to home heating and cooling and to transport. In the context of green transition, all such measures are crucial. They necessitate short-term expenditures of materials and energy to procure long-term and long-lasting reductions to the quantity of energy that we need to consume. That, in turn, helps to constrain the scale of concrete (and concrete alternatives) that we need to deploy for green power generation, power storage, and electricity transmission.

4.3.8 Nature-based infrastructure

All of the nature-based construction materials outlined above (Section 4.2) tend to be associated primarily with the construction of buildings. Stone and earth are already widely used in infrastructure instead of concrete. However, there is greater potential for nature-based infrastructure to meet basic needs, globally.

Nature-based infrastructure (NBI) refers to the use of living nature and the landscape to address infrastructure needs. It is particularly relevant for two broad sets of tasks. First, it can provide water-related infrastructure: freshwater delivery, water filtration, water storage, and wastewater treatment. Second, it can bolster resilience to climate change. Here we outline these approaches.

Infrastructure projects and public works in the modern era have, as we have seen, predominantly relied on man-made built infrastructure systems. These have often been pursued to the detriment of the immediate natural environment, with an ensuing loss of natural carbon sinks, to say nothing of the upstream costs and damages that have accrued through cement and concrete production (chapter 2).[181]

Moreover, we have also seen that, currently, infrastructure construction globally consumes roughly one-third of the cement and concrete produced. Too much of this construction tends *not* to go towards meeting basic needs, and goes instead towards supplementing resource-intensive lifestyles and over-consumption – for instance, urban highways and airports. Nevertheless, according to the UN, NBI has the potential to directly address many basic infrastructure needs, either in part or “entirely”.[182]

When infrastructure is directed according to basic needs, water and sanitation (alongside housing and electricity) tend to come first, and these most significantly advance the welfare of populations.[183] Water and sanitation infrastructure comprise a significant bulk of the 8 tonnes of cement per capita deemed to correlate, historically, to the satisfaction of basic needs (see 1.6).[184] NBI could replace much of that. It would do so at a fraction of the environmental cost of prevailing concrete-based construction.

Traditional communities have de facto utilized NBI for generations, imposing a light touch on natural processes while supporting complex ecosystems. Industrial societies have much to learn from these techniques, characterized by their ability to promote hydrological and ecological sustainability, and maximize agricultural productivity and land-use intensity, within "closed-loop" material cycles. Examples include the Kuttanad Kayalnilam paddy farming system in India that accommodates salinity intrusion on reclaimed land; and passive irrigation systems at the Ramli lagoon farms in Tunisia.[185] Indian water johads and cheruvus, and similar community-scale projects, can (at least in part) substitute for large-scale, centralized water engineering infrastructure – such as those for irrigation and flood control.[186] One example that "combines green and grey" infrastructure can be seen in and around New York City: the area's three protected watersheds are 75 % forested, and this reduces the need for man-made water treatment facilities.[187] In coastal regions, NBI might include, for instance, the targeted regrowth of mangrove swamps as natural flood defences, and as sites of rich ecological diversity.

In urban coastal areas, "sponge cities" are designed to combine flood protection with systems of fresh water and wastewater management, integrated into a hybrid urban-natural environment.[188] Reducing the number of hard surfaces and volumes mitigates overheating and flooding. The introduction of green space and plant life, "rain gardens" and sustainable urban drainage systems (SUDS), can assist with effective natural drainage. Moreover, the addition of plants and trees increases shade in urban areas; and ponds and waterways help to bring temperatures down, especially in arid climates. All such measures are examples of "climate-sensitive planning".[189]

On the other hand, man-made infrastructures are themselves becoming more and more vulnerable to the effects of climate change: flooding, tropical storms, drought. NBI can help to build resilience by providing protection against urban flooding, dissipating coastal waves, and giving flood and storm surge protection.[190] Reducing the amount of new-build infrastructure that is required also means that more material resources can be redirected to the maintenance and repair of existing infrastructure and to meeting basic needs elsewhere.[191]

There is broad scope for using nature-based infrastructure to "enhance" existing infrastructure – for instance, by offering flood and storm protections, heat regulation, or erosion and sediment control.[192] However, much existing infrastructure could also be dismantled and wholly replaced with nature-based alternatives: a good example of this is the needless prevalence of non-porous surfaces in towns and cities, many of which should be torn out and replaced with natural drainage instead (see 5.7, below).[193]

NBI offers plenty of additional benefits besides these. A major benefit is carbon sequestration and enlarged natural carbon sinks through increased plant life. Another is reversing the loss of nature, with ecosystem restoration and improved "ecosystem health" through expanded habitats, enhanced ecosystem connectivity, and increased canopy cover.[194] Various "co-benefits" also follow, including better air quality, energy-savings through urban cooling, and improved mental and physical health via greater access to nature.[195] As such, NBI could be vital simply as an instrument of restoration as we tackle the "triple planetary crisis" and fight to repair the devastation that has been inflicted on the natural world.

In many ways, NBI is the ideal "integrated approach" to the challenges we collectively face: it provides alternative forms of infrastructure that avoid the embodied costs and damages of prevailing approaches; it can provide important sources of mitigation for the climate emergency; it can restore ecosystems and habitats that are dangerously degraded; and it can additionally protect traditional forms of connection to the land. However, as with all such interventions, one has to guard against greenwashing – with NBI used simply to "offset" the continued overuse of built infrastructure elsewhere and permit an otherwise unreserved consumption of concrete and steel and the continued burning of fossil fuels.

On the other hand, NBI, and the expansion of forestry in the name of infrastructure and climate change mitigation, cannot be allowed to come at the expense of a widespread loss of biodiverse habitats, natural carbon sinks, and local / Indigenous rights to use land and resources.[196] While the evidence base for such projects points tentatively in a positive direction, the environmental and social risks must be carefully considered.[197]

4.3.9 Dense, nature-infused cities

A further measure to reduce the use of concrete – and reduce the use of other building materials too – is to build settlements differently: through densification and infusing them with nature. This can also lead to less carbon intensive, more environmentally friendly, and healthier ways of life.[198]

A key part of that is sufficiency of living space. Homes need to be big enough for people to live in comfort, with the ability for privacy, and without overcrowding. How much space a person needs to live in basic comfort and dignity is not always the same across time and cultures. However, one recent study suggested that $30m^2$ of interior space per person is a viable universal norm, compatible with an equitable approach to global development, while simultaneously averting climate disaster.[199] However, homes should also not be too big either, or too far apart. Land and space are a valuable resource; they need to be shared equitably if everyone is to have enough to meet their basic needs. More than that, everyone should be able to live well.

Figure 4.9: A pedestrianized plaza in Sant Antoni superblock, Barcelona.

Source: Cataleirxs, adapted under CC BY-SA 4.0 licence. https://commons.wikimedia.org/wiki/File:Superilla_del_barri_de_Sant_Antoni,_Barcelona_4.jpg

In terms of bringing more nature into cities, we have just mentioned the various “co-benefits” of bringing people and nature closer together through nature-based infrastructure. They include improved drainage, urban cooling effects, and improved mental and physical health. Everyone needs sufficient access to green space and nature.

Once such basic individual needs are met, density can bring huge (and compounding) sufficiency and efficiency advantages for urban development. In the first instance, denser cities literally take up less space and require fewer materials for construction. This creates efficiency savings by physically reducing the volume of concrete, cement, and other materials that need to be laid down, in order to connect homes, workplaces, amenities, and people. The per capita length of piped infrastructure (for fresh water, waste water, communications), and the associated material stocks tends to decline as cities densify. Similarly, situating people closer together, within easy reach of one another, and close to essential resources and amenities like food and entertainment, directly reduces our need for transport. Public transit systems likewise decrease motor vehicle dependency.[200]

Another aspect of urban density is its benefits for physical and social wellbeing. Greater density fosters social integration.[201] Integrated spatial planning meanwhile supports and encourages walking and cycling wherever possible.[202] In all these respects, urban sprawl is the enemy, as are strict zoning rules that divide people from essential amenities and their places of work. While making cities less walkable, sprawl breeds social isolation as well as material inefficiencies, very often entrenching car dependency – which in turn requires new infrastructure and imposes large burdens of maintenance (see 4.3).

Density can be achieved from the get-go through good urban planning. With sufficient structural modifications, existing buildings can be "upsized", with another storey added on top. However, greater density can also be achieved by retrofitting entire neighbourhoods. Infill development is one way to go about this, and most appropriate for areas of low density housing, where a new home can be added in the unused garden of another, or placed between two adjacent lots ("incremental development"); or where entire mixed-use, walkable neighbourhoods can be inserted on otherwise vacant land.[203] Where single family homes are the norm (a particular affliction of North America), such measures may require changes to zoning ordinances to allow for "missing middle" housing: "the housing that falls in between single-family detached homes and large apartment buildings."[204] When pursued in already dense cities, however, infill development must be undertaken with particular sensitivity to existing residents: too often, the notion of infill can become a "green" fig leaf hiding the naked appropriation of urban space frequented by the poor and the eradication of vital green space: another form of "ecological gentrification" (4.3.2).[205]

One very positive example of compact, nature-infused urban space and of integrated spatial planning is the "superblocks" of Barcelona. These are units of nine city blocks that restrict the flow of traffic and introduce green space, with steps taken to increase walkability as well as social cohesion.[206] A culture of walkability, "active streets", and a new infusion of life to the sidewalk, have benefitted retailers, cafes and restaurants.[207] However, as with the instances of "ecological gentrification" mentioned above, such policies can bring associated risks of displacement if tenants are not protected from housing market speculation and rent hikes.[208]

Densification, however, also comes with physical sustainability challenges. Building taller is certainly not always better. Tall buildings generally require larger foundations and greater structural support. All other things being equal, this brings greater embodied emissions, and less likelihood that you can replace concrete and steel with nature-based alternatives.[209] Like suburban sprawl, highrise buildings tend to be socially isolating. The socially-planned "megastructures" of the 1960s are similarly questionable from the standpoint of sustainability and livability. Livable cities require density without tallness and density without scale. The best middle ground is probably medium-sized, low- or mid-rise buildings of 4-8 storeys.[210]

One such archetype is the British Georgian square: four-storey housing around a courtyard or community park.[211] Others are the mixed-use home-atop-shop neighbourhoods of pre-war London, old Delhi, or Marrakesh.[212] Such configurations achieve high levels of urban density, while operating at a scale that tends to be kind to the human spirit, both aesthetically and socially. Small, pedestrian-focused streets with frequent street-level entryways to homes, mitigate social isolation and encourage conviviality through continuity of urban form.[213] Small green spaces provide play areas, communal gardens and other protected spaces that afford respite from the urban environment. The UN's mid-rise "hybrid" building concept, quoted above, which has an urban density comparable to downtown Paris or Cairo (see 4.2.7), fits the bill.[214]

4.3.10 Downsizing, redistribution and sharing

Finally, downsizing, redistribution, and sharing present crucial further avenues for reducing the use of cement and concrete in the built environment – and for reducing the unnecessary use of other materials too. Moreover, these principles can be used to improve the living standards of those who have least, without requiring for more consumption to take place – they are a crucial instrument for redressing class inequality and other disparities – for instance, disparities in access to living space or green space or clean air, and the resulting disparities in health.

Downsizing, first of all, means that those with "too much" space, and "too many" resources, lose some of that, in order to live sufficiently but with less. For instance, the wealthy may live in needlessly large homes, which they can give up; roadways may grant a disproportionate share of space to car traffic and parking, and could be broken up; gated communities may enclose a disproportionately large share of the built and natural environment, unnecessarily hoarding concrete and other materials instead of sharing them equitably. All such instances of over consumption can be reduced.

Downsizing can permit net reductions of material use across the whole of society, although we hold that the focus should be on those who have most. For instance, in the case of Japan, it has been estimated that a 20 % reduction in building floor area per capita and a 9 % reduction in infrastructure stock per capita could reduce the annual demand for cement (and subsequently its emissions) by about 10 %.[215]

Downsizing for some can also permit the redistribution of resources: transferring the use of materials and space from those with too much to those with too little. At least in part, this implies breaking apart and disbanding the pursuit of hyper-individualized, "imperial" modes of living and high levels of consumption among the upper and middle classes.[216] It means, wherever possible, transferring existing use of some share of built structures from those with too much to those who need more. Access to, and use of, existing stocks of concrete (and other materials) are redistributed. This, in turn, reduces the need for new construction to cater for existing unmet needs.

In recent decades, for instance, there has been a rapid increase in living space per capita in the Global North, mainly for the well-off.[217] In Germany, the size of individual living spaces has more than doubled since 1960.[218] The main beneficiaries of this growth have been those willing and able to move outside of cities. The losers have been left to languish in small urban apartments, unrenovated buildings, and large housing estates.[219] One crude estimate suggested that within Europe just filling up under-occupied residential space could provide sufficient housing for an additional 100 million people, or 22 % of the population of the EU.[220] As things stand, much of that surplus space is held idle as an investment or used for short-term lets for tourists, through AirBnB and similar services – thereby reducing housing supply and driving up prices.[221]

Stark examples of housing inequality can be seen in luxury developments that exist right next to areas where people live in poverty with inadequate housing. We mentioned two such wealthy enclaves in Lagos, Nigeria: Banana Island and Eko-Atlantic. These neighbourhoods could be used to house the city's slum dwellers instead. As above, this redistribution would reduce the need for new cement and concrete construction. Such housing is already connected to high quality infrastructure, and could additionally be extended through high quality, sustainable in-fill developments (see 4.3.9)

Then there is the additional potential of converting unused commercial and office space for other uses: a form of "adaptive reuse" (4.3.4). There has been a large-scale shift towards working from home in the Global North, especially as a result of the Covid-19 epidemic. This has rendered much existing office space redundant: "26 Empire State buildings could fit into New York's empty office space", reported the New York Times in May 2023, even as new office space was being developed at scale across the city.[222] Repurposing office space for homes could, in Germany alone, supply another 100,000 additional dwellings per year.[223]

4.4 Vision: the regenerative, vernacular, and people-driven built environment

There is a vast array of alternative measures available, once we look beyond the cement industry's narrow, techno-optimist tunnel vision (see 3.4). While no single measure is sufficient on its own, together they form a transformative framework, one that could significantly reduce the industry's staggering CO_2 emissions and other damages. Collectively, these approaches enable us to draw up an alternative vision: the regenerative, vernacular, and people-driven built environment.[224]

The first aspect of this vision is that it is regenerative. Instead of relying extensively on Portland cement, concrete would be made using alternative cements, and avoided whenever possible. The built environment would shift towards alternative materials, including plant-based materials, such as bamboo – and these would turn our densified cities into enormous climate sinks. All such plant-based materials would be used efficiently and sourced from sustainable, holistic forestry and agriculture, rather than through extractive monocultures. However, the most fundamental shift would be that new construction is reduced wherever possible and instead laser focused on meeting basic needs on a global scale. In many cases nature-based infrastructure would take the place of man-made infrastructure. Across all parts of the built environment, the focus would move onto caring for what exists already and maximizing its lifetime of use.

Secondly, this vision is vernacular. The built environment would be made with predominantly local labour, locally-resourced materials and regional supply chains – all adapted to the specific needs, cultural and environmental contexts that they serve. Rather than creating the same homogeneous architecture around the globe, modern and traditional techniques would be used together, creating a highly diverse built environment. Industrial production and global trade would still have a role, but they would be supplementary rather than dominant. Instead, the focus would shift to resilient, decentralized and pluralized construction.

Finally, the vision is people-driven. Decision-making about the built environment would not be dictated by profit maximization, top-down urban planning, or the singular visions of so-called “starchitects.” Instead, it would be democratized, empowering communities to have agency over their spaces and ensuring that architectural and urban planning processes served public interests. In this vision, architects would take on a new role as mediators “bridging between different forms of knowledge, […] bringing together disparate communities.”[225]

This vision of a regenerative, vernacular, and people-driven built environment offers a viable pathway to staying within planetary boundaries, while establishing a strong social foundation for all. Unlike the cement industry’s vision (see 3.4), this alternative does not depend solely on deeply uncertain techno-fixes.

However, such a transformation is not without challenges. Most challenging of all is directing resources to where the most acute needs exist in the world – and this will ultimately require large-scale changes to our political economy. The meeting of everyone’s basic needs within planetary boundaries should become the core function of our political institutions and of our global economy – not a mere appendage or distant “trickle down” side-effect of business as usual. We require a politics of sufficiency on the world scale (see 4.3.1).

With regard to the cement and construction industries specifically, it is clear that some barriers are purely regulatory. However, the most significant obstacle in the way of the alternatives outlined here is that key players in the construction industry (cement majors, major developers, or large construction firms) stand to lose power and influence; moreover, they stand to lose capital.

In the next chapter, we therefore explore political levers for progressive actors to pursue, in order to fight these entrenched interests and work towards the regenerative, vernacular, and people-driven built environment that the world needs.

Endnotes

1 These build on the “Avoid. Shift. Improve.” framework introduced in UNEP 2023a: ix.
2 Nelson & Allwood 2021.
3 Adapted from Miller et al. 2024. In addition to the types of alternative cement mentioned here, there are several other novel mineral cements and material technologies undergoing research, though their future widespread use remains even more uncertain than the ones above.
4 Juenger et al. 2011; Shi et al. 2019.
5 Habert et al. 2020.
6 Magnesium oxide (MgO)-based cements processed at lower temperatures are often referred to as “reactive magnesia”. Walling & Provis 2016.
7 In regions with local MgO availability, however, costs can be relatively competitive, especially for niche applications such as wall panels or specialty building materials.
8 The niche applications of magnesium-limestone-based cements include road repair and as an immobilizing medium for nuclear waste. Walling & Provis 2016.
9 Gartner & Sui 2018.
10 Habert et al. 2020; Juenger et al. 2011.
11 Miller et al. 2024.
12 Juenger et al. 2011; Shi et al. 2019.
13 Astle et al. 2024; Pitcher 2021.
14 Astle et al. 2024; Habert et al. 2020; Ma 2023; Scrivener, John, et al. 2018.
15 Fuhaid and Niaz, 2022.
16 Miller et al. 2024.
17 For example researchers in Norway have developed “BioZEment”, which uses powdered limestone as a feedstock; see also the US company Biomason or the Netherlands-based company BioBasedTile. There are also companies working on supplementary materials (see 3.2.2) based on this principle, also termed biocement. Biomason 2021; MaterialDistrict 2022.
18 Astle et al. 2024; Miller et al. 2024.
19 Based on Li et al. 2022; Miller et al. 2024; Scrivener, John, et al. 2018.
20 Mathapati et al. 2022; Palomo et al. 2014.
21 Habert et al. 2020; Scrivener, John, et al. 2018.
22 Nehdi et al. 2024.
23 Habert et al. 2020.
24 K. Brown & Pruss 2021; Habert et al. 2020; Shi et al. 2019.
25 For a critique on research of alkali-activated cements see Shi et al. 2019.
26 Hart 2022.
27 Dettmering 2019
28 Vismaya Paralkar 2024
29 Seymour et al. 2023
30 Seymour et al. 2023; Chandler 2023.
31 Scrivener 2022.
32 Habert et al. 2020.
33 Martin 2024; Scrivener, John, et al. 2018.
34 Materials not covered here include metals and glass.
35 The term “geogenic” is used to refer to materials that come from the soil (EEA / GEMET n.d.; Lokko et al. 2024) or those that are the product of geological activity, or related more broadly to the history of the Earth (Oxford English Dictionary 2023).
36 Kropp & Aicher 2024.
37 Alternative construction materials are in this sense similar to renewable sources of energy and various solutions for storing and transmitting this energy: each has their own strengths and shortcomings.
38 Stones placed above ground may be able to provide a limited functional alternative for buildings. Material Cultures 2024: 82.
39 Belabid et al. 2022; Kucharek 2024.
40 Kucharek 2024.
41 Göswein et al. 2022.
42 Bamboo Technical Support Group, Kerala n.d.; M. Yadav & Mathur 2021.
43 UN FAO 2020. In the EU too, forests comprise roughly 37 % of the total land area.
44 Göswein et al. 2022.
45 Material Cultures 2024: 56.
46 Material Cultures 2024: 82.
47 Harte 2017
48 Bauhaus Earth 2024; Harte 2017; Karlsson et al. 2021.
49 Bauhaus Earth 2024; Material Cultures 2024: 54, 62.
50 Bauhaus Earth 2024.
51 Abrahamsen 2017.
52 Peacock 2023.
53 Kropp & Aicher 2024.
54 “It is also reasonably straightforward to design with – it behaves predictably and so is easy to integrate into digital design processes.” Material Cultures 2024: 62.
55 Kropp & Aicher 2024.

56 Material Cultures et al. 2021: 58.
57 Gattupalli 2022.
58 Berge 2009: 176. Examples of such vernacular housing styles in India include Mizo houses, Adi Gallong houses, and the traditional homes constructed by the Riang people. M. Yadav & Mathur 2021.
59 Bauhaus Earth 2024; Prasath & Arunachalam 2017; M. Yadav & Mathur 2021.
60 Bauhaus Earth 2024; M. Yadav & Mathur 2021.
61 BambooU 2022.
62 Young 2024; Wade 2021; Florian 2023. For another contemporary use of bamboo in a fairly "unworked" form, see "The Arc", a gymnasium for a school in Indonesia, which was completed in 2021 and built in a period of just 8 months. A. Griffiths 2021.
63 Lokko et al. 2024
64 Lugt & Vogtlander 2015; Xu et al. 2022; Pomponi et al. 2020.
65 Author's own calculations based on Hart et al. 2021; Lugt & Vogtlander 2015; Xu et al. 2022; Pomponi et al. 2020.
66 Liang et al. 2022; Maddalwar et al. 2024.
67 Flax and hemp crops also produce straw-like materials. Material Cultures 2024:104.
68 Material Cultures 2024: 104, 107.
69 Göswein et al. 2022, cited after Bauhaus Earth 2024.
70 Material Cultures 2024: 107-108.
71 Göswein et al. 2022, cited after Bauhaus Earth 2024.
72 Bauhaus Earth 2024.
73 Duque Schumacher et al. 2020.
74 Bauhaus Earth 2024.
75 Hemp has far lower levels of the psychoactive compound THC (tetrahydrocannabinol) than marijuana. Visković et al. 2023.
76 Rehman et al. 2021.
77 According to a recent study by the Biorenewables Development Centre at the University of York in the UK, industrially-grown hemp crops can sequester up to 22 tonnes of CO2 per hectare annually: "more than any other crop or woodland". BEIS 2021: 9
78 Rehman et al. 2021.
79 Muhit et al. 2024; Designing Buildings Wiki 2020.
80 Strength varies according to the binder used. Cement-based binders impart greater strength. Muhit et al. 2024; Designing Buildings Wiki 2020.
81 M. Yadav & Saini 2022.
82 Pomponi et al. 2020.
83 Arehart et al. 2020.
84 The Stone Collective 2024: 5.
85 For a famous example from the modernist canon of architecture, see Mies Van der Rohe's Barcelona Pavilion. Prieto 2022.
86 Material Cultures 2024: 84.
87 Kucharek 2024; The Stone Collective 2024: 5.
88 The UK is one of the largest importers of granite, most of which comes from China. Portugal, Italy and Spain are all prominent suppliers of stone in Europe. Material Cultures 2024: 84; Kucharek 2024.
89 Material Cultures 2024: 80; Kucharek 2024.
90 The Stone Collective 2024: 5,10.
91 R. Moore 2023; The Stone Collective 2024: 8.
92 Kucharek 2024.
93 The Stone Collective 2024: 18-19.
94 Kucharek 2024; The Stone Collective 2024: 6.
95 Kucharek 2024; The Stone Collective 2024: 8,15.
96 RIBA 2018; Kucharek 2024. Pierre Bideau (quoted above and cited throughout this section) worked on 15 Clerkenwell Close.
97 Buxton 2018; Young 2021. For some other recent examples, see Moore 2023, 2024.
98 Material Cultures 2024: 85.
99 R. Moore 2023.
100 It is virtually infinite, 'with the exception of permanently frozen regions, sand deserts, and naked bedrocks.' Van Damme & Houben 2018
101 Elert et al. 2022
102 Jaquin et al. 2009. The Alhambra was primarily built during the 13th and 14th centuries (de la Torre López, Sebastián, and Rodríguez 1996). The Great Wall of China (most of whose surviving sections date from the Ming dynasty, 1368-1644) is an amalgam of construction materials such as rubble, rammed earth, stone, brick, timber, and mortar (Yang, Tan, and Tan 2017).
103 Tuckey et al. 2023; Westerholm 2023: 38. The use of earth in infrastructure is also common, via the direct rearrangement of the landscape and the effective production of large earthworks. However, we focus here on buildings.
104 Rammed earth construction makes use of formwork molds made of timber, which are used in the same way as in situ cast concrete.
105 Earth blocks and walls are solid, whereas breeze blocks tend to be hollow. UNEP et al. 2018.
106 Singh et al. 2024; Barber 2016.
107 One commonly quoted estimate (dating back to 1983) suggested that a third of the world's population then lived in earth-based buildings. However, that proportion has declined significantly over the last forty years. Marsh and Kulshreshtha 2022.
108 Tuckey et al. 2023.
109 Blondet 2011: 391-392.
110 Needless to say, such advantages could be crucial under conditions of global warming, especially in arid climates, and with increased incidence and severity of heatwaves (see chapter 2.4.1) UNEP 2023a: 60. Rammed earth walls tend to be very thick, and especially when combined with additional interior insulation, this means that windows automatically have in-built solar shading. Tuckey et al. 2023.
111 Material Cultures 2024: 28; Blondet 2011, 392.
112 Tuckey et al. 2023.
113 While clay binds earth together, it can also be the cause of degradation, "due to its response (i.e. swelling or contraction) to changes in the substrate's moisture content. Repeated volume changes and associated stress can result in the deterioration of the consolidant's effectiveness over time." Elert et al. 2022
114 Examples include: Iran in 2003, Peru in 2007, Chile in 2010, and Turkey in 2023. Note that modern buildings also collapsed in these episodes (in particular in Turkey): a fact blamed on poor construction and failures to enforce building codes and regulations. Blondet 2011; D'Ayala & Benzoni 2012; T. Johnson 2023; Reyes et al. 2020.
115 Blondet 2011; Reyes et al. 2020.
116 Misseri et al. 2020. Recent research also suggests the efficacy for seismic protection of shredded recycled car tyres, mixed in with the earth. Belabid et al. 2022.
117 Recommended design options include: detailing that spreads loads while shedding water and long eaves to provide additional protection for exterior walls. Both of these are features of traditional buildings design. Tuckey et al. 2023.
118 Belabid et al. 2022; de la Torre López et al. 1996.
119 Scrivener, John, et al. 2018; Van Damme & Houben 2018.
120 UNEP 2023a: 63.
121 Dove et al. 2016; Mostafa & Uddin 2016; Westerholm 2023.
122 Fischer & Losacker 2024.
123 Fischer & Losacker 2024.
124 Oliver 1997; Rapoport, 1969; Rudofsky 1964.
125 An influential version of this claim was espoused by the British-American anti-modernist architect Christopher Alexander. See Alexander et al. 1977; Alexander 1979; Alexander et al. 1975.
126 For a compendium of examples, see J. Watson 2020. Vernacular architecture (in engineering terms, as well as aesthetics) has long been appreciated by many professional architects and designers. For an early modernist celebration of "architecture without architects", see Rudofsky 1964.
127 D. Watson 2013
128 Westerholm 2023: 28,46
129 Westerholm 2023: 73-91
130 Westerholm 2023.
131 Belabid et al. 2022.
132 Hornberg et al. 2024; IPCC 2022a: 101,956-958. The concept of sufficiency was introduced into policy debates about sustainability by Wolfgang Sachs. Sachs 1993; IPCC 2022a: 957.
133 The IPCC notes that "incumbent business (in contrast to overall economic performance) may face challenges," when such "demand side" interventions are pursued. IPCC 2022a: 523
134 IPCC 2022a: 894.
135 Pattison 2020.
136 Májà-Pearce 2023.
137 Mitchell et al. 2019: 332-347
138 See Mitchell 2013. For a detailed account of monetary finance as a "dysfunctional taboo", see Will Bateman & Jens van 't Klooster (2024).
139 Mitchell et al. 2019: 508.
140 Lemer 1996.
141 Imrie 2021: 123.
142 HLRN 2024: 10,18.
143 Elefante n.d.
144 UN-Habitat 2021.
145 O'Connor 2004.
146 Miller 2020.
147 Miller 2020.
148 Motley 2024. "[I]t is not implausible to estimate that up to 186,000 or even more deaths could be attributable to the current conflict in Gaza." Khatib et al. 2024.
149 Juenger et al. 2011.

150 A 2017 study that looked at the lifetime embodied emissions of a typical public housing unit in Lagos, Nigeria, built with reinforced concrete, found that an astonishing 41 % of those lifetime emissions came from the maintenance of the building ("recurring" embodied emissions), and that around a third of those were due simply to a recurrent need for repainting. Ezema et al. 2017.

151 LETI 2020: 63; Gorse et al. 2020.

152 Moe & Friedman 2024

153 Miller 2020. Another study, looking at Japan, estimates that extending the future service life of all buildings by 90 % (that is, roughly doubling their lifetime of use), and extending the lifetime of all infrastructure by 30 %, would together reduce Japan's annual cement consumption by 4 %. Watari et al. 2022.

154 With respect to the use of materials such as UHPC, "overdesigned materials and systems that have high production impacts and last longer than the desired service-period would lead to waste of viable products [ie, construction materials]." Miller 2020.

155 For some interesting case studies in the context of Ireland, see Paul Keogh Architects 2012.

156 Lacaton & Vassal 2017

157 The Pritzker Architecture Prize 2021.

158 Between 2030 and 2050, the EU's buildings will require renovations at the rate of 3 % of the entire building stock renovated every year. Presently, the rate of deep retrofits stands at just 0.2 % per year. BPIE 2021: 2,8,9, 2017

159 Göswein et al. 2022, cited after Bauhaus Earth 2024.

160 Anguelovski et al 2022; Heindl 2022; Dooling 2013

161 Tuckey et al. 2023.

162 Kalleshwaraswamy et al. 2022.

163 A nice example of failure in all these respects is provided by the teak window assemblies of architect Louis Kahn's celebrated Salk Institute for Biological Studies, in La Jolla, California. The material appears to have been specified for (legitimate) aesthetic reasons; with an appreciation of how the material would weather under other circumstances; but without onboarding the client in its required care, and (more importantly) without attending to the likely far greater extent of wear imposed by the ocean air of the site. Resulting changes in appearance were not appreciated by the owner of the building, who pursued an ill-advised and long-term "maintenance" routine that significantly harmed the teak. Moe & Friedman 2024.

164 Stricker et al. 2021: 279.

165 Kanters 2020.

166 Stricker et al. 2021: 278-279.

167 Aneke and Shabangu 2021.

168 Designing Buildings Wiki 2021.

169 Stricker et al. 2021: 284-285.

170 UNEP 2023a: 23. See, for instance, Orms 2021.

171 RotorDC n.d.

172 IPCC 2022a: 958.

173 Berkhout et al. 2000; Zink & Geyer 2017.

174 Siderius & Poldner 2021.

175 Also known as "light-weighting" (Hertwich et al. 2019; LETI 2020: 61). In German, *Leichtbauweise* (lightweight construction). *Leichtbauweise* principles are used in *Skelettbau* (skeletal building), which characteristically relies on steel or timber in order to separate the function of load-bearing from space-enclosure. *Leichtbauweise* and *Skelettbau* both contrast with *Massivbauweise* (massive / solid construction), which uses masonry (concrete, bricks) to perform the dual function of load-bearing and space-enclosure.

176 LETI 2020: 74. In Japan, approximately 2 % of all concrete consumed is presently lost as needless on-site construction waste. Watari et al. 2022.

177 For instance, by varying concrete reinforcement or durability requirements for different parts of a structure. A recent survey of the literature cites a 50-90 % variation in greenhouse gas emissions for different reinforced concrete columns that all nevertheless perform exactly the same function, and meet the same building code requirements. It notes similar variations in specification and embodied emissions for components placed under bending tension, such as building floor slabs. Miller et al. 2024.

178 Allwood & Cullen 2012: 183.

179 See, for instance, the Christchurch earthquakes in New Zealand in 2010-11. Rafferty & Murray 2024.

180 In Medellín, Colombia, the "Space Building" residential complex partially collapsed shortly after its completion in 2013 and was subsequently demolished. The collapse was blamed on the deficient structural capacities of the supporting columns, caused by extreme efforts of optimization. Yamin et al. 2018.

181 Harms include habitat fragmentation and biodiversity loss, "sealing up" (chapter 2.X), and pollution. Damarad & Bekker 2003; UNEP 2023b: ix.

182 UNEP 2023b: 7.

183 Müller et al. 2013; Fisch-Romito 2021; Watari, Cabrera Serrenho, et al. 2023.

184 Fisch-Romito 2021.

185 J. Watson et al. 2021.

186 Hussain et al 2014; van der Zaag & Gupta 2008; Brauns et al 2022.

187 This also delivered large economic savings for the state (1.5 billion USD). Browder et al. 2019: 9, 55-58, 86

188 Rau 2022.

189 IPCC 2022b: 1360.

190 UNEP 2023a: 1-2, 14, 19–26. Daro Justine & Seenath 2025.

191 UNEP 2023a: 1.

192 Daro Justine & Seenath 2025; Dunn et al 2022; Esraz-Ul-Zannat et al 2024.

193 The UN Environment Programme proposes the three core functions of NBI: delivery of services; protection; and enhancement of existing infrastructure. UNEP 2023a: 7-28.

194 Key et al. 2022.

195 UNEP 2023a: 32-34, 41.

196 Seddon et al. 2021.

197 Key et al. 2022; Seddon et al. 2021.

198 IPCC 2022a: 897-899.

199 Grubler et al. 2018. In 2018 this was judged to be wholly attainable, while still constraining global warming to 1.5°C above pre-industrial levels.

200 Müller et al. 2013; IPCC 2022a: 897-899.

201 Lampugnani 2023: 50.

202 Ahlfeldt & Pietrostefani 2017. Less motor vehicles on the roads means fewer tailpipe emissions and fewer other harmful pollutants: even electric vehicles, for instance, produce "nontailpipe emissions" arising from dust, from the abrasion of vehicle brake pads and tyres, and the wear and tear of road surfaces. Boogaard et al. 2022; HEI Panel on the Health Effects of Long-Term Exposure to Traffic-Related Air Pollution 2022.

203 Herriges 2024; Stange 2022.

204 Quednau 2024.

205 See, for instance, recent community campaigns against infill development in Southwark in London. Southwark Notes 2021; Anguelovski et al., 2022.

206 Nieuwenhuijsen et al. 2024. The superblock model reconfigures the original, very good, "Cerdà plan" of 1855, which had fallen prey to infill construction, domination by private cars, and the erosion of green space. See Amati et al. 2024.

207 Szabo et al. 2022.

208 Anguelovski et al 2023

209 Pomponi et al. 2021.

210 Lampugnani 2023: 50-54. One recent study conducted a quantitative assessment and reached the conclusion that mid-rise buildings of approximately 6-10 storeys set together in a medium density offers the most environmentally friendly option for buildings (Pomponi et al. 2021).

211 Broadbent 1995: 177.

212 P. Barber 2018: 56.

213 P. Barber 2018: 60. Barber quotes Walther Benjamin writing about Naples in *One-Way Street (Einbahnstraße,* 1928): "Buildings and action interpenetrate in the courtyards, arcades and stairways. In everything they preserve the scope to become a theatre of new unforeseen constellations. The stamp of the definitive is avoided. No situation appears intended forever." P. Barber 2018: 52; Benjamin 1996: 416.

214 Westerholm 2023: 73-91.

215 Watari et al. 2022.

216 Brand 2020.

217 Reasons for this include "growing social prosperity, increasing individualization, changing gender relations, demographic change, changes in the labour market, such as the erosion of the single-earner model, and also values, norms and ideas of normality that are changing along with material conditions" Authors' translation from Lage & Christ 2020: 191.

218 Lage & Christ 2020: 190-191.

219 Lage & Christ 2020: 191.

220 Lage et al. 2025.

221 Heindl 2022: 224.

222 D. A. Barber 2024; Glaeser & Ratti 2023.

223 Zimmermann et al. 2023: 40-42.

224 The vision is based to a large extent on Schreiber et al. 2023.

225 Harriss et al. 2020; Minkjan 2019.

5 Political levers

Overcoming the damages of concrete and moving beyond the techno-optimist framings of the cement industry towards a regenerative, people-driven and vernacular built environment will not be achieved by simply appealing to governments or companies. It will only result from collective struggles. In this chapter, we introduce seven political levers that can transform the built environment and its industries.

Transforming construction is complex and challenging. There are significant and growing needs for housing, enormous volumes of decaying infrastructure that need replacement, and significant shares of jobs and GDP dependent on cement and concrete. Any transition in this area will be confronted by the political power and the vested interests of the cement giants (see 3.1), and has to work with the existing socio-technological systems (see 4.2.7) and concrete-based imperial modes of living (see 1.3).

Given the significant challenges for the transition away from Portland cement, there is no silver bullet or simple solution, but there is a need to discuss a multitude of strategies and tactics that involve not only politics and business, but also activists, communities and workers. For this, we adapt and build upon the framework of sociologist Erik Olin Wright, who in his book *Envisioning Real Utopias* presented an approach featuring three basic transformational strategies: counter-hegemony; transformative reforms; nowtopias.[1] We explain these strategies below.

The goal of moving beyond Portland cement stands in direct opposition to many vested interests, investments, and technological pathways, particularly within the cement and concrete industry. Hegemony refers to the dominance of certain ideas, practices, and power structures that become accepted as normal or inevitable, even when they serve the interests of a powerful few. There is a need for disruptions that stop the expansion of this material and related efforts to build *counter-hegemony*. This counter-hegemony involves directly contesting the destructive status quo and the hegemonic norms, ideas, and practices of global "development" and construction while advancing new ideas of what is good and necessary. We can also call these "ruptural strategies" – approaches that deliberately break with existing systems and create openings for alternative ways of organizing society and the built environment. Central actors in these ruptural strategies can be local (often Indigenous) communities that are impacted by the cement industry's damages, place-based struggles of "blockadia" against mining, industry, and infrastructure, as well as organized workers and wider social movements, including artists, architects, and designers.

The potential victories of protests, blockades and counter-hegemonic interventions can be complemented by reforms within existing institutions and radical politics through *symbiotic strategies*. These strategies begin with existing structures (from building standards to finance and housing law) but aim at transforming these to move beyond not only Portland cement and the world it has built, but also beyond the capitalist, growth-oriented construction sector by shifting resources and power towards those in need and those working on real solutions. The main actors of this strategy will likely be green and leftist parties, lawyers and other experts. Beyond that, strategic alliances are possible, since a regenerative, vernacular, people-driven built environment would bring direct benefits for middle classes within cities, and this transition will create opportunities for factions of green capital and competing industries.

Finally, creating small-scale or immediate versions of a world beyond cement can serve as important prefigurations within the niches of the current extractive system. Scaling up non-concrete-based construction methods, the political downscaling of Portland cements, and developing a post-concrete imaginary all require experimentation with real solutions based on other materials and construction methods but crucially also social innovations that make certain kinds of construction obsolete. Central in these “interstitial strategies” are local communities, especially the ones neglected or even actively harmed by the existing construction system – namely the urban dispossessed. It also involves architects, innovators, small businesses, and all those involved in vernacular forms of construction. Their work does more than inspire alternatives: it redistributes knowledge, resources, and agency in the construction sector. By reviving local materials, skills, and ownership models, they reduce dependence on corporate supply chains and cement-intensive infrastructure. In doing so, they shift power structures within the built environment away from global conglomerates and towards communities capable of shaping and maintaining their surroundings. These grounded experiments demonstrate how construction can occur within ecological limits while strengthening local economies and collective control.

Throughout these three categories, we have identified seven political levers for improving the kinds of cement that are used, for changing materials, and for using fewer materials overall (see Figure 5.1 and Table 5.1). We focus particularly on the countries in the Global North, mainly because of the extensive concrete stocks already built up in these regions and the resulting need for phasing out concrete, but also since most of the authors are situated there.

Figure 5.1: Political levers for transforming construction (authors' illustration).

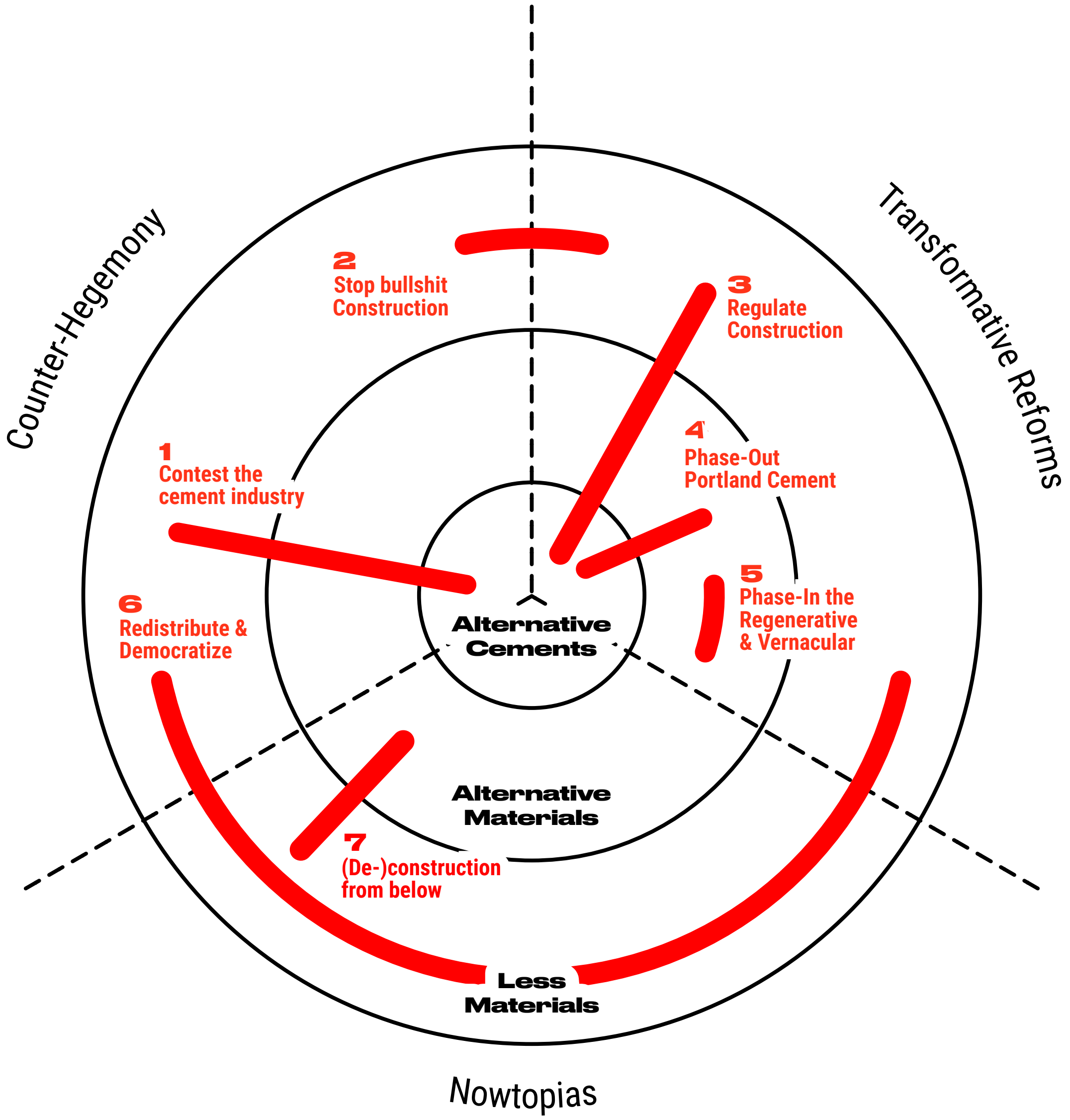


Table 5.1: Proposed political levers for transforming construction.

Lever	**Counter-Hegemonic Tactics** for social movements.	**Transformative Reform Tactics** for progressive parties.	**Nowtopia Tactics** for local communities.
1. Contest the Cement Industry: Expose & stop the damages and narrative of the industry directly.	Civil disobedience, legal challenges, sabotage. Spread of counter-hegemonic narratives (i.e. through alternative plans, art).		
2. Stop Bullshit Construction: Expose & stop the damages and narratives of bullshit construction directly.	Civil disobedience, legal challenges, sabotage. Spread of counter-hegemonic narratives (i.e. through alternative plans, art). Workers-led "Green Bans".	Moratoria on Demolition.	
3. Regulate Construction: Regulate all construction projects towards regenerative practices.		Removal of restrictive regulation. Regulation on new construction to enforce the use of alternative materials, participatory design processes etc. Regenerative public housing.	
4. Phase out Portland cement: Phase Out Portland cement and secure a Just Transition.		Full pricing of future (carbon pricing) and past CO_2 emissions (climate reparations). Limits on Portland cement production. Strict air pollution and biodiversity regulation. Reskilling and safety net for workers.	
5. Phase in the Regenerative: Build up regenerative and vernacular construction.		Local governments: revival & build-up of local regenerative supply chains. (Supra-)national governments: regenerative industrial policy, funding, environmental & labour regulation.	
6. Redistribute & Democratize: Redistribute and democratize the built environment.	Tenant unions, anti-gentrification movements, neighbourhood assemblies to reclaim the city and build power on a local level	Fight speculation and luxury housing. Participatory governance. Participatory or deliberative planning. Housing in common ownership.	Bottom-up housing in common ownership.
7. (De-)construct from below: Start community-led construction and deconstruction outside the construction system.			Construction from below by Circumventing the industrialized housing system. Depaving initiatives.

5.1 Contest the cement industry

The cement industry has successfully presented itself as necessary and part of a green future, for which we need to accept the damages that cannot be avoided. They even claim to be an essential solution for adapting our world to climate breakdown.[2] But as its own techno-optimist answers are insufficient, the first political lever is to contest their hegemonic narratives and exploitative practices, as well as the false solutions they present.

Figure 5.2: Blockade of a Heidelberg Materials cement plant in Leimen, Germany.

Source: Courtesy of Extinction Rebellion. Used with permission.

While critical research can play its part in contesting the industry, the central role falls to social movements. Protest, most importantly civil disobedience, has been historically vital in shifting hegemonic ideas of what is good and necessary in society. As we've seen throughout the case studies, people around the world have already begun with this, be it the Samin in Indonesia, Climate Activists in Sweden or Farmers in Slovenia. Those involved have used an extensive repertoire of tactics, ranging from demonstrations to legal challenges, blockades and sabotages, to not only expose the damages, but also to stop them.

These struggles have, up to date, only reached a local or regional scale. One major reason for this is the decentralized and mostly domestic nature of limestone mining, with extraction sites often comparatively small but pretty numerous, leading to equally dispersed conflicts.

These struggles could be stronger if they worked together instead of fighting in isolation, making each other more visible. With better networks and connected organizations, the cement industry's spread-out geography could actually help, since it creates many opportunities for disruptive action. The industry's centralized ownership – with just a few large companies controlling almost everything – also creates opportunities for coordinated resistance and international solidarity. Additionally, while activists must focus on the cement industry as the main problem in construction, they should also watch out for the harmful effects of alternative approaches to make sure we don't just replace one destructive system with another (like unsustainable timber harvesting).

Figure 5.3: Struggles against Holcim and Heidelberg Materials around the world.[3]

5.2 Stop bullshit construction

The second political lever is to contest and stop unnecessary, "bullshit construction" – that is, construction for elite projects and conspicuous consumption (mega mansions, infrastructure for the rich such as private jet airports, mega malls), for financial speculation and exchange value production (such as ghost cities) or that is socially and environmentally unjust (see 4.3.2).

Developers and state institutions often present megaprojects and other capital-serving infrastructure as unavoidable, while countless bottom-up initiatives are left to expose the potential damages and develop alternative solutions. Such protests are already widespread, pursued mostly by local communities, environmental groups, and housing activists. These efforts typically focus on potential biodiversity loss, neighbourhood fragmentation, historic preservation, resource use, or displacement of residents.[4]

Activists employ an impressive range of tactics – from deconstructing the hegemonic narratives of unavoidable Autobahns to artistic interventions to civil disobedience aimed at directly stopping construction. Protests can arguably be most powerful when construction workers themselves are centrally involved. One spectacular example of this has been the "green bans" in Australia in the 1970s, in which the largest construction labour union worked together with local communities to successfully stall or even stop environmentally damaging construction projects. Amongst other victories, they successfully halted the replacement of Sydney's Royal Botanic Gardens with a car park as well as the demolition of historic buildings in The Rocks area to make way for office buildings.[5]

A renewed alliance of local communities and construction workers could become crucially important in efforts to transform the building industry, especially as construction workers are nowadays at an additional crucial intersection. On the one hand, they're the ones actually pouring the concrete, while on the other hand, they are one of the professions most directly impacted by climate change through intense heat during the workday.[6]

Another potential for strengthening future protests lies in connecting the fights against bullshit construction with protests that directly focus on the construction material and target the cement industry. Currently, it's mostly only developers and politicians that are blamed for bullshit construction projects, not the cement industry, despite its material being a main factor in these developments. But concrete has become so omnipresent and considered so useful, that its usage tends to be considered neutral or even natural.[7] This is even more true of the cement industry, hidden even one step further from everyday life, except when its production sites are nearby.

The bottom-up approach of stopping bullshit construction directly could also be complemented with demolition moratoria, implemented by public institutions. Such moratoria could be enacted by local or national bodies and would require that any developer wanting to demolish a building would need to verify first that the structure can no longer be rescued or reused based on an environmental assessment. While short-term demolition moratoria are already a widespread part of city governance, an indefinite moratorium is yet to be seen and urgently called for by many, most notably in Germany in 2022 by a large coalition of construction professionals including the Association of German Architects.[8] The ultimate effect of such a moratorium would not only be the immediate materials and social environments saved, but more importantly, this could contribute to a paradigm shift beyond throwaway architecture.

5.3 Regulate construction

The third major political lever is to fight for urgently needed regulation to make sure that all current and future construction projects are working towards a regenerative, vernacular & people-driven built environment that serves people's needs and respects planetary boundaries. Various demand-side levers, which could build on ongoing experiments in implementing the "Doughnut" model at city levels (such as Amsterdam),[9] could thus regulate not only all public projects, but all private construction projects as well, implemented through state taxation, subsidies and restrictions.

The first step must be to remove restrictive regulation for construction projects, most importantly building standards based on traditional Portland cement (see 3.1.2). The use of any other material is heavily disincentivized in the litigious and risk-averse construction sector.[10] These should be switched to performance-based standards, which would allow for a diversity of building materials and techniques to be used, adaptable to local conditions and resources.[11] Equally, state policies and taxation systems encouraging suburban sprawl, commodification and financialization of housing must come to an end quickly.[12]

The second step should be to establish "shovel-worthy" criteria for new construction, based on whether it would contribute to the regenerative, vernacular and people-driven built environment or not. These could include the materials used (i.e. limits on Portland cement per square metre and obligatory Whole Life Cycle Assessments), the planning process (i.e. that it must be co-designed by the community), the construction process (i.e. that local labour cooperatives should be preferred), the structures' uses (i.e. strict limit on living space per capita and enabling mixed-use) and its lifecycle (i.e. that it must be built loose-fit and for disassembly).[13] The exact formulation of these criteria could be set by citizens assemblies, uniting both expert knowledge and the knowledge and visions of those whose needs are to be satisfied, while possibly avoiding elite capture and industry lobbying.[14]

Even if public procurement alone was based on a thorough list of criteria, this could have large impacts through a spillover effect into private construction,[15] since this already creates an essential demand-side incentive for regenerative building materials and practices and stabilizes alternative industries. This incentive can speed up, for example, firms investing in alternative cement production facilities[16] or training centres introducing courses for bio-based construction.[17]

But as the bulk of construction currently happens in the private sector, these criteria must be expanded to private development as well, through rigid regulation, but also through conditional credits, taxes and subsidies.[18] While some criteria could be set nationally (for example, retrofitting should obviously be supported first and foremost) local variation could be important, especially when local supply-chains are built up and nurtured (see 5.4). Additionally, these measures should not hurt the less well-off or only serve as additional profit for the well-off, requiring for example measures to ensure costs are borne by landlords, not tenants, or special programmes for communities in informal settlements.[19]

Third, to make sure that needs are met and materials not wasted, the state should take on a more active role in the provision of housing and infrastructure oriented towards the common good. "Market forces" and privatization have not delivered on the urgently needed housing and have instead wasted colossal amounts of materials for unnecessary and elite-centred construction.[20] Ideally, this would happen through expansion of existing public housing through eminent domain or expropriation from private companies, followed by retrofitting, expansion and social reorientation. But to avoid repeating past mistakes of public housing – namely social segregation and technocratic management – new forms of participatory governance within public housing are needed (see 5.6). Also, reimagined public housing could focus on sufficiency and the just distribution of existing housing, thus countering the trend of average living space being pushed up by excessively large single family homes, and enabling a needs-based allocation of apartments.[21]

State action and regulation on regenerative construction is urgently needed. By combining this with support for retrofits and increasing the stock of modern public housing, this political lever could probably garner a broad alliance, especially from those pushed out of increasingly unaffordable cities.

5.4 Phase out Portland cement

The fourth political lever is a state-led deliberate phase-out of Portland cement – the just transition of the cement industry and construction industry. Just like the burning of coal, gas and oil, the calcination of limestone is a climate killer and must be phased out. This can happen through two measures: pricing and limits, guided by principles of a "Just Transition".

Pricing would mean implementing the "polluter pays" principle, and fully integrating cement and other construction materials into carbon pricing schemes. Together with the costs of CCS and other technical efficiency measures, this could considerably raise the price for cement and thus incentivize alternatives.[22]

While not a transformative game-changer politically, and problematic in driving up prices in the construction sector in general and thus acting as a socially unjust tax, fully integrating cement and other construction materials into existing emissions trading schemes will make many other measures easier. All the more so, if the price of emissions is continuously raised and income from taxes is redistributed on a per capita basis to everyone, this measure could be both effective and socially just.

Additionally, past damages should not be forgotten, as every dollar of cement industry profit has relied on extensive amounts of historical CO_2 emissions. Therefore, climate reparations, as the Pari residents are currently demanding from Holcim (see Case Study A.1), should be part of the demand and could add up to considerable yearly payments.[23]

A complementary measure could be strict, yearly decreasing limits on the production of Portland cement, more precisely on limestone extracted for calcination. An important historic precedent for such limits has been the effective international phase-out of ozone depleting CFCs through the Montreal Protocol beginning in 1989. A similar global phase-out, or "Portland cement non-proliferation treaty", could take into account globally differentiated needs, ecological and climate debt, the concept of "contraction and convergence", and socially just transitions. Although harder to achieve than a pricing mechanism, this could prove more reliable and egalitarian. And as limestone extraction mostly happens domestically, this could be led through national phase-out plans.[24]

Until Portland cement has been phased out, the environmental damages of the cement and concrete industry – beyond its climate impact – must be curbed as well. This would include strict biodiversity measures at quarries and thorough limits on air pollution. Finally, there is a need for a "Just Transition" such that already intensely exploited construction and building materials workers are not hurt most by this transition. This must involve unions, social safety nets, and state support of upskilling in the use of regenerative materials (see 5.5).

5.5 Phase in the regenerative and vernacular

The fourth political lever is supporting the revival, innovations in, and expansion of future-fit, regenerative and vernacular construction. This is a huge shift, requiring change in "construction practices at every level, from education and training through to insurance and maintenance regimes".[25] The market and pricing mechanisms won't solve this transformation on their own. Therefore state institutions need to take an active role, partly in a supporting role that strengthens new ownership models along the lines of common – and community-driven – ownership.[26]

Local and regional governments are absolutely central here, as construction must be moved towards local resources, labour and supply-chains that need to be imagined, nurtured and built differently everywhere (see 4.2.7). Although this shift is enormously challenging, local and regional governments could benefit greatly from it, as it could support local jobs and investments.[27]

These policies require a supportive regulatory environment (such as indices and standards for the possible deconstruction of buildings or the usage of wastes);[28] and fiscal capacity – which must be ensured by national and supranational bodies.[29] One can hardly imagine municipalities investing in new supply chains while an austerity regime or extremely restrictive fiscal rules prevail, as they do in the EU.

Additionally, national and supranational bodies should also steer industrial policy in accord with the requirements of a regenerative construction sector. Instead of channeling state subsidies towards one-off CCS projects, effectively just enabling the status quo to continue, the state could enhance and foster the truly important innovations within the production of alternative cements and alternatives to cement.

Finally, it's up to (supra-) national legislation to ensure that this new construction wave is governed by meaningful environmental and labour regulation. Without clear standards and enforcement, even well-intentioned regenerative practices risk reproducing the same extractive logics under a "green" label. Environmental regulation should therefore go beyond carbon accounting and address land-use, material sourcing, biodiversity impacts, and the circularity of building materials. Similarly, labour regulation must safeguard workers' rights and ensure that emerging local construction economies do not rely on precarious, underpaid, or informal labour. In the best case, the transition to regenerative and vernacular construction could substantially improve working conditions – making construction jobs safer, more skilled, and more autonomous, as workers gain control over local processes and materials.

5.6 Redistribute and democratise

The sixth political lever focuses on the redistribution and democratization of the built environment. To do "more with less", saving materials while meeting real needs, it's essential to highlight the principle of sufficiency, to end unjust overconsumption by some and guarantee a just distribution of usage rights for infrastructures and buildings.[30]

The first step must obviously be to deal with excessive vacant spaces lying idle for speculation and luxury housing, which diminish the housing stock for the less well-off. State regulation can address this indirectly, through taxes and limits, such as caps on rents, heavy taxation of excessive living space, and taxation on commercially- and residentially-zoned land that is kept unused for speculative purposes.[31] Another option is direct state involvement, through for example the socialization of large housing companies and their subsequent reorientation towards affordable and shared housing.

The second step must be to democratize the governance of neighbourhoods, blocks and cities, to work towards shared spaces and, as Mariana Mazzucato and Dan Hill argue, to "unlock ways of living in less individual space, yet with greater collective possibility, generating forms of increased abundance through shared 'public luxuries'."[32] Only through participative practices can we "unlock these richer sets of possibilities for sustainable building and living in a way that speculative housing – designed for unknown, generic and individualized 'units of human' – usually cannot."[33]

A key component should be participatory or deliberative planning processes. If meaningfully implemented, these can help build community while also addressing the complex challenge of working towards increased density, mixed-use neighbourhoods, careful clustering (densifying while preserving access to light, air, and green space), localized construction, and urgent needs. By including multiple perspectives from the start, existing neighbourhoods can be reimagined and woven together more effectively.[34]

To democratize in the long-term, buildings, infrastructure and land should be moved into common ownership, governed by residents and communities themselves. For buildings this can take the form of cooperatives, not-for-profit and limited-profit associations as well as shared self-build construction,[35] while for example community land trusts can play an important role in land governance. Collectively owned or managed housing has a long and rich history, built up as nowtopias by local communities – functioning as a "niche" between public and private housing.[36] While local communities are central to the creation of these projects, state institutions must provide the appropriate regulatory and financial environment and can also provide direct support through for example reduced taxation, provision of legal guides and other kinds of information, direct financial assistance and regularization of squatted buildings.[37] There is also significant potential in public-commons partnerships such as letting renters in public housing co-manage their housing, as this reduces the failures of top-down governance and shields housing against privatization during future neoliberal policy shifts.[38]

5.7 (De-) construction from below

The seventh and final political lever is to encourage niches and societal experiments – the nowtopias. Instead of waiting for the overall system to shift, this strategy is based on practical examples that envision post-concrete futures and experiment with concrete spaces for cultural experimentation.

First, this can take the form of depaving: mostly community-led removal of concrete and re-introducing natural elements. These actions have spread rapidly around the globe and create direct change within the built environment, while creating strong ties between neighbours and offering a vision of a different built environment. Illustrative examples are the "Depave" organization based in Portland, US; the "ruelle verte" movement in Montreal, which started as a citizens movement to green and depave alleys and became official city policy to manage rainwater drainage; or the "Tegelwippen" initiative which gamified the actions into a contest of Dutch cities.[39]

Figure 5.4: People depaving in the Pierce Conservation District, Washington State, USA.

Source: STORM Outreach. Public Domain. https://commons.wikimedia.org/wiki/File:Depaving.jpg

Another form of bottom-up efforts can be self-built housing outside of the classic housing supply system. Building on centuries of vernacular architecture, modern open systems and commoning structures, such as community land trusts, self-build housing has seen a new upsurge, as with Bristol's WeCanMake initiative or Wikihouse's Skylark system.[40] These allow for self-organized, sustainable, modern housing that can fill in the gaps in neighbourhoods.

While both depaving and self-built housing are immediate, small-scale steps in the overall transition, their more important power lies in illustrating a different practice of construction and how much community and "public luxury" there is to win.

Overall, while the challenge remains enormous, there is so much that can be won. Thinking beyond the techno-optimist tunnel vision of the concrete and cement industry can allow us to turn our built environment from a climate killer to a carbon sink, while changing construction from a substantially extractive industry, to a local, circular and regenerative practice.

Endnotes

1 The following paragraphs draw from E. O. Wright 2010: 303-307 and Schmelzer et al. 2022: 251-282.
2 GCCA 2021b.
3 Author's own research and Temper et al. 2018; Wüthrich 2020.
4 Examples include protests against the Indian Enayam port project, German Stuttgart21, French A69 motorway, Indonesian Karawang airport, British Heathrow expansion, the Dakota Access oil pipeline in the US or the Nigerian Obudu Airport project. EJOLT n.d.
5 Koffman 2021.
6 Schaupp 2024: 293-295.
7 Wieser et al. 2023: 23.
8 Abrissmoratorium 2022.
9 Florian 2024.
10 Material Cultures 2024: 68.
11 This affects both alternative cements, but also alternative materials. One example can be the regulation of timber, which can be based on a certain type of wood while including different, less widespread timber types, therefore encouraging monocultures. Alliance for Low-carbon Cement & Concrete 2024; Material Cultures 2024: 68.
12 Mazzucato & Farha 2023.
13 TAL 2021.
14 Durand et al. 2024.
15 Zhang et al. 2018.
16 Several municipalities and regions have already enacted resolutions on the use of low-carbon cements or setting limits on the use of Portland cement (Adams 2021).
17 Islam et al. 2021: 111.
18 Initial steps in this direction can be seen in France, where new public materials must include a certain percentage of timber, while in the Netherlands, Life Cycle Analyses are required by all construction projects. A more ambitious proposal is brought forwards by several construction industry players in the UK to set hard and tightening limits to embodied carbon emissions of construction projects. Islam & Moatazed-Keivani 2023: 110.
19 Hill & Mazzucato 2024: 40.
20 Mazzucato & Farha 2023.
21 Park 2022.
22 S. Griffiths et al. 2023.
23 Grasso & Heede 2023.
24 Chivers 2024.
25 Material Cultures 2024: 37.
26 Hill & Mazzucato 2024: 5.
27 Powerful examples of such local transitions have been drawn up in Islam et al. 2021; Islam & Moatazed-Keivani 2023.
28 ACAN et al. 2024.
29 Murau et al. 2024.
30 Hill & Mazzucato 2024: 46.
31 Mazzucato & Farha 2023: 25.
32 Hill & Mazzucato 2024: 46.
33 Hill & Mazzucato 2024: 27.
34 Successful examples are co-design processes surrounding Barcelona's Superblocks and the rebuilding of Constitución in Chile. Hill & Mazzucato 2024: 27,30,36; TAL 2021: 24-25.
35 Hill & Mazzucato 2024: 12.
36 Examples of housing cooperatives and their minimized resource use spread from Zurich's Mehr Als Wohnen to Malbourne's Nightingale and Uruguay's FUCVAM. Ferreri & Vidal 2022; Hill & Mazzucato 2024: 12-14.
37 Ferreri & Vidal 2022.
38 An illustrative example is the socialization model of the German 'Deutsche Wohnen & Co Enteignen' initiative where a joint council constituted by state officials, residents, civil society representatives and workers would make the key decisions. Deutsche Wohnen & Co enteignen 2021. For an overview on public-common partnerships in housing see Lawson 2020.
39 Baraniuk 2024; Depave 2024; NK Tegelwippen n.d; Regroupement des éco-quartiers n.d.
40 Hill & Mazzucato 2024: 18-19.

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