Concrete 2.0

PARKASSOCIATI

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Intro

What is concrete?

Concrete is a composite material composed of cement, water, coarse and fine aggregates, and sometimes additional chemical admixtures. It is one of the most widely used construction materials due to its strength, durability, and versatility. The primary component of concrete is cement, which is a fine powder made from limestone, clay, shells, and silica. When mixed with water, it forms a paste that binds the aggregates together and hardens over time through a process called hydration. Coarse aggregates, such as gravel or crushed stone, and fine aggregates, such as sand, are mixed with the cement paste to provide bulk and fill the gaps between the particles. This combination creates a solid and strong material when properly mixed and cured.

Concrete can be customized to meet specific requirements by adjusting the proportions of its components. By varying the mix, different properties can be achieved, including strength, workability, and resistance to environmental conditions such as freeze-thaw cycles or chemical exposure. Once poured or placed into the desired formwork or molds, concrete is left to cure and harden. This process typically takes several days or weeks, during which the hydration reactions continue and the concrete gains strength. Afterward, the hardened concrete forms a solid mass that can withstand compressive forces and is used in various construction applications, such as buildings, bridges, roads, dams, and more.

Composition

Cement

Cement is the binding agent in concrete. It is typically made from a mixture of limestone, clay, shells, and silica that are finely ground into a powder. The most commonly used cement is Portland cement.

Water

Water is added to the cement to form a paste. This paste binds the aggregates together and initiates the chemical reaction known as hydration, which causes the mixture to harden and gain strength over time.

Fine aggregates

These are smaller particles, typically sand, which fill the gaps between the larger particles and help to create a dense and solid concrete composition.

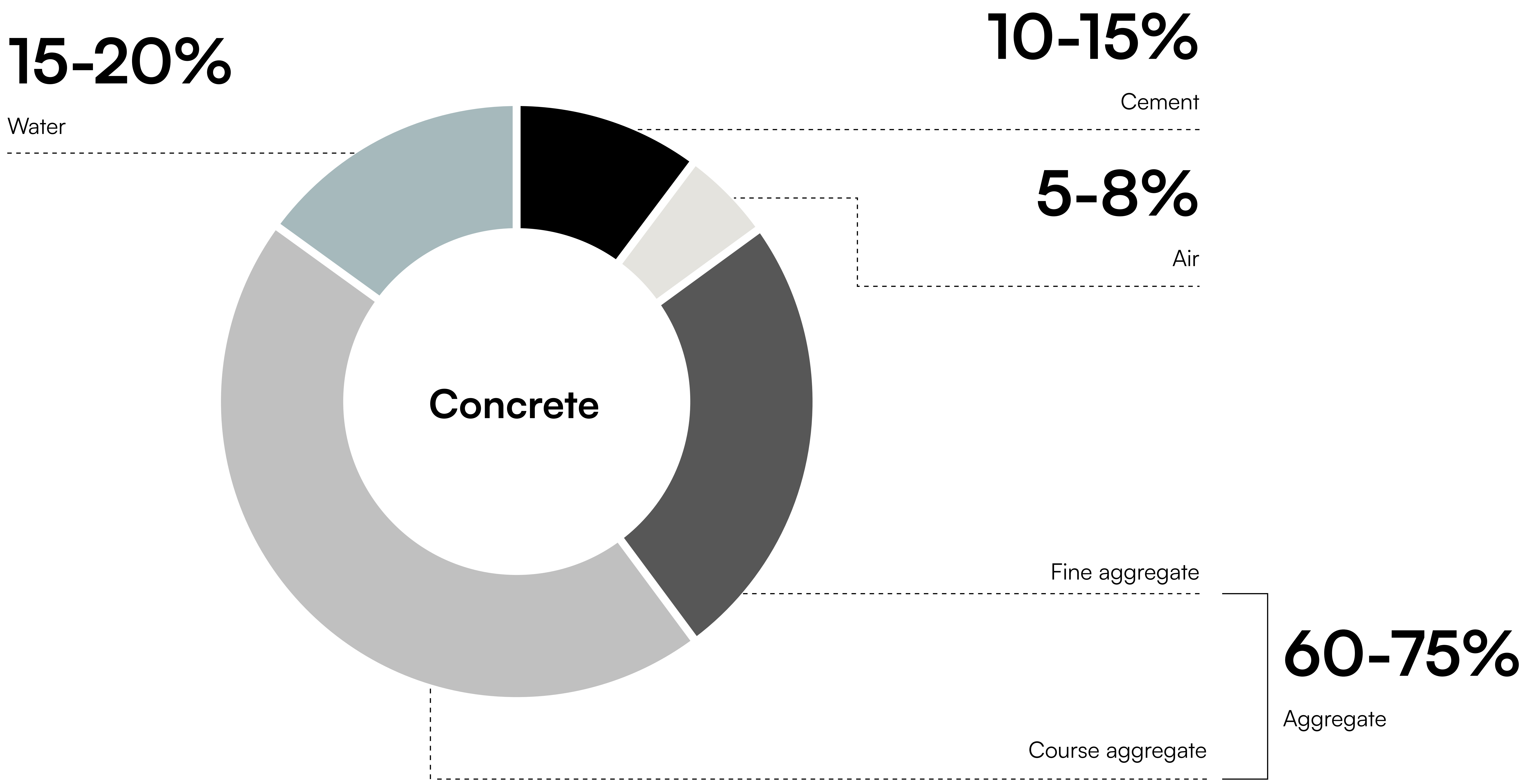
Coarse aggregates

These are larger particles such as gravel or crushed stone. They provide bulk and stability to the concrete mixture.

Admixtures

Admixtures are optional ingredients that are added to concrete to enhance its properties or improve workability. They can include chemical compounds such as plasticizers, accelerators, retarders, air entrainers, or superplasticizers.

Composition



Source: Concrete State Org

Concrete is the most abundant manufactured material on earth. It provides the literal foundations of modern life, but this comes with a high environmental cost.

Timeline

3000 BC	Egyptian pyramids
800 — 400 BC	Great Wall of China
300 — 500 AD	Roman architecture
1824	Portland cement was invented
1903	First concrete high-rise (The Ingalls Building, Ohio)
1936	Hoover Dam
1956	1992 U.S. Interstate highway system
1963	First concrete sport dome (Assembly Hall, Illinois)
1992	Tallest reinforced concrete skyscraper (Central Plaza, Hong Kong)

Role of concrete

Concrete is a complex material that is both indispensable and challenging to live with. Despite its seemingly basic composition of cement, water, and inert materials, it has played a pivotal role in construction throughout history, propelling us into the modern era. However, as we face the crisis of climate change, our approach to concrete usage must undergo a profound transformation as its production cycle contributes significantly to emissions. In the past, we have harnessed the admirable qualities of concrete, and today we rely on it as a fundamental element in shaping the anthropogenic changes occurring in our biosphere. Yet, unless we address the inherent issues in its production, we will suffer the severe consequences it poses to the ecosystem. Numerous alternative solutions are now being proposed, ranging from altering production methods to developing less environmentally impactful substitutes or even phasing it out entirely.

Although eliminating concrete might appear as the most appealing option among these proposals, the most effective strategy at present is to use concrete sparingly, employing it only where necessary and employing low-emission techniques in its production. By adopting this approach, we can strike a balance between leveraging the benefits of concrete while minimizing its detrimental effects on the environment.

The cement industry is responsible for 8% of global carbon dioxide emissions, surpassing emissions from global aviation. If the cement industry were a country, it would be the third-largest emitter of carbon dioxide in the world, after the U.S. and China.

Global Concrete Production

3 years

4.5 gt

United States
(1901-2000)

100 years

6.6 gt

China
(2011-2013)

Source: USGS, Cement Statistics 1900-2012; USGS, Mineral Industry of China 1990-2013

Global Concrete Production

25-30

Billion metric tons of concrete the world produces each year

Source: Cement Sustainability Initiative

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Status quo

After water, concrete is the most widely used substance on Earth. The concrete industry emits more than 4 billion tonnes of carbon dioxide every year.

Enviromental impact

Concrete, being an affordable and readily available building material, holds the distinction of being the most widely used construction material globally. It serves as the fundamental building block for modern cities, forming the basis for structures such as roofs, streets, bridges, and walls that separate us from the natural environment. The prevalence of concrete in our surroundings has become so commonplace that many people hardly take notice of its ubiquity. Consequently, the ecological harm caused by this essential tool for urban development often goes unnoticed or unrecognized.

During COP27, climate experts emphasized the urgent need to reduce greenhouse gas (GHG) emissions originating from the construction sector. This sector encompasses industries like concrete, iron, and steel, which collectively contribute to approximately 27 percent of the world's industrial carbon emissions. This call for action reflects the recognition of the significant role these industries play in global carbon emissions and the necessity for targeted measures to mitigate their environmental impact.

CO2 Emissions

Energy consumption

Water Usage

Embodied Carbon

CO2 Emissions

The production of cement, a key component of concrete, is a significant source of CO_2 emissions. The chemical process of cement production involves the release of CO_2 as limestone is heated to produce lime. Additionally, the energy-intensive process of cement kilns and the use of fossil fuels contribute to CO_2 emissions.

Energy consumption

Water Usage

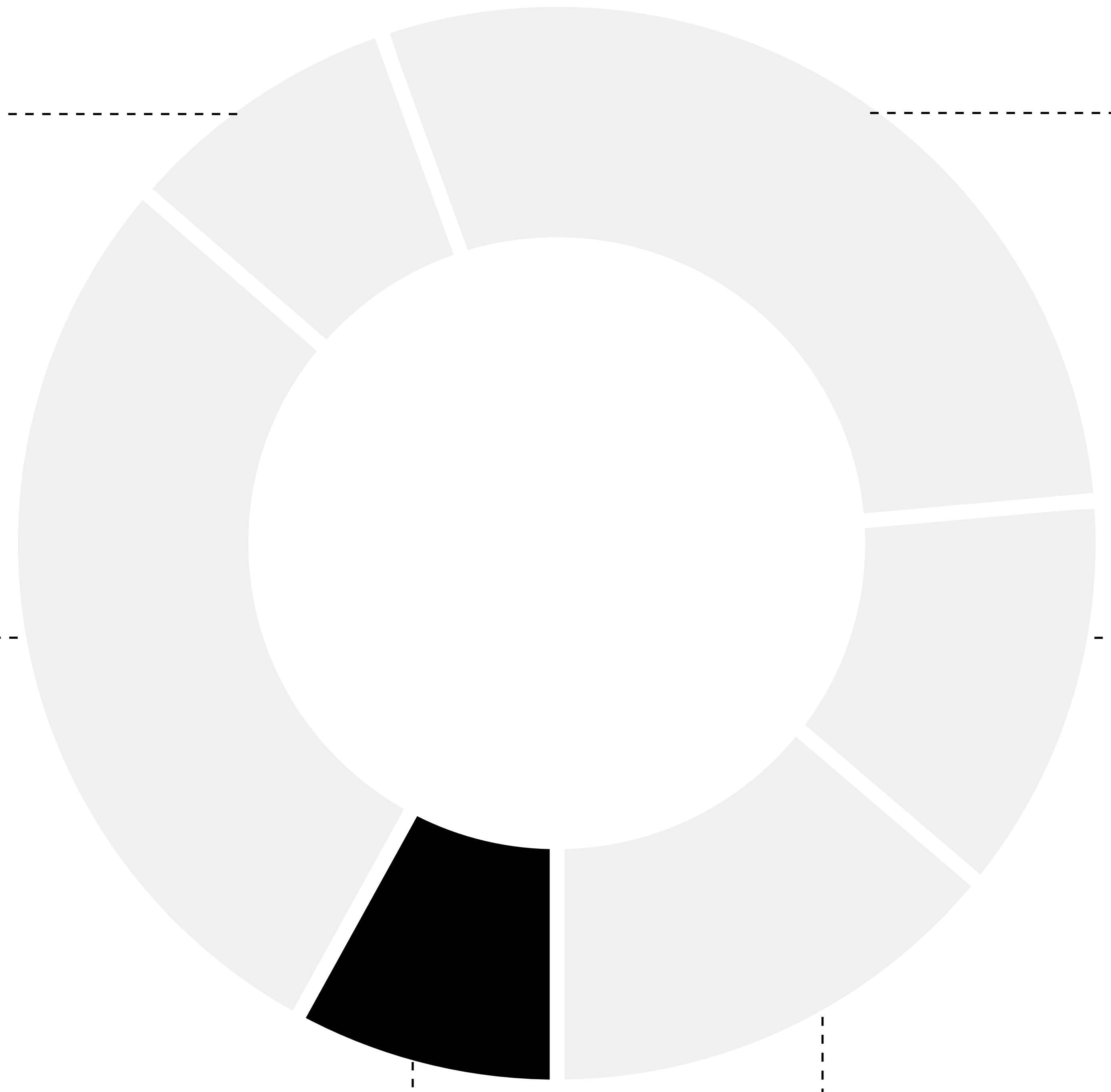
Embodied Carbon

CO2 Emissions

The production of cement constitutes the most carbon-intensive stage in the process of manufacturing concrete. This is primarily due to two key activities: the calcination of limestone and the heating of cement kilns. During the production of Portland cement, limestone undergoes calcination, a process that results in the release of significant amounts of CO_2 through chemical reactions. This particular stage accounts for a substantial portion of the carbon emissions generated by the cement industry, contributing up to 50 percent of its overall emissions.

Furthermore, the conversion of raw materials into clinker, an intermediate product used in cement production, requires a considerable amount of energy. This energy is utilized for activities such as heating, mixing, and cooling the ingredients within large-scale kilns. Traditionally, it has been estimated that one tonne of cement production in conventional kilns results in the emission of one tonne of carbon dioxide.

CO2 Emissions



9%
Agriculture

29%
Transportation

28%
Electricity

12%
Commercial and residential

8%
Concrete

14%
Industry

Source: Princeton University (Cement and concrete: the environmental impact)

CO2 Emissions

Energy consumption

The production of concrete involves significant energy consumption at various stages of its life cycle. The energy consumption associated with concrete production can vary depending on factors such as the type of cement used, the mix design, and the production methods employed.

Water Usage

Embodied Carbon

Energy consumption

2,775MJ - 4,000MJ

of energy is required for the production of 1 m^3 of concrete.

Source: Revista de Arquitectura. Universidad Catolica de Colombia. Número: Vol. 13 Núm. 1 (2011): Enero - diciembre

Energy consumption

Aggregate production for concrete production

GHG emissions

30-40 MJ/t

Is the energy consumption for aggregate production

2.5-10 kg

CO_2/t are the GHG emissions range for aggregate production

Energy consumption

Source: California Department of Transportation (https://www.pavementpreservation.org/icpp/paper/65_2010.pdf)

CO2 Emissions

Energy consumption

Water Usage

The water usage in concrete production can vary depending on factors such as the mix design, production methods, and local conditions. In some cases, water used in concrete production can be recycled and reused. Water treatment and recycling systems can help reduce water consumption and minimize environmental impact.

Embodied Carbon

Water Usage

Water plays a crucial role in the concrete production process. It is added to cement, aggregates, and other materials during the mixing process to create a workable mixture. The amount of water used in mixing directly impacts the workability and strength of the concrete. The water-cement ratio, a key parameter, determines the consistency and performance of the concrete mix. The moisture content of aggregates used in concrete production also affects water requirements. If the aggregates are already damp, it may reduce the need for additional water during mixing. Dry aggregates may require additional water to achieve the desired consistency.

Curing, which is essential for promoting hydration and strength development in concrete, involves maintaining a moist environment around the concrete surface. The amount of water needed for curing depends on factors such as ambient conditions, concrete thickness, and the chosen curing method (e.g., wet curing, membrane curing, or curing compounds). To reduce water consumption and minimize environmental impact, water recycling and reuse systems can be implemented in concrete production, where applicable. These systems help conserve water resources and enhance sustainability in the industry.

Water Usage

150-220

liters of water per cubic meter of concrete
approximately are used for mixing process

Source: CivilSir

CO2 Emissions

Energy consumption

Water Usage

Embodied Carbon

Concrete has a significant embodied carbon footprint due to the high carbon intensity of cement production. The production of cement involves the calcination of limestone, which releases CO_2 as a byproduct.

Embodied Carbon

The embodied carbon of concrete refers to the total amount of carbon dioxide (CO_2) emissions associated with the entire lifecycle of concrete, from raw material extraction to manufacturing, transportation, use, and disposal. It encompasses both the direct emissions from the production of cement and the indirect emissions from the energy consumption throughout the concrete production process. According to various studies and estimates, the embodied carbon of concrete can vary depending on factors such as the cement composition, mix design, regional energy sources, and production efficiencies. However, it is generally accepted that concrete production accounts for a significant share of global carbon emissions.

To address the issue of embodied carbon, there is a growing emphasis on adopting sustainable practices in the concrete industry. This includes using alternative cementitious materials with lower carbon footprints, optimizing mix designs to reduce cement content, improving energy efficiency in production processes, and exploring carbon capture and storage technologies. It's worth noting that advancements in concrete technology and the implementation of sustainable practices can help mitigate the embodied carbon of concrete, making it a more environmentally friendly building material.

Embodied Carbon

75%

Of a building's carbon footprint is due to its construction (grey energy)

50%

Of the construction's carbon footprint is due to the concrete

Source: CHRYSO

Given these issues, concerns about the environmental impact and structural longevity of concrete, why do we continue to build with it?

Advantages of concrete

Strength and Durability

It can withstand heavy loads and is resistant to compression.

Versatility

It can be used to create intricate architectural designs or simple structural elements, providing flexibility in construction projects.

Fire Resistance

Is inherently fire-resistant and does not contribute to the spread of flames. It has a high melting point.

Thermal Performance

It has excellent thermal mass properties, meaning it can absorb, store, and release heat effectively.

Sound Insulation

It has good sound insulation properties, reducing the transmission of noise between rooms or from external sources.

Low Maintenance

It requires minimal maintenance over its lifespan, reducing long-term costs and efforts.

Cost-Effectiveness

Its widespread availability, ease of production, and long lifespan make it an economical choice for construction applications.

Availability and Accessibility

Concrete is a widely available material, making it accessible for construction projects in various regions.

Advantages of concrete

Concrete is renowned for its economic advantages, versatility, and rapid production process, making it a favored choice in the construction industry. However, it is important to acknowledge that concrete, due to its composition and production methods, has a significant impact on the biosphere and the environment. The inherent characteristics of concrete, combined with recent developments aiming for more sustainable formulas, have reinforced its status as a viable construction material. Nevertheless, any radical changes to industry standards are likely to be met with caution and careful consideration.

While concrete's environmental impact is a concern, it is crucial to recognize that the material offers certain advantages that cannot be easily overlooked. Reinforced concrete structures, for instance, have demonstrated superior resilience in the face of seismic activities, outperforming unreinforced brick buildings. This ability to withstand earthquakes is a significant factor in areas prone to seismic hazards, enhancing the safety and longevity of structures built with concrete.

Efforts are being made to reduce the environmental impact of concrete production through various means. This includes the development and adoption of "greener" formulations that incorporate alternative cementitious materials and supplementary cementitious materials (SCMs). These alternative materials can help reduce the amount of cement needed in concrete production, thereby lowering its carbon footprint.Moreover, advancements in technology and manufacturing processes are aimed at improving the sustainability of concrete production.

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Low-emissive concrete

Low carbon concrete consists of industrial cement combined with mineral compounds, such as calcined clays, fly ash or blast-furnace slag. Depending on the dosage of these additions, the carbon footprint of concrete can be reduced by up to nearly 70%.

Strategies for low-emissive concrete

Alternative Cementitious Materials

Low emission concrete incorporates alternative cementitious materials, such as fly ash, slag, or silica fume, which have lower carbon emissions during their production. By replacing a portion of the cement with these materials, the carbon footprint of the concrete can be reduced.

Carbon Capture and Utilization (CCU)

Carbon capture technologies capture CO2 emissions from industrial processes, such as cement production, and convert them into useful products or store them underground. These technologies can be employed to capture CO2 emissions from concrete production and reduce their impact on the environment.

Energy Efficiency

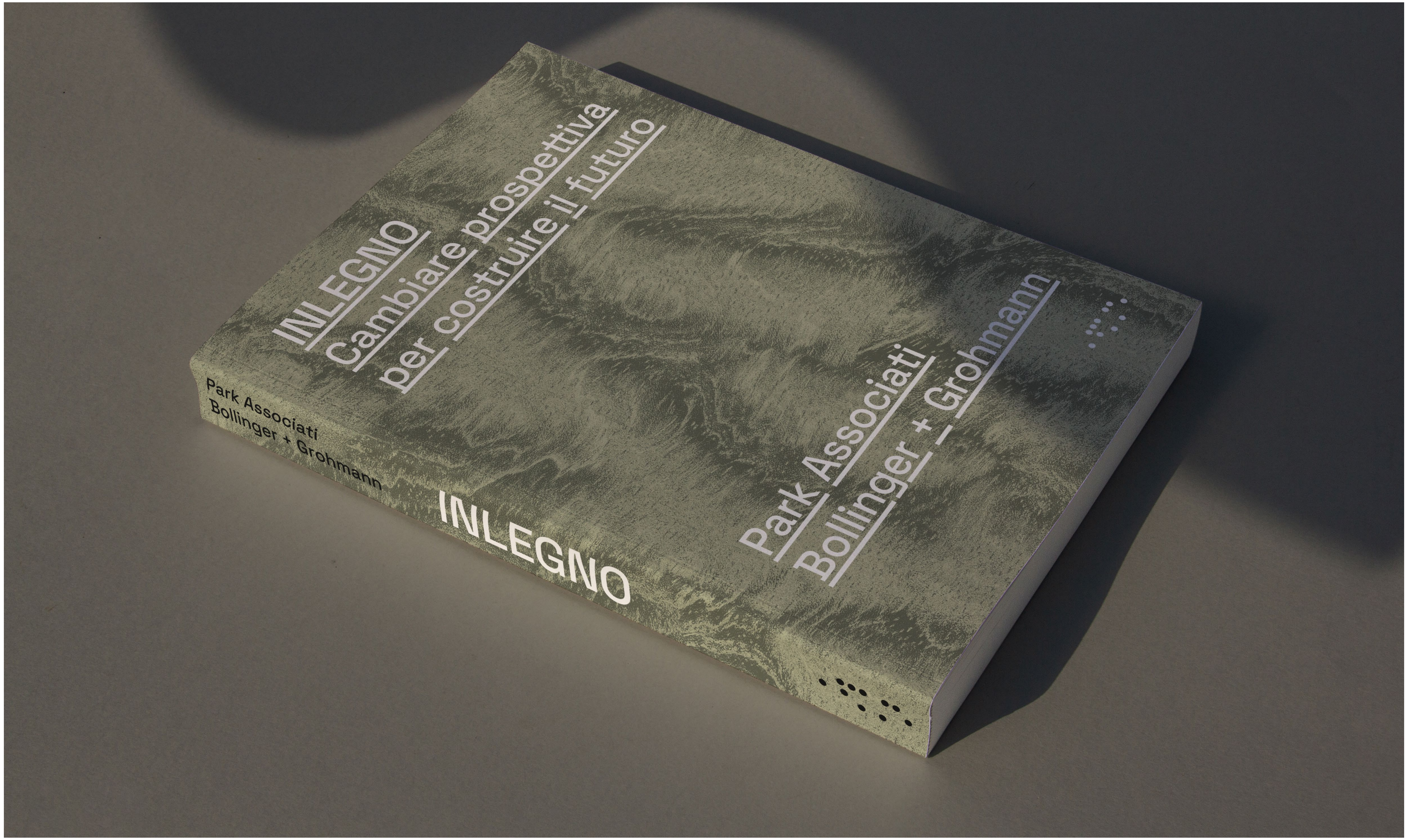
Optimizing energy efficiency in concrete production can reduce carbon emissions. By using energy-efficient equipment, improving production processes, and utilizing renewable energy sources.

Life Cycle Assessment

Conducting a life cycle assessment (LCA) of concrete helps identify areas where emissions can be minimized. By considering the entire life cycle of concrete, from raw material extraction to disposal, and implementing sustainable practices at each stage, the emissions can be reduced.

Low emission concrete is important for sustainable construction and can contribute, even if on a minor scale, to mitigating climate change By adopting these techniques and strategies, the concrete industry can play a significant role in reducing carbon emissions and transitioning towards a more environmentally friendly and sustainable future.

Evolving our INLEGNO exercise



The exercise carried out in the INLEGNO volume involved the retro-design of a building currently under construction, from which it would be easy to extrapolate project data for objective comparison with a new innovative proposal. The idea was to compare the traditional construction technique. In the reference case, a hybrid concrete-wood construction was utilized to explore the interconnections between various aspects such as emission reduction, cost implications, resolution of technical challenges, and the perceived architectural quality. The objective was to assess how these factors interacted and influenced each other within the context of the construction site management.

The results obtained were encouraging and provided tools with which to defend, numbers in hand, an important choice such as that of focusing on timber structures for the construction of tomorrow's architecture. Part of the maturity with which this research work was carried out also lies in the fact that, reasoning first and foremost on the actual feasibility of the proposed concept, it was decided to design a hybrid structure with the use of concrete as the predominant technology for the construction of foundations and lift shafts.

We tried to find out how to work on the least sustainable component of the already formalized proposal: concrete. We aim to explore ways to improve its sustainability and reduce its environmental impact.

Low-emissive concrete exercise

Even a high-emissive industry such as the concrete one is moving towards options that allow the containment of the CO_2 emissions associated with it. One of the main reasons behind reluctant attitudes towards more sustainable solutions, on paper, lies precisely in the fact that they are often not economically feasible. By anchoring part of the feasibility of a project to a technology that is known, tested, economically viable and made less impactful by a refurbishment, one can certainly increase the percentage of possibility that a proposal sees the light. In light of these considerations, the cement-containing components of the project were revisited in collaboration with Italcementi.

The main objective was to calculate how many emissions attributable to the concrete structure could be cut if the raw material came from more innovative processing. The lift shafts, ground floor structures and foundations were redesigned according to this criterion. To gain insights into the relationship between the strength characteristics of concrete and its emission levels, an analysis was conducted to examine the potential variations in CO_2 production as the cross-section of concrete varies. This investigation aimed to determine if and how changes in the cross-section impact the emission contributions of concrete.

Different design scenarios were evaluated, and data analysis led to the selection of a hybrid option. Choosing the maximum characteristic resistance was not viable due to increased construction costs, despite the significant reduction in CO_2 emissions.

Low-emissive concrete exercise

The project was rethought with structures that respect the characteristic resistance and integrate the emission reduction technologies related to the production of Portland cement, the material used as a binder in the concrete mix, proposed by Italcementi. The implementation of the ECO Low Carbon range in the structures described above has resulted in a reduction of approximately 65.4% of CO_2 at a cost increase of approximately 2%. By integrating this approach to concrete production with a carbon offsetting strategy, it becomes possible to not only mitigate emissions but also address the release of greenhouse gases throughout the construction process. This combination allows for a comprehensive reduction in environmental impact and promotes more sustainable construction practices.

Climate contributions are defined as a support mechanism for sustainable projects with positive environmental impacts that enable individuals and organizations to contribute to global carbon neutrality. Projects supported through climate contributions are not limited to the absorption or avoidance of CO_2 emissions but deliver additional positive environmental and social impacts in line with the achievement of the United Nations Sustainable Development Goals (SDGs), such as health benefits, biodiversity protection, gender equality and economic development.

Carbon offsetting must always be combined with CO_2 reduction practices for it to be a valid and effective action. CO_2 offsetting and neutralization measures play a critical role in accelerating the transition to net zero emissions globally, but do not replace the need to reduce CO_2 emissions in the corporate value chain in line with the latest scientific findings.

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04 Scenarios

Two different scenarios are examined in order to identify the most advantageous type of concrete for the purposes of this study. Both scenarios involve a comparison with a traditional type of concrete, which in the first case is compared to one with implemented environmental characteristics, while in the second case a ‘green’ type is analyzed.

Price fluctuations

Regarding the economic valuation, given the particular historical moment, it was preferred to proceed according to a price difference between a concrete of a class taken as a reference and those with different characteristics. In the present case, the reference is type C30/37 and a variation of 5-7% was taken into account. Specifically, the percentage variation entails a decrease in price for grades with lower characteristics and an increase for those with higher characteristics.

Resistence R^{ck}	**Economic enhancement**	
(MPa)	**Tradizionale**	**Low Carbon**
C25/30	95	99
C30/37	100	104
C35/45	106	110
C40/50	113	117
C45/55	120	124

CO2 emissions

Please be aware that the provided values are intended as general guidelines and may require redefinition based on specific factors such as the construction site conditions, the specific raw materials utilized, or the additives incorporated.

In addition, at the time of design, some solutions can be adopted that would entail further advantages from an environmental point of view. A first example is the use of photocatalytic concrete for external walls since this combines the characteristics of the low carbon product with the reduction of NOx (nitrogen monoxide). Another project implementation could be the replacement of the asphalt of the external areas with products from the Idro Drain line which, in addition to the excellent environmental performance, also involve the reduction of CO2 and the reabsorption by carbonation, which in a porous cementitious element is much faster than normal concrete.

Additionally, within the framework of the circular economy, it is valuable to explore the utilization of raw materials obtained through recycling processes. This can be accomplished by substituting aggregates with locally sourced materials derived from recycling, thereby fostering sustainable resource management practices.

Resistence R^{ck}	**Emissions CO2**			**Reduction CO2**	
(MPa)	**Cem 1 [kg CO2/m3]**	**Cem 2 [kg CO2/m3]**	**Low Carbon [kg CO2/m3]**	**Low Carbon vs. Cem 1 [%]**	**Low Carbon vs. Cem 2 [%]**
C25/30	290	246	195	32.9	20.8
C30/37	329	277	218	33.6	21.3
C35/45	357	301	236	33.9	21.5
C40/50	396	333	260	34.4	21.9
C45/55	418	351	274	34.6	22.0

Section reduction

Concrete section reduction refers to the practice of reducing the dimensions or cross-sectional area of concrete elements in structural design. This approach involves optimizing the amount of concrete used while still maintaining the required structural integrity and safety. By reducing the section size, the overall weight of the concrete element can be decreased, resulting in benefits such as cost savings, improved construction efficiency, and reduced environmental impact.

However, it is essential to carefully consider and analyze the structural requirements and consult with engineering professionals to ensure that the reduced section still meets the necessary design criteria and performance standards.

Resistence R^{ck}	**Section reduction**
(MPa)	%
C25/30	109
C30/37	100
C35/45	94
C40/50	89
C45/55	83

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Cost estimates

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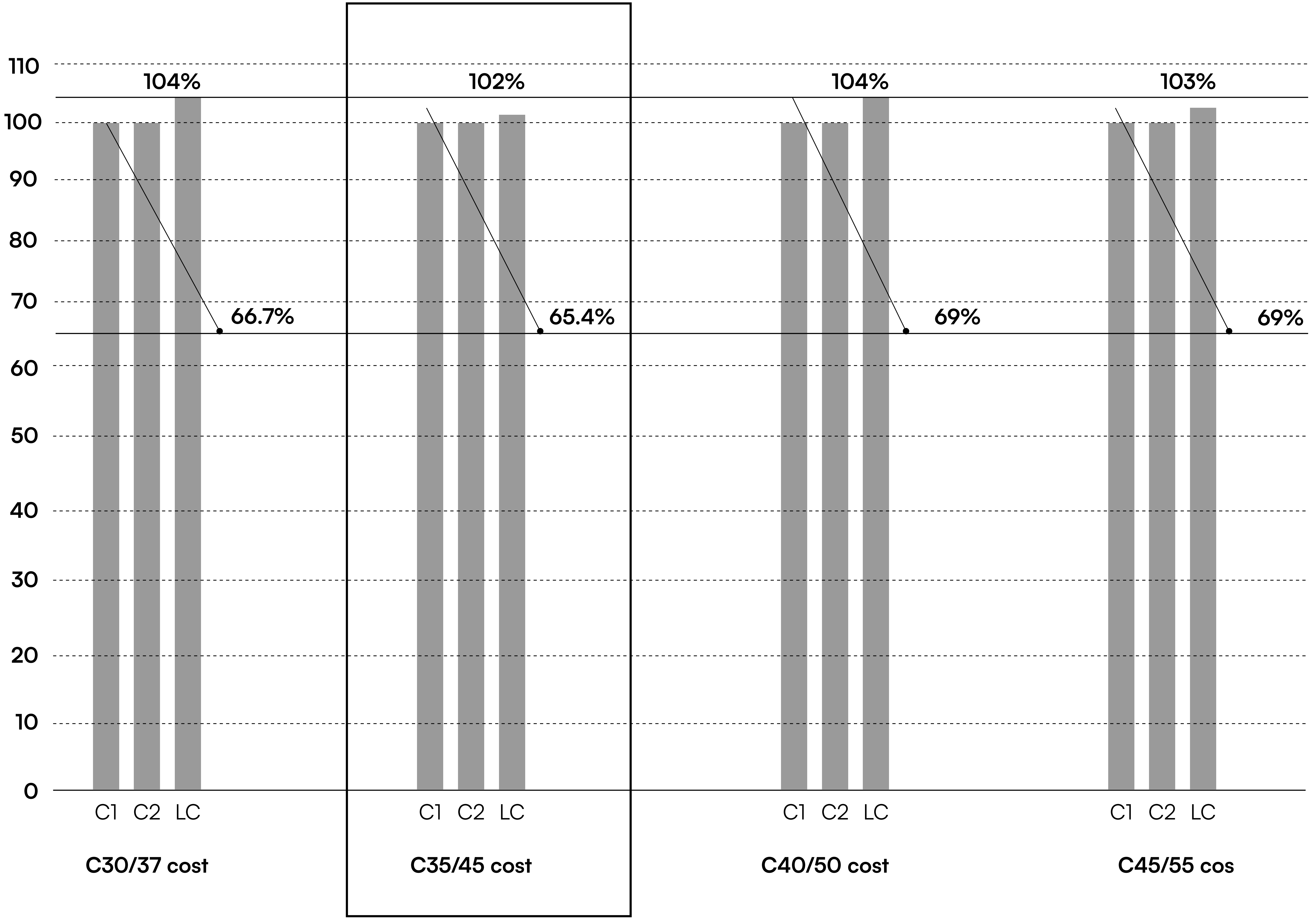
Following the metric calculation carried out on the structures, two new design hypotheses can be presented. The purpose is to compare the cost of the construction and the emissions produced in the case of a traditional cement versus a cement with implemented environmental features or a “green” cement. characteristics and an increase for those with higher characteristics.

Cost estimates

It is important to emphasize that the parameters studied do not have a direct correlation with each other. In fact, a concrete with better characteristics does not allow a linear reduction in the dimensions of the structural sections as the characteristic resistance increases. This is due to the fact that reinforced concrete is a composite material consisting of concrete and steel reinforcing bars. Furthermore, several factors need to be considered, including compliance with current structural regulations, which stipulate minimum section sizes and minimum steel reinforcement requirements.

These elements were taken into consideration during the study carried out, which is why, as the strength of the concrete used increased, the reduction in the size of the sections was limited to a maximum of 17%, a percentage obtained from a case study on varying the dimensions of a pillar in reinforced concrete keeping constant the load acting and the quantity of reinforcing bars.

The diagram summarizes the results obtained following the study carried out on the INLEGNO project. These analyses show that the correlation between the factors is not linear because increasing the concrete characteristics does not necessarily lead to advantages in terms of cost and emissions



One would expect, in fact, that the best alternative would be C45 / 55 concrete, while in reality using a low carbon C35/45 concrete entails the disadvantage of a 2% increase in costs but an advantage in terms of reduced emissions, which corresponds to 65.4% compared to the traditional C30/37 concrete solution.

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Future horizons

The post-pandemic period has seen a surge of attention and interest in the ESG protocol and its objectives of promoting environmental, social, and corporate governance practices.

ESG protocol

ESG protocol refers to a set of guidelines and practices related to Environmental, Social, and Governance factors. ESG stands for Environmental, Social, and Governance, and these factors are used to evaluate the sustainability and ethical practices of a company or organization. The ESG protocol provides a framework for assessing and managing the environmental, social, and governance risks and opportunities associated with a business. It takes into account the company's impact on the environment, its relationships with employees, communities, and other stakeholders, as well as its governance structure and practices.

The environmental aspect of ESG evaluates a company's performance in terms of its resource consumption, energy efficiency, carbon emissions, waste management, and other environmental factors. It focuses on issues such as climate change, pollution, natural resource conservation, and the company's efforts towards sustainability.

ESG protocol

It remains important, however, to clarify how this term applies to the construction sector and how impact and progress towards these goals can be quantified. The concept behind ESG, making sure that one's investment movements also generate positive externalities on others, is something that has roots going back a long way.

Today, the ESG discourse has taken on a much wider resonance as public opinion, which has finally realized the urgency of changing course to mitigate the most disastrous effects of climate change, presses companies to show a different focus on the future. Therefore, investors are recognizing the need to show what impact they are having on the environment and the community. There are many ways to invest in sustainability: from energy-efficient facilities that reduce a building's operational carbon footprint, to mobility features that improve community access to services. In addition to social and environmental benefits, ESG also brings value to developers: buildings that are 'forward-looking' and prepared for a changing climate are worth more, attract and retain better talent, and protect long-term investments.

At present, ESG is a retrospective tool: clients and planners tend to build first and then measure the impact of what they have achieved. Instead, one should try to reverse this situation and show how ESG metrics can, in fact, influence and guide the design phase.

By incorporating low emission concrete into construction projects, it is possible to achieve significant pollution reduction and promote a more sustainable and environmentally conscious construction industry.

Futher reading:

- How to make low-carbon concrete from old cement
- Carbonaide turns CO2 into carbon-negative concrete blocks that can trap emissions
- How does concrete and cement industry transformation contribute to mitigating climate change challenges?
- Six material innovations aimed at slashing concrete's outsized carbon footprint
- Low-carbon concrete: Is the future now?
- Concrete: the most destructive material on Earth
- Cement and Concrete: The Environmental Impact

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Work with us

info@parkassociati.com
www.parkassociati.com