EMBODIED CARBON – A HIDDEN HEAVYWEIGHT FOR THE CLIMATE

How financing and policy can reduce the carbon footprint of building materials and construction

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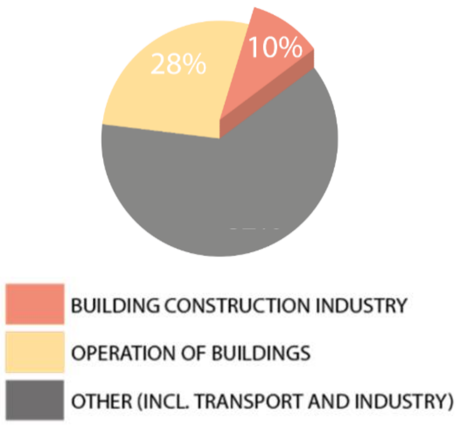
PROGRAMME FOR ENERGY EFFICIENCY IN BUILDINGS

CONTENT

EXECUTIVE SUMMARY

A new area the size of Paris is built every week, as the world is going through an unprecedented era of massive construction. As a result, the global building floor area is expected to double by 2060. Buildings and construction have a massive carbon footprint. This sector is responsible for 38% of energy-related CO_2 emissions, that is more than other types of industry, or transport.



Building construction causes 10% of energy-related emissions
Graph: PEEB; data from GlobalABC, 2020

The production of building materials and construction activities is responsible for a quarter of this buildings climate challenge, causing **10% of global energy-related greenhouse gas emissions**.

The **manufacturing of cement and steel causes most of these emissions**, given the high emissions that occur during the production process, and the widespread use of these materials. Aluminum, glass and insulation materials also have considerable emissions.

Buildings and construction emissions		
	2019 (Mt*CO_2)	**Share of energy-related emissions**
Material manufacturing	**3.430**	10%
Cement and steel manufacturing for construction	2.038	
Other materials	1.391	
Buildings Construction	**130**	
Construction energy use	130	
Buildings Operation	**9.953**	28%
Buildings and construction value chain	**13.512**	**38%**

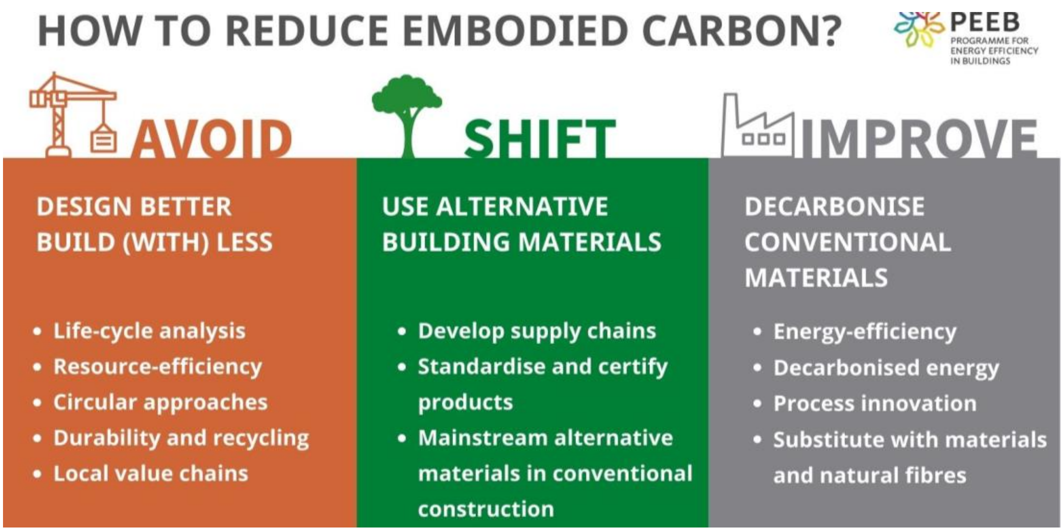
Buildings operation and construction emissions from energy use. Based on IEA 2020

Construction works, as well as refurbishment and deconstruction, are energy intensive. Nevertheless, the relative weight of construction, when compared to the production of building materials is small.

The strategies exist – from building smarter to decarbonising building materials

Despite its massive weight, embodied carbon is still a "blind spot" in strategies to reduce building emissions. We need to rethink how we construct our buildings to reduce embodied carbon. Strategies range from building less, to improved designs that have a longer lifetime, require less material or use low-carbon materials. **Circular approaches** to construction turn buildings into banks of valuable materials that can be reused through "**urban mining**", to reduce the need for new materials.

For building materials, we need a double strategy: **There is no alternative to reducing the emissions of the most used building materials**: steel-reinforced concrete and other conventional building materials like aluminium, plastic and glass. We therefore need swift action to **reduce the carbon footprint of conventional building materials** such as concrete and steel. At the same time we need to increase the market share of **alternative soutions, such as bio-based materials**.



Low-carbon building materials and construction are ready to be scaled up. Companies and start-ups across the globe have developed alternative materials as a state-of-the-art product for today's real-estate markets, and large corporations are looking to decarbonise the production of cement and steel.

Still, **without dedicated policies or dedicated support, sustainable building materials will not get into the mainstream**. Embodied carbon targeting policies are necessary for a business environment that tackles embodied carbon.

How can policy and financing reduce embodied carbon[1]?

Dedicated support is needed to decarbonise building materials and construction and accelerate the uptake of sustainable building materials.

Policy

- **Climate targets -** NDCs to guide policy and attract climate financing
- **Regulations** - life-cycle emissions reporting requirements and limits
- **Standards and norms** - certification of new low carbon materials and adaptation of standards.
- **Labels** for low embodied emission buldings
- **Public procurement** - life-cycle carbon, resource-efficient design and recycling.

Finance

- **Financial incentives** - green building programmes and incentives such as tax rebates
- **Investors**- support investor in implementing decarbonization policies and transparency through reporting requirement.
- **Development banks** – embodied carbon accounting in projects and including embodied carbon as a criteria for financing

Knowledge and Capacity

- **Technical knowledge** - applied research, innovation among manufacturers and suppliers, knowledge of architects and construction companies and national testing facilities.
- **Data** – country-specific building material databases to calculate emissions.
- **Market development**- business skills for sustainable building materials; market potentials and customer awareness.

This PEEB Working Paper presents the key facts on embodied carbon, as well as practical strategies on how to reduce embodied carbon during the planning, design and construction process, as well as for building materials. To promote action on embodied carbon, it then lays out how policy and financing can be used to accelerate the decarbonisation of building materials and construction.

[1] Embodied carbon refers to the carbon dioxide (CO_2) emissions from building materials and construction processes throughout the whole lifecycle of a building. It includes both the emissions from energy use and chemical processes during the production of building materials.

1. BUILDING MATERIALS AND CONSTRUCTION – A HIDDEN HEAVY WEIGHT FOR THE CLIMATE

The world is going through an unprecedented phase of massive construction. The **global building floor area is expected to double by 2060** (GlobalABC, 2017). An area the size of the city of Paris is added to the global built surface every week (IEA, 2021). Asia and Africa are predicted to see the highest growth (cf. figure 3).

Figure 1: The global building stock is expected to double

Buildings and construction have a massive carbon footprint. This sector is responsible for 38% of energy-related CO_2 emissions, that is more than other types of industry, or transport (GlobalABC, 2020b; cf. figure 2). The energy used for heating, cooling and appliances during the lifetime of a building makes up the largest part of these emissions and must be rapidly addressed through energy efficiency and decarbonisation of the energy supply.

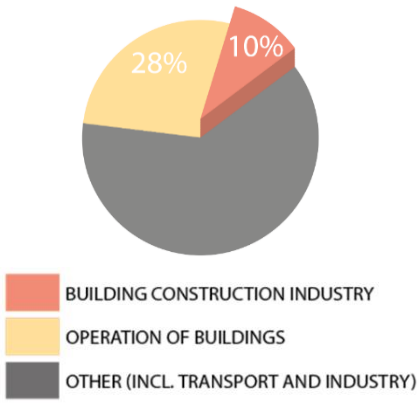


Figure 2: Building construction causes 10% of energy-related emissions
(Graph: PEEB; data from GlobalABC, 2020)

Still, the impact of building materials and the construction industry is often forgotten. The production of building materials and construction activities (*embodied carbon*[2]), are responsible for a quarter of this buildings climate challenge, causing **10% of global energy-related greenhouse gas emissions** (GlobalABC, 2020b, cf. figure 2).

The manufacturing of cement and steel causes most of these emissions, given the high emissions that occur during the production process, and the widespread use of these materials. Aluminum, glass and insulation materials also have considerable emissions (GlobalABC, 2018).[3]

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[2] *Embodied carbon* refers to the carbon dioxide (CO_2) emissions from building materials and construction processes throughout the whole lifecycle of a building. It includes both the emissions from energy use and chemical processes during the production of building materials.

Embodied carbon includes the emissions arising from each stage of the building life-cycle model, as defined by EN 15978 and ISO 21930: raw material extraction (A1), transport to manufacturing facilities (A2), manufacturing (A3), transport to a construction site (A4), construction (A5), use phase (B1), maintenance (B2), repair (B3), replacement (B4), refurbishment (B5), deconstruction (C1), transport to waste processing (C2), waste processing (C3) and final disposal (C4) (WBCSD 2021b)

[3] There is no internationally accepted estimate giving the full amount of emissions from building materials and construction. A complete picture of these emissions would include both the 10% share of global energy-related greenhouse gas emissions from building materials and construction, as well as those emissions from chemical processes.

The construction of new infrastructures in developing countries and emerging economies alone could lead to 350 Gt of CO_2 emissions by 2050, if the same patterns of CO_2-intensive materials continues. That represents a **third of the entire CO_2 budget that is available, if climate change is to be limited to less than 2°C** (WGBU, 2016).

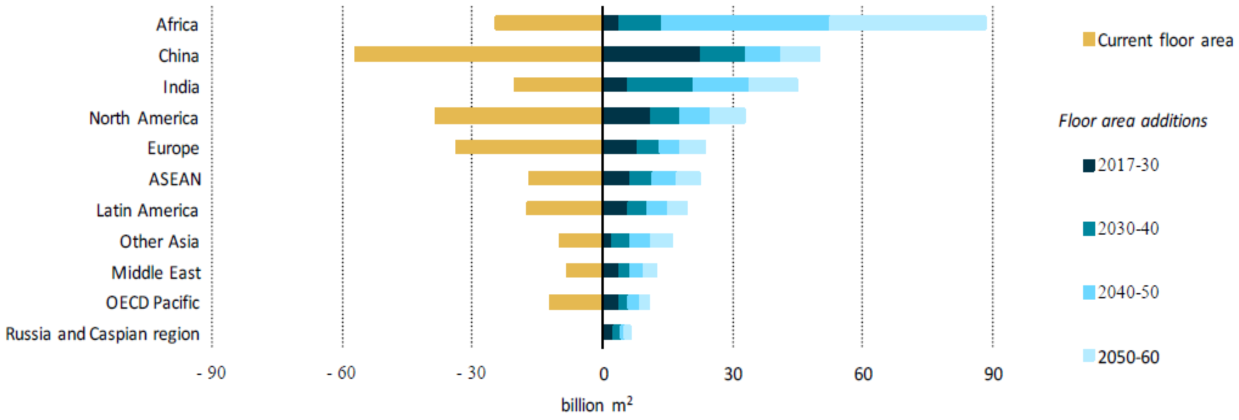

Figure 3: Floor area additions to 2060 by key regions (Source: GlobalABC, 2017)

Embodied carbon, i.e. the carbon cost of manufacturing building materials and construction activities, is a "blind spot" in strategies to reduce building sector emissions. International initiatives have started to address the topic and promote action on whole-life carbon (cf. box 1). Still, much more needs to be done to reduce greenhouse gas emissions from building materials and construction.

International initiatives to address embodied carbon

- World Green Building Council (2019): Bringing Embodied Carbon Upfront https://www.worldgbc.org/embodied-carbon
- World Business Council for Sustainable Development, WBCSD (2020): Building System Carbon Framework https://www.wbcsd.org/contentwbc/download/9731/146973/1
- UNFCCC (2020): Climate Action Pathway: Human Settlements https://unfccc.int/sites/default/files/resource/ExecSumm_HS_0.pdf
- ACT Initiative - Assessing low-Carbon Transition initiative https://actinitiative.network/

2. EMBODIED CARBON – WHAT CAUSES MOST EMISSIONS?

The emissions from building materials and construction are irreversible once a building has been built. **The production of building materials makes up the largest share of embodied carbon**. Material manufacturing caused 3.4 Gt of CO_2 emissions in 2019 due to energy use alone – not counting the additional emissions from chemical processes. Transport, construction, maintenance and refurbishment, as well as demolition and waste management add to emissions, but on a much lower scale (cf. Table 1).

Buildings and construction emissions		
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Table 1: Buildings operation and construction emissions from energy use. Based on IEA 2020

The relative weight of embodied emissions to emissions from operations increases, as buildings become more energy-efficient, and as decarbonization of energy supply proceeds. Figure 4 illustrates when emissions occur and their relative weight, based on a sample of five low-carbon buildings in the UK, the Netherlands and Denmark.

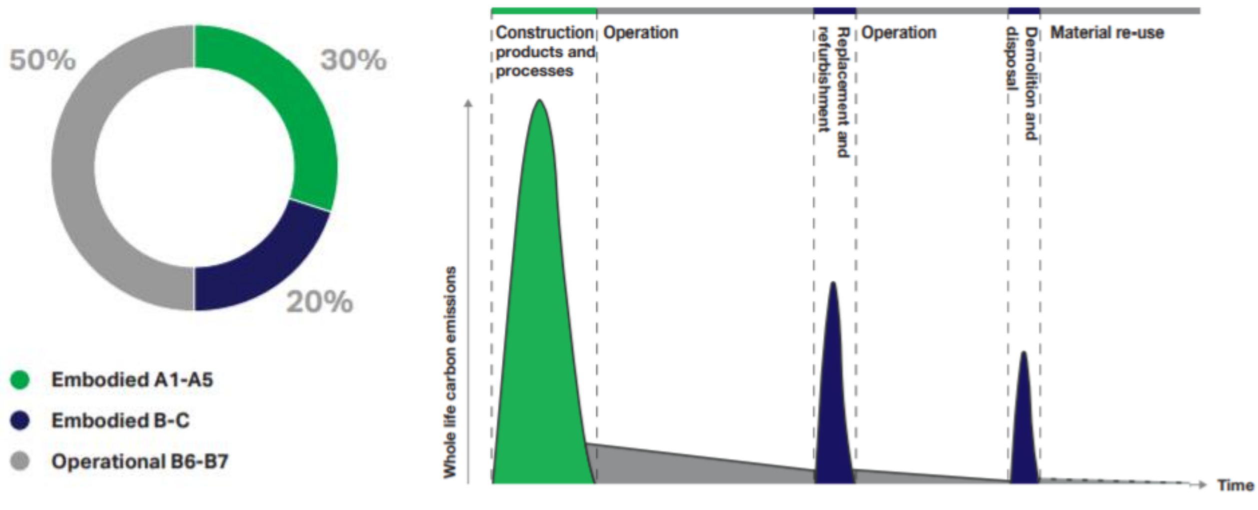

Figure 4: Estimated distribution of carbon emissions per life cycle stage (Source: WBCSD, 2021a)

2.1. The heavy climate impact of steel and cement

Cement and steel manufacturing weighs heavily in energy-related emissions, making up almost **three-fifths of energy-related emissions from material manufacturing** (cf. Table 1). Their share is even larger if process-related emissions are accounted for.

In 2018, **cement production alone accounted for 7% of all energy and process-related[4] greenhouse gas emissions worldwide** and is expected to rise by 12-23% by 2050 (SEI, 2018; IEA, 2018). About half of global cement production is used for buildings (GlobalABC, 2020b). The extreme demand for concrete is illustrated by the high need for sand that leads to massive illegal sand mining activities, threatening shorelines, rivers and seabeds (Block, 2019). The construction industry consumes over 25,9 billion tonnes of sand per year (UNEP, 2019).

Figure 5: Cement production is expected to increase by 12-25% by 2050

Steel represents 7-9 % of global emissions, with an expected growth rate of 30% by 2050 (Energy Transitions Commission, 2018). 30% of the global production of steel is used for buildings (GlobalABC, 2020b). For EU countries, a study found that in 2011, steel and aluminium made up 51% of the total embodied energy emissions in EU countries (cf. A8 in *Annex*) (ECORYS, 2014).

Figure 6: 30% of the global production of steel is used for buildings.

Nevertheless, **other conventional materials like aluminium, plastic and glass** also weigh heavily, making up two-fifths of of energy-related emissions from material manufacturing (cf. Table 1).

[4] In addition to the energy related emissions, the production of cement also emits inherent chemical absorption. These emissions make up more than 50% of the global embodied emissions of cement (Lehne et al. 2018).

2.2. The need for data

Lifecycle analysis of building design options is a gamechanger to address embodied carbon. Quantifying and comparing embodied emissions allows planners and architects to compare options for design and materials. It is also the basis for national and local policies and investment decisions.

Life Cycle Assessment (LCA) is the most widely recognized procedure to quantify embodied emissions and examine environmental impacts throughout a building's life cycle. It follows an internationally standardised procedure (ISO 14040:2006). Several tools are available to assess embodied emissions (cf. *A1 in Annex*).

Scopes of Emissions in Life-Cycle Assessments

A Life-Cycle Assessment allows the calculation of different scopes of emissions (ISO 14040:2006).

- **Emissions from embodied energy** include emissions from the **use of energy for the production of building materials and construction activities** throughout the life cycle of a building. This includes material extraction, transport, processing, manufacturing, construction, maintenance, repair, replacement, refurbishment, deconstruction, waste processing, and disposal (EN 15978, 2011).
- **Embodied emissions** (or embodied carbon) include both the emissions from embodied energy and the inherent chemical absorption and emission properties of building materials. For example, cement is produced through the decarbonisation of limestone, a chemical reaction that emits carbon dioxide (CO_2), while wood absorbs CO_2 during growth.
- **Whole-life emissions** are the **sum of embodied emissions and operational emissions** from energy **consumption** for the operation of the building and its appliances over its entire life cycle.

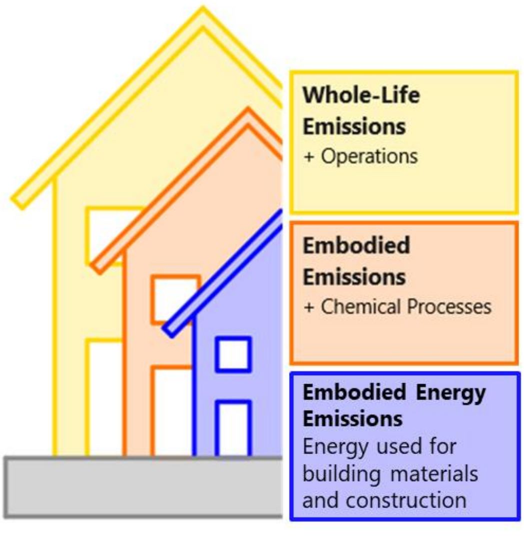

Figure 7: Scope of Emissions. Graph: PEEB

Data about building materials and their properties in a specific local context are needed to calculate embodied carbon. In several countries and jurisdictions, databases have been developed that specify the properties of certified products (cf. examples in Annex A2 and A3). There is a need to further build up and refine such databases, especially in developing countries. Innovative new (or even "traditional") low carbon building materials need to be tested and certified to be included rapidly into these databases to promote their use.

Nevertheless, the lack of data of existing building materials and incomplete databases should not prevent the development and application of innovative new low embodied carbon materials. Setting up and developing databases can be complex, time-consuming and costly. Therefore, with time and application experience, databases can be built up in parallel to practical application, then expanded and regularly updated over time.

UNFCCC – Compendium on Greenhouse Gas Baselines and Monitoring

The *Compendium on Greenhouse Gas Baselines and Monitoring. Building and Construction Sector* (UNFCCC, forthcoming) provides an overview of different sources of greenhouse gas emissions from buildings and construction, as well as methodologies for quantifying these emissions to feed into national greenhouse gas inventories. The quantification methodology helps setting up national greenhouse gas inventory data of embodied emissions.

http://www.peeb.build/news-events/unfccc-monitoring-compendium

3. STRATEGIES TO AVOID EMBODIED CARBON – FROM DESIGN TO END-OF-LIFE AND BEYOND

We need to rethink how we design, construct and reuse our buildings. Embodied emissions **must be considered from the early planning and design stages onwards**. The potential to contain embodied emissions decreases rapidly, the further a project is developed (cf. Figure 8).

Strategies range from building less, to improved designs that require less material or use low-carbon materials. **Circular approaches to construction** turn buildings into banks of valuable materials that can be reused ("**urban mining**"), to reduce the need for new materials.

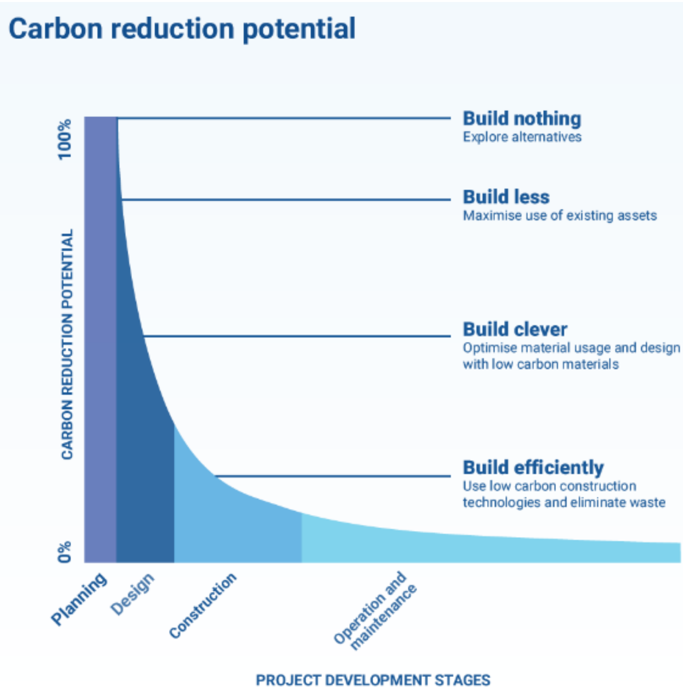

Figure 8: At the planning stage, the potential to reduce carbon emissions is highest. Source: WorldGBC, 2019

3.1. Planning – build less, build smarter

The planning phase is key to reducing embodied carbon. This ranges from questioning the necessity of building something new, to optimising the set-up and location.

- **Renovate** existing assets rather than construct new ones.
- **Mix and optimise uses** rather than plan for single use.
- **Promote compact urban spaces** rather than low-density sprawl.
- **Chose project sites** where less material, foundation work and transport are needed.

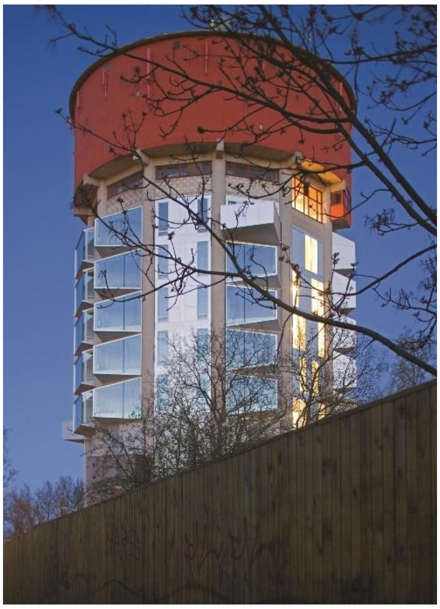

Figure 9: Jaegersborg Water Tower was transformed into a modern student dormitory (Architects: Dorte Mandrup; Photo: Jens Markus Lindhe)

3.2. Design – materials, quantities, durability and recycling

Building designs and construction techniques can reduce embodied emissions. They also anticipate future uses and recycling (IEA-EBC, 2016).

Life Cycle Assessments should be used to guide design choices by evaluating and visualising the impact of different options.

Figure 10: The METI-School in Rudrapur combines climate-friendly design with regional low-carbon building materials (Architects: Anna Heringer & Eike Roswag, Photo: Kurt Hörbst)

- **Reduction of materials used** through building typology, geometry, volume[5] and material-saving constructions (e.g. hollow ceilings).
- **Low-carbon building materials** including **recycled materials.**
- **Recycling** and single-variety separation of individual materials.
- **High durability of components and design** to reduce the needs for maintenance and renovation and to prolong the lifetime of the building.
- **Adaptability to successive uses** to ensure a long lifetime and reduce refurbishment.
- **Less appliances,** following concepts of **sufficiency,** and opt for appliances with a lower carbon footprint and high production efficiency.

Resources

IEA guidance for building designers

EA-EBC (2016). Basics for the Assessment of Embodied Energy and Embodied GHG Emissions for Building Construction.
http://www.iea-ebc.org/Data/publications/EBC_Annex_57_Guideline_for_Designers_Part_1.pdf)

Low-carbon business models for real estate actors

Urban Land Insitute Greenprint Center (2019) Embodied Carbon in Building Materials for Real Estate.
https://americas.uli.org/wp-content/uploads/sites/2/ULI-Documents/Greenprint-Embodied-Carbon-Report_FINAL.pdf

Resources on embodied carbon for designers and real estate actors

http://carbonleadershipforum.org/resources/clf-publications/

[5] This needs to be calculated for each project. Vertical urban structures like skyscrapers might demand a higher amount of building materials in contrast to horizontal urban structures due to the consideration of cumulative loads of each unit (Schmidt et al. 2021).

3.3. Construction, refurbishment and end-of-life – more efficiency, less waste

Construction works, as well as refurbishment and deconstruction, are energy intensive. Improved technologies and smart management methods can reduce energy wastage and lower the carbon footprint (PEEB, 2019).

Nevertheless, the relative weight of construction, when compared to the production of building materials is small. A study in India found that just 2% of the embodied energy in construction projects stems from the actual construction of buildings. Still, improved technologies and smart management methods can significantly reduce energy waste and result in a lower carbon footprint (GIMP, 2021).

Figure 11: To reduce the impact of refurbishment and deconstruction, the Urban Mining and Recycling (UMAR) Experimental Unit uses prefabricated elements made of recycled materials. (Architects: Werner Sobek, Dirk E. Hebel & Felix Heisel, Photo: Wojciech Zawarski)

- **Optimised construction works** save time, energy and money.
  - Improved construction logistics through digital management tools
  - Modular prefabrication to save time and energy on site
  - Trained and well-equipped construction workers
- **Clever refurbishment** can bring efficiency gains on resources such as water, energy and materials.
- **Circular economy or Cradle-to-Cradle** approaches, and **reusing, recovering** and **recycling materials** can drastically reduce the embodied emissions of a building.
- **Investing in material recycling** chains instead of disposal can optimise material use, and lower transport and manufacturing costs over time.

4. BUILDING MATERIALS – FROM DECARBONISING CONCRETE AND STEEL TO ALTERNATIVE MATERIALS

4.1. Conventional vs. alternative building materials? We need both!

To reduce the carbon footprint of building materials and construction, we need swift action to **reduce the carbon footprint of conventional building materials**, while **increasing the market share of bio-based materials.** There is no "either – or"; both approaches are necessary: Concrete, steel, glass and other "modern" or conventional building materials still dominate current models of construction, so there is no way around addressing these emissions.

Figure 12: Upstream and downstream approaches to address embodied carbon in building materials. Graph: PEEB

At the same time, we need to **strive for circularity** in the way we produce and use building materials, both for conventional and alternative building materials.

Figure 13: The Urban Mining and Recycling (UMAR) Experimental Unit is an experimental building mostly constructed with fully reusable, recyclable and compostable building materials. (Architects: Werner Sobek, Dirk E. Hebel & Felix Heisel, Photo: Zooey Braun)

Building materials and design need to be **adapted to local climate conditions**. In hot arid climates, building materials with a high thermal mass are needed, such as clay, natural stone or bricks. In humid subtropical climates, materials should allow for low thermal inertia and natural ventilation, such as timber, bamboo and light-weight facades (cf. PEEB, 2020; *Annex A6*).

Figure 14: Building materials should be selected to fit local climate conditions
(Architects: T3 Architects, Photo: ALISA Production)

Checklist: Sustainable Building Materials

- **Life-cycle analysis**, based on local data, to guide design decisions
- Building materials with **optimal properties** for the local climate.
- **Low-carbon materials** and avoid CO_2-intensive materials like aluminium or steel.
- **Low-processed materials** that consume less resources for production and are easier to recover and recycle; **Single-variety separation** of individual materials.
- **Resistant materials** with a longer lifespan and less replacement or maintenance.
- **Reuse of materials** instead of manufacturing new products ("urban mining").
- **Local value chains** to lower transport emissions and strengthen the local economy.

4.2. Reducing the carbon footprint of conventional materials

There is no alternative to reducing the emissions of the most used building materials: steel-reinforced concrete and other conventional building materials like aluminium, plastic and glass. Given their massive weight in global greenhouse gas emissions, even gradual improvements in their production and use make a huge impact. The main strategies are an optimisation of production, resource-efficient design and recycling and circular approaches.

This section will focus on steel-reinforced concrete, given its high prevalence among building materials emissions. While in concrete big impacts can be made by changing the ingredients[6], for steel the biggest gains can be made by reducing or decarbonizing the enormous energy demand for production. Resource-efficiency in design construction, as well as recycling applies to both.

Figure 15: The energy-intensive production of steel and concrete has high savings potential

Production

a) Optimise Production Processes

The energy intensive production of cement and steel can be made more efficient by using waste heat to produce electricity. Additionally, producing clinker with carbonation rather than hydration can reduce CO_2-emissions by up to 70% (UN Environment, 2017). Low-carbon, renewable energy sources and better management of byproducts decrease the impact on the environment (Raabe et al., 2019).

b) Adding waste materials to substitute energy-intensive components in cement

Reducing the amount of clinker in cement by adding waste materials is an efficient possibility to lower greenhouse gas emissions. Still, cement contains on average only around 20% of substitutes, like fly ash from hard coal combustion and blast-furnance slag from iron ore mining (UN Environment, 2017). At the same time, the sustainability of substitutes needs consideration. While fly ash is an unused by-product of coal combustion now, its use depends on the continued use of coal-fired power plants. Agriculture waste products like cassava husks are possible “green” substitutes and already successfully tested in projects (BAM, 2019).

c) Innovation to improve the environmental impact

Research is ongoing into how to make concrete more sustainable, for example on CO_2 absorbing concrete using magnesium sulfate. Still, a lot of innovations are still in the trial stage and need to be improved (PACA, 2019).

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[6] Cement, a highly energy-intensive materials, is the main component for concrete, next to sand and gravel. 50% of the cement sector emissions are caused by the calcination of limestone to produce Portland clinker, a pre-product of cement. Another 40% of emissions are generated by energy use to heat the cement kilns to high temperatures (Lehne et al. 2018).

Design and construction

a) Combination with natural materials

Reinforcing elements made of natural materials can replace energy-intensive steel to reduce the overall carbon footprint of reinforced concrete. Bamboo can be a sustainable alternative to steel. Bamboo fibres are combined to create a building material with equal or better properties in terms of bending capacity compared to a steel-reinforced system with identical diameters (Hebel et al., 2017).

b) Resource efficient construction to reduce the amount of concrete

The amount of concrete used can be reduced through economical construction techniques, by introducing hollow-core or even biaxial hollowed slabs. The reduced amount of concrete (25%-30%) in biaxial slabs also reduces the dead load of the slab element compared to a solid flat slab system, which contributes to even further material savings (CSBCBCA, 2012).

Recycling

After the end-of-life of a building, materials should get separated and reused. Buildings should be planned to be recycled from the outset, and information recorded digitally. Whole building components might be reused, but mostly, individual materials are recycled. Recycling can reduce the overall carbon footprint of building materials, still some conditions limit the potential of the process. While steel can be made by recycling of metal scraps, the application is limited by the availability of metal scraps (Raabe et al., 2019).

Concrete building components can be crushed and reused as an ingredient for concrete and can substitute up to 45% of the gravel in concrete. Nevertheless, due to higher transport emissions, the primary energy demand of recycled concrete can be higher than conventional concrete. An analysis is needed before implementation (Lieblang, 2013).

4.3. Alternative building materials – from bio-based to recycled

Bio-based materials have been used for a long time all across the globe. Worldwide, specialized value chains are being developed to produce these materials as "modern" building materials with excellent static and thermal properties. The following presents a snapshot of alternative materials that can be used in construction – from bio-based materials such as wood and clay to recycled plastic. Given their local nature, a large range of alternative building materials exists.

Wood and bamboo

Figure 16: Especially in moderate climate zones, wood can be a climate-friendly building material with excellent thermal properties.
ARTIS GmbH in Berlin, (Architects: ZRS)

Timber has excellent thermal as well as static properties and can replace steel and reinforced concrete. Trees act as a carbon sink, and the use of wood can considerably bring down emissions. To lower transport emissions, the usage of native wood species should be preferred.

While wood is a great building material, it can be an environmentally harmful choice when there are not enough local wood resources.

Clay and earth

Figure 17: Clay materials have excellent moisture absorption properties and increase thermal comfort in buildings.
Jiyan Health Garden, Iraq
Architects: ZRS Architekten)

Locally sourced and unprocessed rammed earth can replace concrete and is increasingly being used as a "modern" building material. Clay can be processed and transformed into clay bricks or boards. Clay and loam building materials provide an excellent thermal indoor climate but, unlike fired bricks, they have only limited load-bearing capacity. Therefore, these materials are suitable for infill and non-load-bearing walls.

Because of an almost infinite capacity to be recyced or upcycled, earth building materials have a low energy balance in the entire lifetime (Blaschek et al., 2017). In Senegal, the company Elementerre produces compressed earthblocks with improved quality standards by replacing the traditional handmade production of the earth blocks with mechanical presses.

Recycled plastic

Figure 18: Plastic waste is available everywhere and can be used as a building material

Every year, the world produces around 400 million tonnes of plastic, of which only 9% gets recycled. Converting plastic waste into building materials offers a huge potential to increase the lifespan of previously unrecyclable plastics. Enterprises like conceptos plasticos or ByFusion use plastic waste to transform it into waterproof bricks (WorldGBC, 2020).

Natural fibres

Figure 19: Typha, a cane, can be used for insulation and in earth bricks
Eco-Pavilion, Senegalese Ministry of Environment
Architects: CraTerre

Straw and other plantbased products provide excellent insulating properties and are less polluting than conventional insulations, and often 100% compostable. Other plant-based insulations include hemp, wood wool or flax**.**

Types of cane, like typha an invasive fast growing plant in watery areas, are water repellent and can be used for roof cladding, insulation and in earth bricks. Typha can be transformed into insulation with a high compressive strength at a low heat conductivity ($\lambda \approx 0.055$ W/mK). This is promoted in the TyCCAO project in Senegal.

Innovative types of concrete mixing organic materials such as hemp or recycled fibres reduce the need for reinforcement.

Mycelium

Figure 20: Mushroom materials are durable and naturally fire resistant

Mycelium, the root system of fungi, could be used as a building material with both structural and thermal properties. It can be cultured on low-grade agricultural waste, sequestering the carbon stored in the biomass.
Manufacturers like BIOHM or MycoWorks are testing technologies to convert mycelium into functional building components (Fairs, 2021).

5. WAY FORWARD – HOW CAN WE ACCELERATE THE SHIFT TO LOW-CARBON BUILDINGS?

Low-carbon building materials and construction are ready to be scaled up. Companies and start-ups across the globe have developed alternative materials as a state-of-the-art product for today's real-estate markets, and large corporations are looking to green the production of cement and steel.

Still, without dedicated policies or dedicated support, sustainable building materials will not get into the mainstream. Embodied carbon targeting policies are necessary for a business environment that tackles embodied carbon. In the absence of an effective price on carbon, the following measures are needed to incentivise and accelerate the shift (cf. GlobalABC, 2016; WGBC, 2019; CNCA 2021).

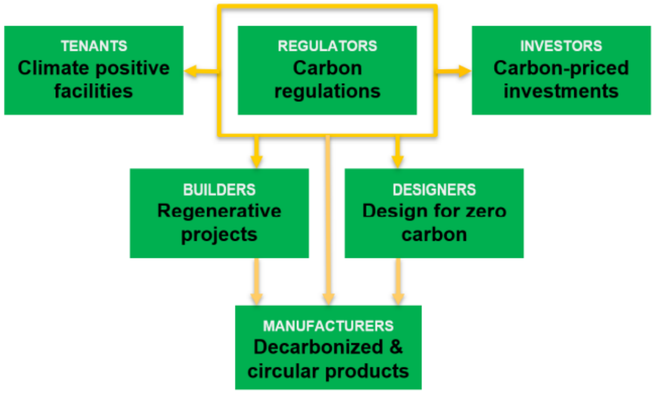

Figure 21: Business environment and requirements to bring about zero carbon construction. Graph: CNCA 2021

5.1. Policy

Policies at the national and local level are essential to set the framework for action in the building sector and send signals to industry actors (cf. figure 21). Regulation remains the most effective way to address embodied emissions.

Climate targets

- **NDCs:** ambitious national climate targets to guide national policies and attract climate financing. For example, nine countries in Africa have set NDC targets related to decarbonizing concrete production (cf. *A9* in *Annex*).
- **Baseline data:** Knowledge about the embodied carbon content of the current building stock is needed for calculating emission baselines and setting mitigation targets and for monitoring, reporting and verification (MRV) of impacts over time.

Regulation

- **National policies** addressing embodied carbon (cf. One Click LCA Ltd., 2018), for example:
    - Life-cycle emission reporting requirements
    - Setting limits to the embodied carbon content of building parts and components
    - Specific strategies and policies addressing the highest emitting materials (e.g. cement and steel and other high-emissions materials)

Standards and norms

- **Certification** of alternative or new materials and products, including recycled materials or pre-fabricated elements, to make their use possible.
- **Adaptation of building standards** to accommodate lower-carbon building materials, e.g. in the cement industry.

Labels and certification

- **Labels and (voluntary) certification schemes** increase transparency for consumers and provide the basis for public support. 26 countries had about 130 voluntary certifications and standards for low embodied emissions buildings in 2018 (One Click LCA Ltd., 2018).

Public procurement

- **Life-cycle carbon requirements**, or specifications about materials and **resource-efficient design and recycling** for new buildings and refurbishment.

Cities and embodied carbon

Cities can be important actors, for example by setting standards in the context of **land sales and urban planning policies**, embodied carbon **requirements for building permits** and **public procurement for municipal buildings**, as well as through waste management.

French environmental building regulation "RE2020"[7]

The new French environmental regulation for buildings and construction will enter into force on 1st January 2022. This regulation represents a major step in the decarbonisation of the building sector by setting ambitious targets for the reduction of the energy consumption of new buildings compared to the previous regulation (RT2012), and by requiring, for the first time, that new buildings meet embodied carbon targets.

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[7] http://rt-re-batiment.developpement-durable.gouv.fr/
https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043877196
https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000043936431

5.2. Finance

Financial decisions are fundamentally influenced by policy. At the same time, targeted actions by and for financial actors can accelerate the shift.

Financial incentives

- **Green building programmes** that provide financial incentives to buildings that meet embodied carbon criteria
- **Incentives, such as tax rebates** to manufacturers for low carbon building components or products

Investors

- **Support investors** setting and implementing decarbonization policies for the real estate part of their investment portfolios (cf. WBSCD 2021b).
- **Transparency through reporting requirements:** Sustainable financing initiatives such as the European Union's Renewed Sustainable Finance Strategy with its taxonomy of sustainable investments makes reporting on lifecycle emissions mandatory for assets deemed renewable (cf. PEEB 2021).

Development banks

- **Embodied carbon accounting**: Development banks should demand lifecycle assessments for the projects they finance and monitor embodied carbon as part of their project monitoring.
- **Financing criteria:** Eligibility criteria for financial project support should include requirements to reduce the amount of embodied carbon.

5.3. Knowledge and capacity

Knowledge about how to construct with, certify and sell low-carbon materials is needed to transform the market.

Technical knowledge

- **Applied research:** Cooperation between research institutions and construction companies is needed, from innovative building materials to more efficient construction techniques.
- **Manufacturers and suppliers**: Innovation knowledge for new products including recycled materials
- **Technical capacities:** Design and construction professionals need to build up expertise about life-cycle analyses, low-emissions materials and material-saving techniques.
- **National testing laboratories and facilities** need to gain experience with low-carbon materials and innovations

Data

- **Building material databases:** Databases with country-specific information on the properties of building materials are needed to calculate emissions as the basis for regulation and financing. Such databases are not available in most developing countries.

Market development

- **Business skills:** Private sector suppliers of sustainable building materials need to develop larger value chains to increase their market share.
- **Developers:** Information about design solutions, market potential and business models are needed.
- **Builders, construction companies:** Knowledge on new construction methods and installation procedures during construction.
- **Customer awareness:** Market demand can be stimulated through awareness raising about the benefits of building materials and labels, especially for commercial users.

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Figures

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Figure 3: Graph by GlobalABC 2017

Figure 4: Graph by WBCSD 2021a

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Figure 7: Graph by PEEB

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Figure 21: Graph by CNCA 2021

Tables

Table 1: Buildings operation and construction emissions estimates, 2019. Based on IEA 2020

Boxes

Box 1: International Initiatives to address embodied carbon

Box 2: Scopes of Emissions

Box 3: UNFCCC Compendium

Box 4: Resources - Building Design

Box 5: Checklist to ensure sustainable concepts

ANNEX

Annex [A1]: Examples of life-cycle assessment tools

To quantify carbon emissions over the complete life-cycle of a building, life-cycle carbon footprint (LCA) methodologies can be used. LCA accounts for the carbon impacts of material manufacturing, transport, site wastage and installation, maintenance, use and repair, replacements during the life cycle, as well as end-of-life processing after the useful life of the building. Many LCA programmes are also capable of providing Life Cycle Costing (LCC), a powerful tool to present maintenance and replacement processes as well as operational energy and water use costs (One Click LCA Ltd., 2018). The LCA tools often have internal databases of different building materials, sometimes they use external data bases which are presented below.

Title	Country/Region		Website
EC3Tool	Global	Free Online Tool	www.buildingtransparency.org
eLCA	Germany	Free Online Tool	www.bauteileditor.de
eTool	Global	Free Online Tool	www.etoolglobal.com
GaBi	Global	Software	www.gabi.sphera.com
OneClickLCA	Global	Online Tool	www.oneclicklca.com
openLCA	Global	Free Software	www.openlca.org
SimaPro	Global	Software	www.simapro.com

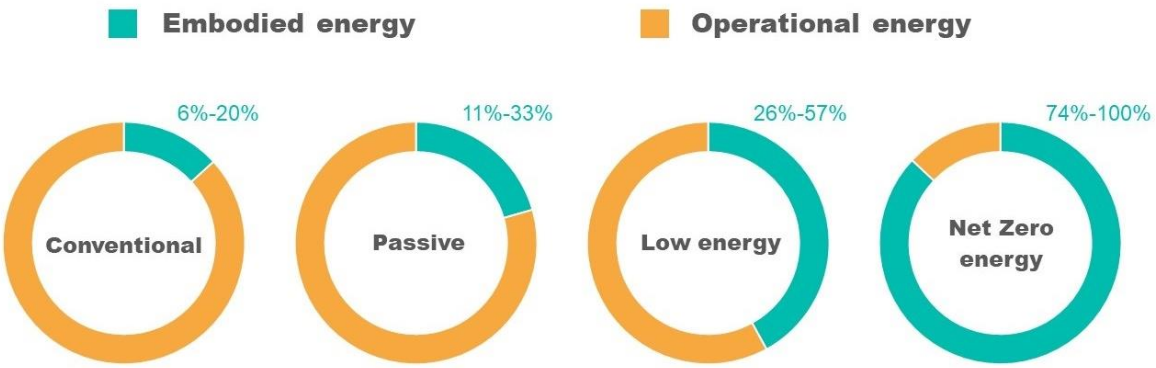
Annex [A2]: Examples of LCA - Databases

Title	Country/Region	Description	Website
LCA Database	Global	Global Database	www.lcadatabase.com
ecoinvent	Global	Global Database	www.ecoinvent.org
GaBi LCI Data	Global	Global Database	www.gabi.sphera.com
ProBas	Germany	Free Database	www.probas.umweltbundesamt.de
Ökobaudat	Germany	Free Database	www.oekobaudat.de
InData	Global	Free Database	https://www.indata.network/

Annex [A3]: Information Portals & Certifications

Title	Country/Region	Description	Website
Building Material Scout	Global	Database	www.building-material-scout.com
Cradle to Cradle	Global	Database, Certification	www.c2ccertified.org
Green Seal	Global	Database, Certification	www.greenseal.org
Ul Spot	Global	Database	www.spot.ul.com

Annex [A4]: Rising importance of embodied energy in whole-life energy use of residential buildings



(author: PEEB; Source: Azari, R. (2019).

Annex [A5]: Detailed Life Cycle Stages defined in EN 15978

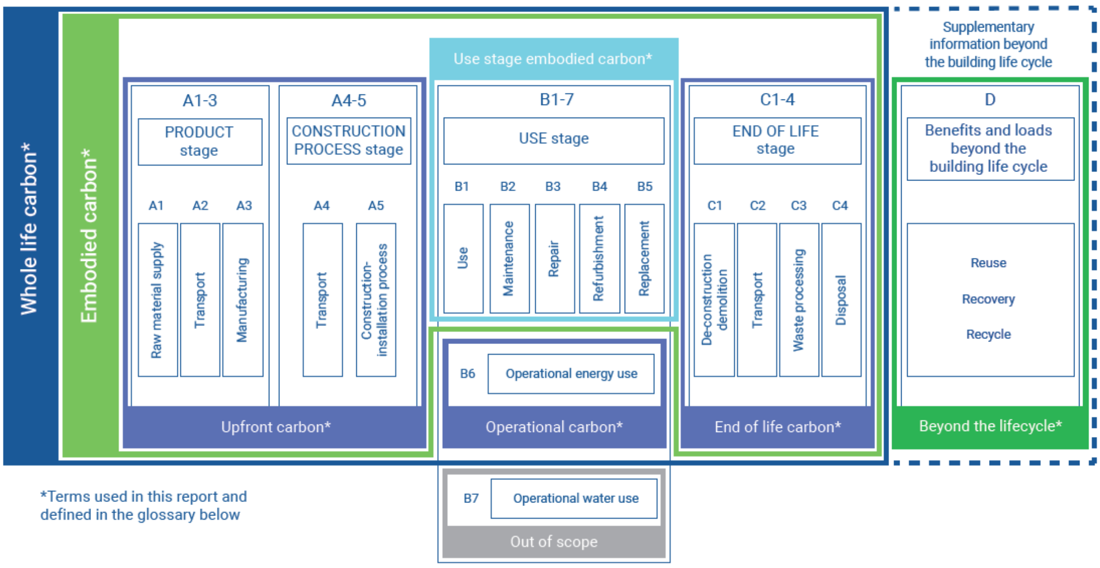


Figure 1: Terminology used in this report cross-referenced to terms and lifecycle stages defined in EN 15978

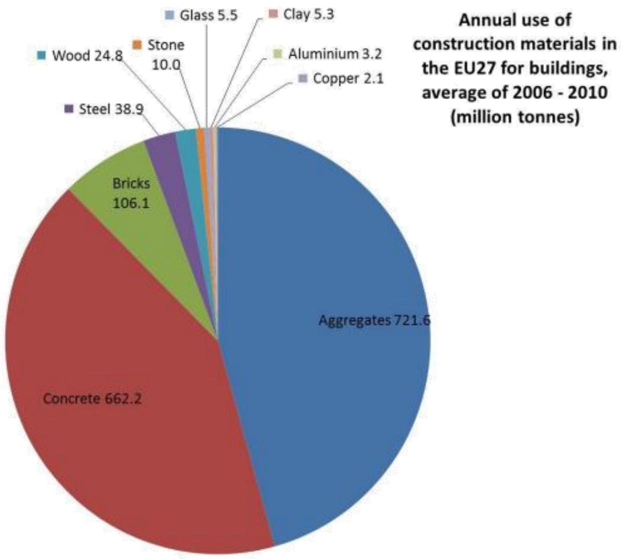
Annex [A6]: Building Design Principles in Hot Climate Zones

Climate-friendly design involves the choice of the right building materials and the adaptation of the building design to the regional climate conditions. The following table gives an overview of fundamental design principles for a hot climate:

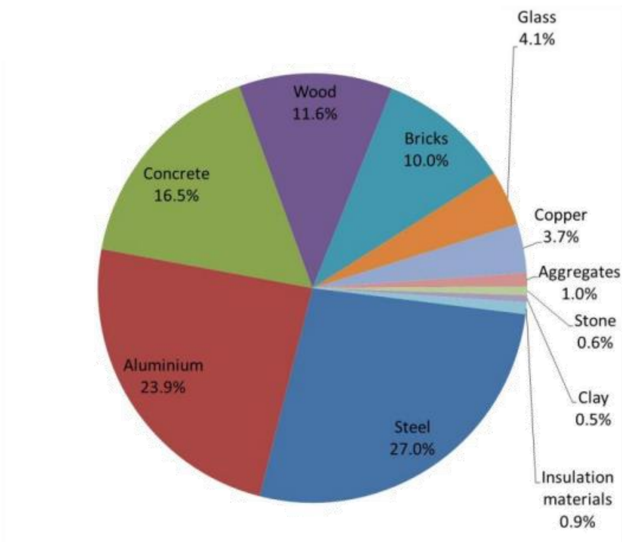
	HOT ARID	TROPICAL DRY	TROPICAL WET	HUMID SUBTROPICAL	MEDITERRANEAN
THERMAL MASS	◯◯◯	◯◯	◯◯◯	◯	◯◯◯
NATURAL VENTILATION	◯	◯◯◯	◯◯	◯◯◯	◯◯
THERMAL INSULATION	◯◯◯	◯◯	◯◯◯	◯	◯◯
SOLAR GAINS	◯	◯	◯◯	◯◯	◯◯
BUILDING DESIGN					

◯◯◯	= HIGHLY NEEDED
◯◯	= SLIGHTLY NEEDED
◯	= NOT NEEDED

Annex [A7]: EU Construction Materials by Weight (% of total) (ECORYS, 2014)



Annex [A8]: Total Embodied Energy in Building Materials, 2011 (in EU) (ECORYS, 2014)



Annex [A9]: NDC's of African countries with concrete/cement Contribution

Country	Submission Year (NDC)	Text in NDC
Morocco	Link (2021)	l'inclusion de nouveaux sous-secteurs de l'Industrie, à savoir la production du ciment et la production des phosphates. Substitution d'une partie du clinker par les cendres volantes dans un mélange permettant d'obtenir du ciment aux caractéristiques désirées et contribuer à la réduction des émissions de GES par la réduction de la production du clinker.
Ghana	Link (2015)	No
Senegal	Link (2020)	Efficacité énergétique des cimenteries et la substitution du clinker et l'usage du gaz.
Ethiopia	Link (2021)	Clinker substitution – Replacing clinker in cement with adequate and available materials without compromising cement properties while saving from increased nitrogen use efficiency.
Tunisia	Link (2017)	The mitigation plan includes the use of a NAMA in the cement industry from 2016 onwards and access of this sector to carbon markets from 2021 onwards. The mitigation plan provides for the implementation, from 2016, of a plan to install facilities to transform solid waste into RDF (refuse derived fuel) intended for cement facilities.
Nigeria	Link (2021)	The priority mitigation measure in the IPPU sector (cement, iron, steel and ammonia production) is to reduce HFC gases in line with the Kigali Amendment to the Montreal Protocol. This means a phase-down of hydrofluorocarbons (HFCs)
Namibia	Link (2021)	Replace 23% clinker in cement production
Rwanda	Link (2020)	Mitigation potential from IPPU sources is by comparison relatively limited, with the majority of emissions reductions arising from increased use of clinker substitute for cement production (volcanic pozzolanas). Increased resilience of cement industry. Reduced reliance on imported energy supply.
Egypt	Link (2017)	Optimize the production of cement, lime, iron and steel, ammonia not used in urea, nitrogenous fertilizers and nitric acid

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