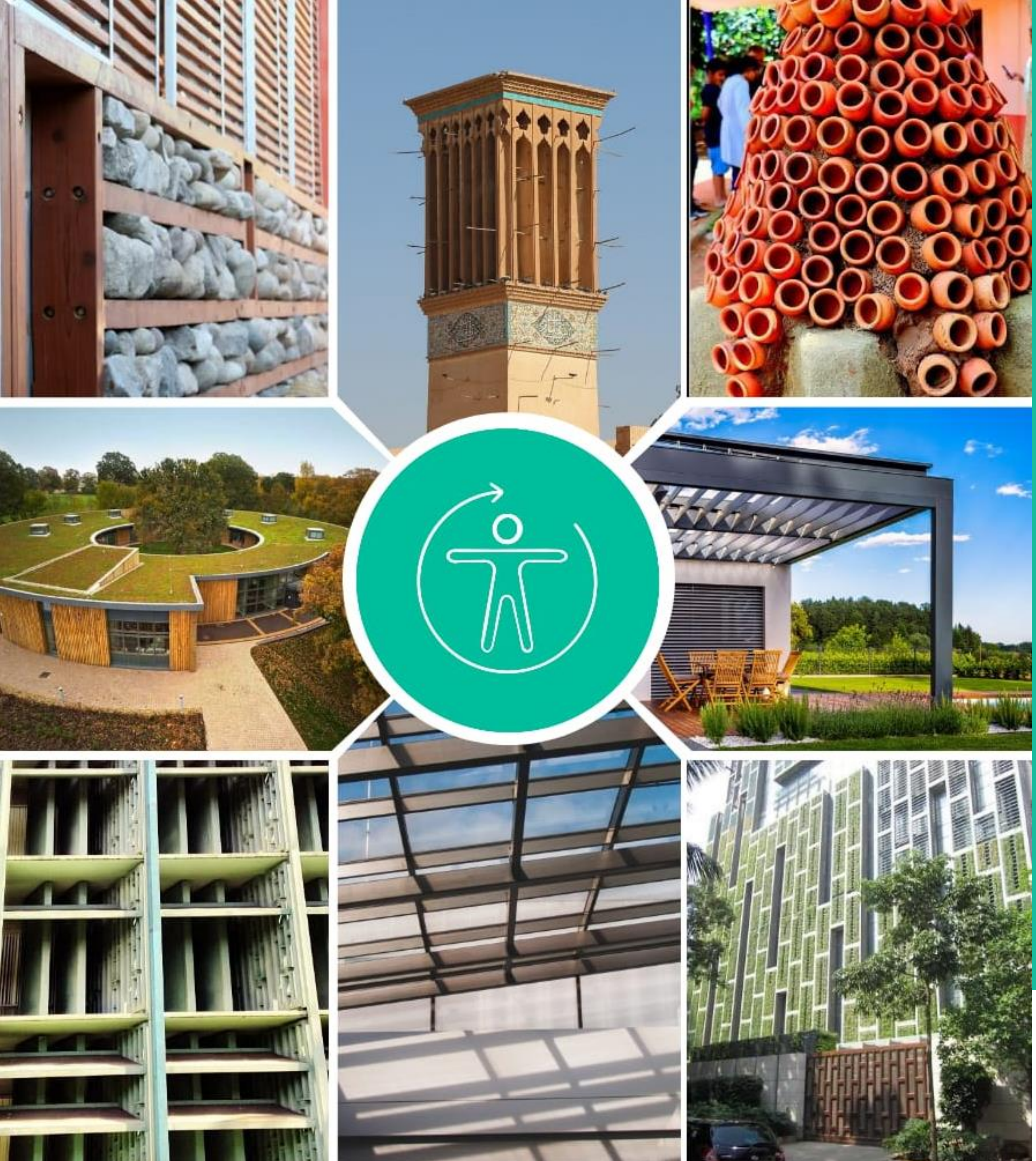


ASIA LOW CARBON BUILDINGS TRANSITION PROJECT
Life Cycle Assessment for Transitioning to a Low-Carbon Economy

3.2 Understanding Embodied Carbon in Buildings

November 2024

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag
INTERNATIONAL CLIMATE INITIATIVE

WHAT WILL YOU LEARN?

01 Embodied Carbon and its Importance

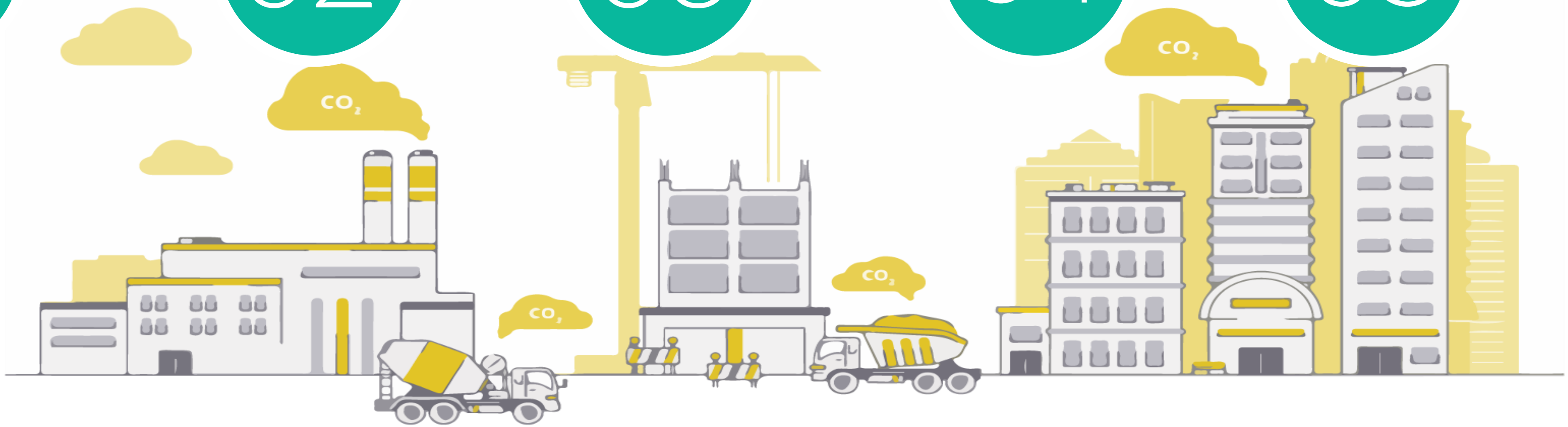
02 Key Materials Driving Embodied Carbon

03 Calculating Embodied Carbon

04 Reducing Embodied Carbon

05 Embodied Carbon Regulations

06 Case Examples



WHOLE LIFE CARBON

Embodied and operational carbon

- The **whole life** of a building is the entire life of a building from the material sourcing, manufacturing, construction, use over a given period, demolition, and disposal or reuse
- **Whole life carbon** refers to the carbon impacts over the entire life cycle of a built asset, from its construction through to its end of life
- The whole life carbon of a building broadly consists of **embodied carbon and operational carbon**
- In addition, there are user carbon impacts from the activities of the users of a built asset, outside of the use of energy and water to operate the asset

Source: Royal Institute of Chartered Surveyors, 2023

Image source: Gensler, Garett Rowland

Embodied Carbon in Buildings

Relevance and Importance

Image source: https://www.lek.com/insights/by/building-materials-supply-chain-disrupted-changes-consumer-behaviour

BUILDING LIFE CYCLE STAGES

Whole life carbon assessment information

Whole life carbon – system boundary

Embodied carbon / life cycle embodied carbon

Production
- A0: Non-physical process before construction, preliminary study, test & design
- A1: Raw materials supply
- A2: Transport
- A3: Manufacturing

Upfront biogenic carbon

Construction
- A4: Transport
- A5: Construction and installation process

Biogenic carbon

Operation
- B1: Use
- B2: Maintenance
- B3: Repair
- B4: Replacement
- B5: Refurbishment

Biogenic carbon

End of life
- C1: Deconstruction/ Demolition
- C2: Transport
- C3: Waste processing
- C4: Disposal

Biogenic carbon

Operational Carbon
- B6: Operational Energy
- B7: Operational Water

User Carbon
- B8: User activities not covered in B1-B7

Circular Economy

Beyond asset life
- Benefits and loads beyond system boundary
- D1: Net output flows from reuse, recycle, energy recovery, other recovery
- D2: Exported utilities, e.g., electric energy, thermal energy, potable water

Biogenic carbon

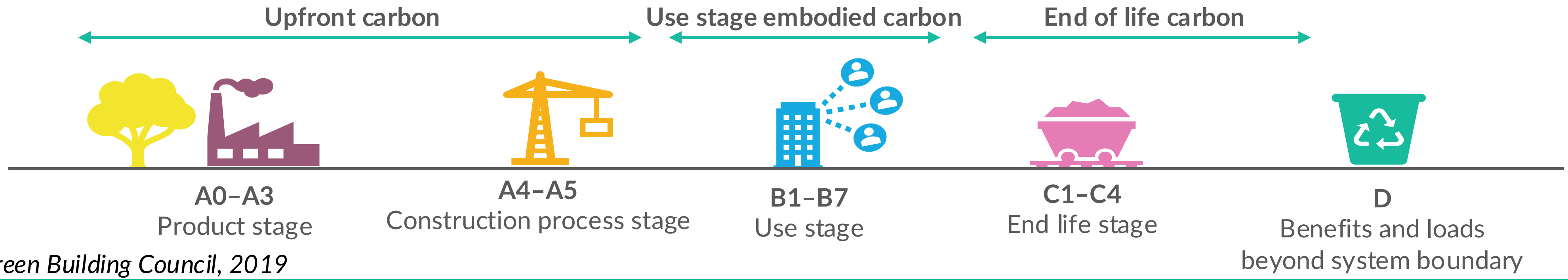
Source: Royal Institute of Chartered Surveyors, 2023

EMBODIED CARBON

Upfront, during use and end of life

Embodied carbon denotes carbon emissions associated with materials and construction processes throughout the whole life cycle of a building. This includes:

- **Upfront carbon:** The emissions caused during the building material production and construction phases (A0–A5) of the building's life cycle before it is used. In contrast to other categories of emissions, these emissions have already been released into the atmosphere before the building is occupied or the infrastructure begins operation
- **Use stage embodied carbon:** Emissions associated with building materials and processes needed to maintain the building or infrastructure during use, such as for refurbishments (B1–B5). These are additional to operational carbon emitted due to heating, cooling and power etc.
- **End of life carbon:** The carbon emissions associated with deconstruction and demolition (C1), transportation from site (C2), waste processing (C3) and disposal (C4) phases of a building or infrastructure's life cycle which occur after its use



Source: World Green Building Council, 2019

EMBODIED CARBON

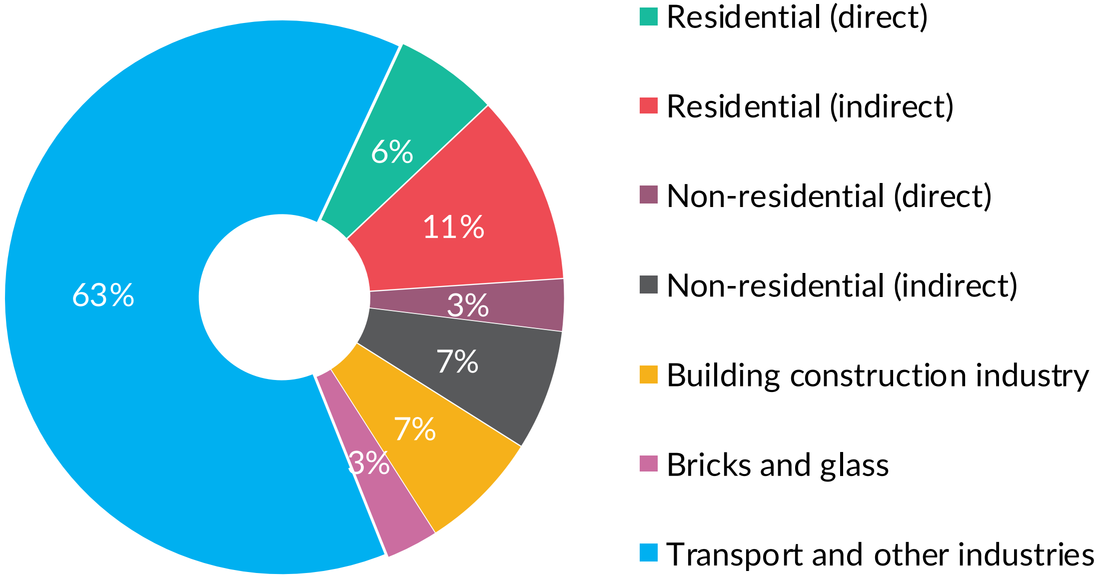
Its relevance and importance

- At least one-quarter of global emissions from buildings result from embodied carbon, i.e., carbon emissions associated with building materials and construction
- As global construction continues to rise, and existing building operations become more efficient, embodied carbon will become an increasingly significant issue – accounting for approximately 50% of global building sector emissions between now and 2050
- This will account for a significant amount of the remaining carbon budget, and it needs to be urgently addressed by policymakers and practitioners

Source: Jungclaus, M. et al., 2021

Share of building in global energy and process emissions

Emissions by sector, 2022



Source: United Nations Environment Programme, 2024

EMBODIED CARBON

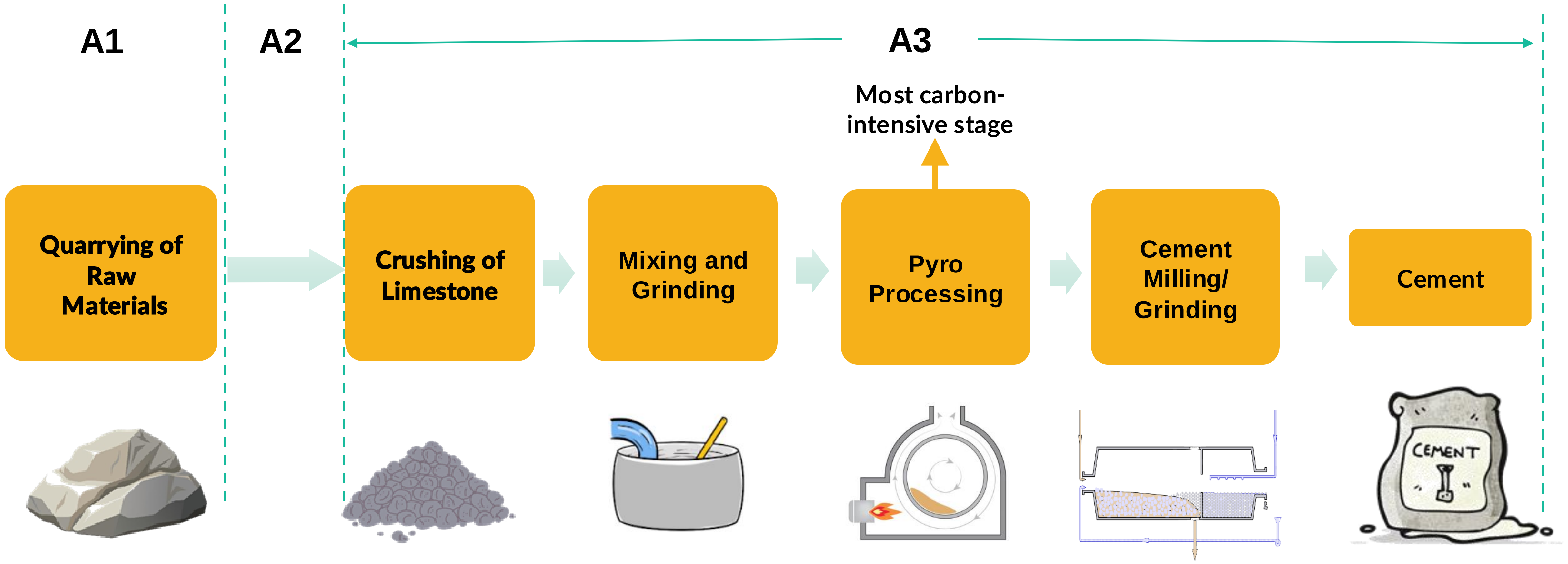
Its relevance and importance

- **Time value of carbon:** Unlike operational carbon emissions, which can be reduced over time with building energy efficiency renovations and the use of renewable energy, embodied carbon emissions are locked in place as soon as a building is built. It is therefore critical to reduce embodied carbon emissions as quickly as possible
- **Lowering embodied carbon can drive value:**
  - Reducing cost by reducing the construction materials needed in a project
  - Carbon-reduction strategies in the production of high-emitting materials like concrete can also reduce cost
  - Unless their process is driven by carbon-intensive chemical reactions, low embodied-carbon products will, by nature, result in energy savings upstream of a material's end use, resulting in cost savings for material manufacturers
  - Projects that reduce embodied carbon and/or include a whole-building life cycle assessment can help to meet green building certification requirements
  - Low-embodied-carbon building design will be better prepared for future code or policy changes that incentivize or require low embodied carbon
  - Reducing emissions in the extraction, manufacturing and transportation of low-embodied carbon materials improves air quality and public health in communities located close to industrial centers

Source: Jungclaus, M. et al., 2021

CEMENT MANUFACTURING

Manufacturing process outline



CEMENT MANUFACTURING

Options for reducing carbon footprint

- **Use of alternative raw materials like fly ash, slag and other supplementary cementitious materials (SCMs)**
- **Use of alternative energy sources for reducing carbon footprint**
  - Using waste materials like tyres, fabrics, paper, municipal solid waste, hazardous waste, etc. as supplementary fuels in kilns for pyro processing
  - Using sustainable fuels like biomass for partial substitution of fossil fuels in kilns
  - Increasing pre-calciner stages to reduce exhaust gas temperature
  - Generating electrical power from process waste heat
  - Using renewable energy sources (biomass / solar) for electricity power
  - Using green hydrogen as fuel in the pyro-processing / clinker-making process
  - Exploring possibility for electrification of kilns (technology is at a nascent stage)
- **Carbon emissions management through carbon capture, utilization and storage (CCUS) and carbon offsets**

STEEL MANUFACTURING

Manufacturing process outline

A1 | **A2** | **A3**

Most carbon-intensive stages

Mining → Iron Making → Steel Making → Crude Steel

STEEL MANUFACTURING

Options for reducing carbon footprint

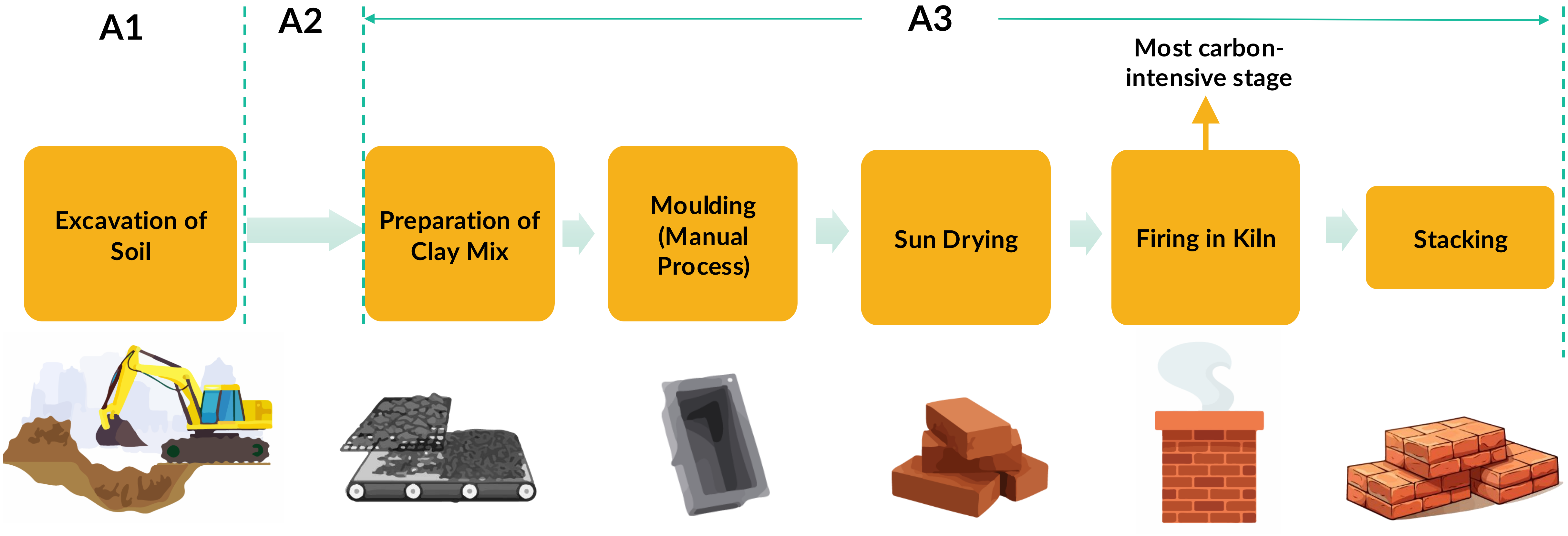
- **Energy efficiency measures**
  - Optimization of raw material consumption
  - Improvement in process and energy efficiencies
  - Augmenting waste heat recovery
  - Minimizing re-heating of intermediate products

- **Use of renewable energy for electricity power**

- **Alternative fuels for combustion and as reducing agents**
  - Explore possibilities for shifting from coal-based process to natural gas, biomass and green hydrogen; however, these options may be practically difficult to implement in existing plants
- **Carbon emissions management through carbon capture, utilization and storage (CCUS) and carbon offsets**

FIRED CLAY BRICK MANUFACTURING

Manufacturing process outline



FIRED CLAY BRICK MANUFACTURING

Options for reducing carbon footprint

- **Energy efficiency measures**
  - Efficient combustion of fuels
  - Manage and monitor use of raw materials and fuel as well as emissions
- **Alternative fuels for combustion**
  - Explore possibility of fuel substitution from coal to natural gas, biomass, etc.
- **Use of renewable energy for electrical power**
- **Changing the fired walling product**
  - Manufacturing alternative fired walling blocks like hollow or perforated bricks etc., which requires less raw material and fuel. This will entail changes in the production process

Embodied Carbon in Buildings

Key Driving Materials

Image source: https://www.bricknbolt.com/blogs-and-articles/construction-guide/building-material-density-importance-

KEY DRIVING MATERIALS

Cement and steel

- A building's structure and substructure typically constitute the largest source of its upfront embodied carbon (up to 80%, depending on building type). However, because of the relatively rapid renovation of building interiors associated with tenancy and turnover, the total embodied carbon from interiors can account for a similar order of emissions over the lifetime of a building[1]
- **Globally, cement and steel are two of the most significant sources of material-related emissions in construction.** Cement manufacture is responsible for 7% of global carbon emissions, with steel contributing 7%–9% of the global total (with half attributed to buildings)[2]
- Both cement and steel are used in buildings in large quantities. These materials are carbon intensive as the manufacturing processes demand very high temperatures, achieved by firing of fossil fuels; carbon dioxide emissions occur due to combustion of fuels and also as part of chemical reactions during the manufacturing process[2]
- **Cement / concrete and steel are the highest contributors in typical construction in India.** One study of residential buildings shows concrete and steel together account for 75%–94% of product stage carbon[3]

[1] Source: Jungclaus, M. et al., 2021
[2] Source: World Green Building Council, 2020
[3] Source: Chetia, S. et al., 2024

KEY DRIVING MATERIALS

Other building materials

- **Walling materials are significant contributors to carbon emissions**, as large number of buildings are RCC-framed structures with masonry infill. Some of the walling materials like fired clay bricks and concrete blocks are carbon intensive
- **Glass and aluminum, which have manufacturing processes at high temperatures, are carbon intensive, although their impact on buildings is smaller in comparison with cement and steel**
- Depending on the type of buildings and the prevalent construction technology used in a region or country, the major materials driving embodied carbon may differ

Embodied Carbon in Buildings

Calculation Methodology

EMBODIED CARBON

Calculation Methodology

- Embodied carbon in buildings is commonly measured in **$kgCO_2e/m^2$ (kilograms of carbon dioxide equivalent per square meter of building)**. This allows comparison of embodied carbon in different buildings
- The calculation is:

Inventory	×	Impacts	=	Total
Quantity of materials or products used in building		Carbon factor or GWP of respective material or product		Total embodied carbon emissions

- The product stage (A1–A3) emissions relating to the raw material extraction, shipping to factory and manufacturing is what is most commonly available in embodied carbon databases
- The calculation above, using figures from the carbon database, gives the carbon emissions of materials only for A1–A3 stages of the building life cycle

Source: Hrivnak, 2023

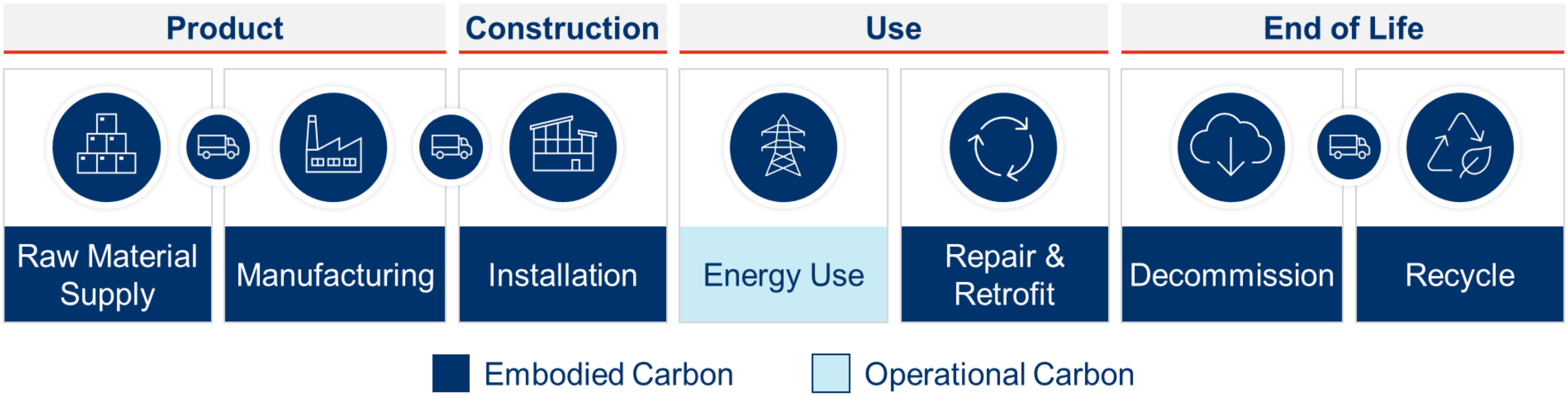
GLOBAL WARMING POTENTIAL (GWP)

Major building materials

Material / Product	Unit	GWP ($kgCO_2$/unit) (A1-A3 stages)	Geography	Source
Ordinary Portland Cement (OPC)	kg	0.842	India	*Centre for Science and Environment, 2023*
Portland Pozzolana Cement (PPC)	kg	0.582	India	
Portland Slag Cement (PSC)	kg	0.381	India	
Concrete	m^3	~450 to ~240 (varies as per mix used)	Global	*Witte and Garg, 2024*
Steel	kg	2.3–2.5	India	*Various, including Ministry of Steel, 2020; CEEW, 2023; Centre for Science and Environment, 2023*
Solid Burnt Clay Brick	m^3	198.87	India	*Maithel, 2023*
Solid Concrete Block	m^3	~200	India	*India Construction Materials Database of Embodied Energy and Global Warming Potential, 2017*
Aluminium	kg	26	India	
Glass (6mm thick)	m^2	~19	India	*Manufacturer's EPD*

LIFE CYCLE ASSESSMENT (LCA)

- Elements of an LCA: Goal and scope definition, inventory analysis, impact assessment, interpretation
- For all the segments reflected below, carbon emissions are quantified for the product level, transportation level, construction phase, use phase and end of life



Source: London Energy Transformation Initiative, 2020

EMBODIED CARBON

Quantifying upfront carbon

Acquiring the bill of quantities (BOQ) from the builder

↓

Identifying all the materials to be included for assessment

↓

Splitting down the composite materials

↓

Identifying the most relevant and suitable emission factors

↓

Calculating the embodied carbon (A1–A3)

Identifying the supplier location, mode of transport, vehicle pay load capacity and emission factor to calculate the transport-based emissions (A4)

Getting information about the energy usage at the construction site (electricity and other fuels usage), multiplying the total quantities used with their most relevant emission factors to get the construction-based emissions (A5)

CALCULATING EMBODIED CARBON

Challenges in calculating embodied carbon from different life cycle stages

- **Product stage (A1–A3)** has been shown to have the highest contribution to the total embodied carbon of buildings. Hence, calculating product stage embodied carbon already shows the embodied carbon hotspots and direction for reduction
- **Emissions for transport to site (A4) and the construction process (A5)** need to be added to fully evaluate a project's upfront carbon. The easiest way to do this is to use industry-accepted proxies at the national level (if available) or global level
- **Use phase stages (B1–B5) emissions** are difficult to estimate as not all have methodologies for accurate estimation
- **End of life stages (C1–C4) emissions** depend heavily on how materials are handled during and after the building demolition. This data is not readily available

Percentage share of product stage carbon to total embodied carbon for buildings in UK

Building type	Percentage share of product stage carbon
Small-scale housing	80%
Medium and large-scale housing	64%
Commercial offices	48%
Schools	65%

Source: London Energy Transformation Initiative, 2020

EMBODIED CARBON

Calculations

Inventory	×	Impacts	=	Total
Quantity of materials or products used in building		Carbon factor or global warming potential (GWP) of respective material or product		Total embodied carbon emissions

Material quantities: Data for material quantities used in a building are usually available with the project proponent in the form of a bill of quantities (BoQ).

Building information modeling (BIM) design tools can provide material quantity estimates in the design phase

Carbon factor / GWP of building materials:

Sources in order of preference:

- Manufacturer's specifications or product-specific environmental product declaration (EPD)
- Generic government, market-based or industry databases or life cycle inventories (LCIs)
- Other databases like the Inventory of Carbon and Energy (ICE) database

CALCULATING TOOLS

For life cycle assessment (LCA) and embodied carbon

Calculators	Simple online or spreadsheet-based tools designed to allow for targeted and quick decision-making: • **Building calculators** help designers get a quick sense of the order of magnitude of embodied carbon. These are typically most helpful in early design stages before modeling has begun and are not typically appropriate for reporting embodied carbon to meet the requirements of standards or rating systems **Examples: Build Carbon Neutral, Athena EcoCalculator** • **Material-specific or assembly-specific calculators** help designers quickly evaluate design or sourcing decisions related to a single material or assembly, such as wood or façades **Examples: Kaleidoscope, Upstream Forestry, Carbon LCA Tool**
Product selection/ procurement tools	These collect product data, such as EPDs, and facilitates comparison to help users select a product or supplier **Example: Embodied Carbon in Construction Calculator (EC3)**

Source: Lewis, M. et al., 2023

CALCULATING TOOLS

For life cycle assessment (LCA) and embodied carbon (continued)

Design integrated LCA tools	These may be integrated into software that architects already use, or they may be freestanding tools: • **Whole building LCA tools** allow users to easily model the whole building at a fair level of detail (in terms of material types and material quantities) and perform the calculations to produce the LCA results **Examples: Tally (a plug-in for Revit), One Click LCA, Athena Impact Estimator** • **Assembly-specific design tools** have been developed to track and manage embodied carbon for a specific physical scope, such as structure or façade **Examples: Beacon, Building and Habitats object Model (BHoM)**
Professional LCA software	These are primarily used by LCA experts and consultants for all types of products, not just those related to the building industry. These tools are commonly used to perform the LCA that an EPD is based upon, and are used to create the background datasets used in most whole building LCA tools **Examples: SimaPro, OpenLCA, GaBi**

Source: Lewis, M. et al., 2023

TOOL SELECTION CRITERIA

For life cycle assessment (LCA)

- **Background data: Life cycle inventories (LCIs)** are datasets that report emissions for different processes that contribute to the creation of a material or product. Different tools may use different LCIs, so it is important to know which datasets each tool uses, since the results can differ. LCI databases are created and managed by governmental, non-governmental and private organizations
- **Geographic location:** LCIs can have different geographic scopes. Ideally, the dataset in the tool should match the geographic location of the project
- **Life cycle scope:** Different standards and rating systems may require reporting of few or all the life cycle stages. If it is being used to report the results of a whole building LCA, the tool must include life cycle stages (product, construction, use and optionally end of life)
- **BIM integration:** BIM-integrated LCA tools are plug-in tools embedded into BIM software, such as Revit. They automate parts of the LCA process by extracting inventory data from the BIM model, increasing integration with the design process and reducing the chance of human errors from manual takeoffs

Source: Lewis, M. et al., 2023

Reducing Embodied Carbon in Buildings

Principles and strategies

Concrete

Optimize concrete mix

14%–33% reduction
None to low cost premium

Rebar

Use high recycled content rebar

4%–10% reduction
None to low cost premium

Insulation

Select low- or no-embodied-carbon insulation products

16% reduction
No cost premium

Glazing

Select low-embodied-carbon glazing products

3% reduction
10% cost premium

Finish Materials

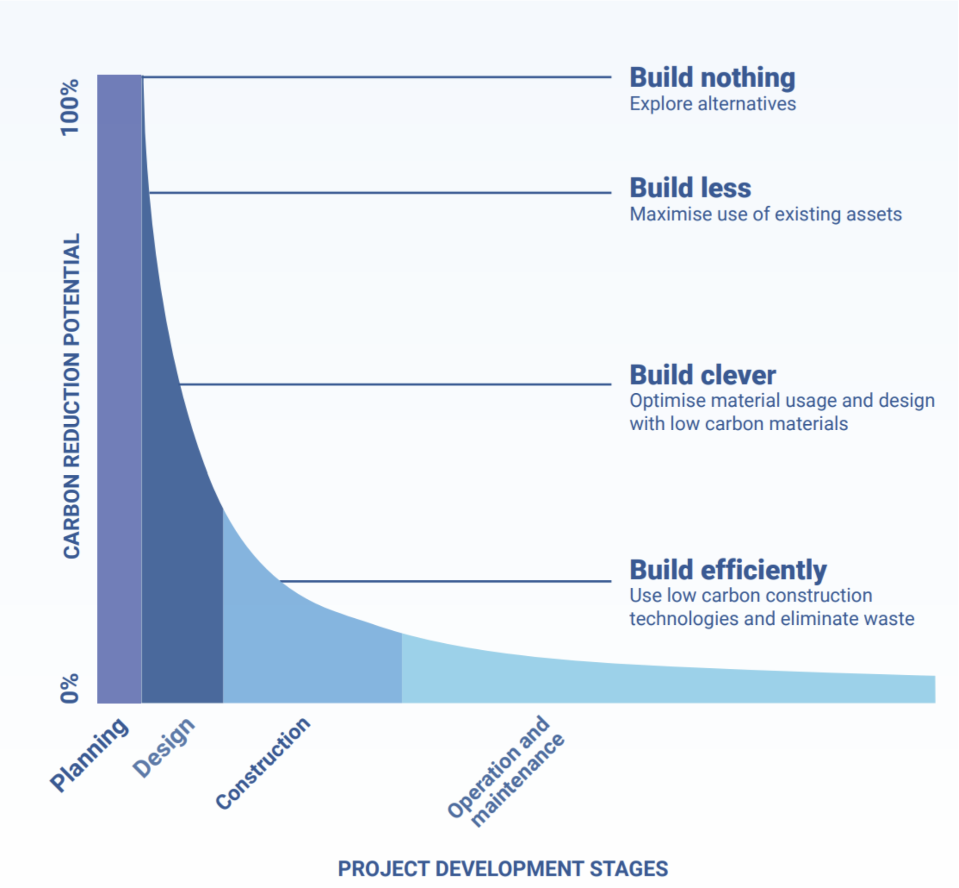
Select low- or no-embodied-carb on finish materials

5% reduction
None to low cost premium

REDUCING EMBODIED CARBON

Factors involved

- Embodied carbon emissions are affected by many factors:
  - Type and volume of structure installed
  - Materials used
  - Carbon intensity of manufacturing the materials
  - Modes and distances by which materials are transported
  - Processes by which these materials are constructed, maintained, and removed and treated at the end of life
- Opportunities for reducing or eliminating embodied carbon vary and will differ between types of projects and regions
- Greatest savings can usually be realized at the early stages of a project



Source: World Green Building Council, 2019

REDUCING EMBODIED CARBON

Principles

1. PREVENT	• Question the need to build new or use materials at all • Encourage reuse, renovation and retrofitting part or whole of an existing building, rather than demolishing to build anew • Reduce new floor area • Reduce below-grade construction

2. REDUCE AND OPTIMIZE	• Apply design approaches that minimize the quantity of new material required to deliver the desired function, e.g., designing efficient structural system, minimize finishes where not required for functional performance, etc.
	• Prioritize materials that are low or zero carbon (including MEP systems with low carbon refrigerants), responsibly sourced, and have low life cycle impact in other areas, such as:
	  ▪ Operational energy use
	  ▪ Health of occupant
	• Choose low or zero carbon construction techniques having maximum efficiency and minimum waste on site

Sources: World Green Building Council, 2019; Lewis, M. et al., 2021

REDUCING EMBODIED CARBON

Principles (continued)

3. PLAN FOR THE FUTURE

- Consider future use scenarios and end of life, maximizing the potential for maintenance, repair and renovation, and ensure flexibility for future adaptation
- Design for disassembly and deconstruction to facilitate future reuse, selecting materials that can be recycled, and can be extracted and separated easily for processing

4. OFFSET

- As a last resort, offset residual embodied carbon emissions, either within the project or organizational boundary, or through verified offset schemes

Sources: World Green Building Council, 2019; Lewis, M. et al., 2021

REDUCING EMBODIED CARBON

Specifications and procurement strategies

- **Integrate EPDs and GWP limits into project specifications:** An environmental product declaration (EPD) is a document that transparently reports the environmental impact of a product or material, based on a product LCA. Embodied carbon limits can be integrated into the performance requirements for a product, requiring an EPD to document compliance with an embodied carbon limit
- **Optimize concrete specification and mix design:**
  - Using performance-based specifications (rather than prescriptive requirements)
  - Minimizing the volume of Portland cement by other supplementary cementitious materials (SCMs), allowing for longer cure times (specifying strength at 56 days instead of 28 days to allow more time for strength gain), etc.
- **Source sustainable wood:**
  - Using reclaimed/salvaged wood
  - Asking for chain-of-custody certificates or other supply chain transparency information
  - Asking for sustainable forest management certifications (e.g., FSC or SFI)
  - Specifying wood that is locally harvested and harvested from working (not primary) forests

Sources: Lewis, M. et al., 2021; Zacharia, M., 2024

REDUCING EMBODIED CARBON

Specifications and procurement strategies (continued)

- **Specify lower-carbon alternatives:**
  - For example, hollow clay bricks, autoclaved aerated concrete (AAC) blocks and cement stabilized earth blocks (CSEB) are low carbon alternatives to fired clay bricks
  - Two materials with the same performance may differ in their carbon footprints due to differing energy source, product design and/or lower-carbon ingredient sourcing
  - Due to the way products are specified and selected, EPDs are typically the best (or only) way for a project team to identify products made with the above strategies
- **Evaluate cost and carbon in the bid process:** Evaluate carbon, in addition to cost and other criteria, as award criteria in the bid process for both private and public projects

Source: Lewis, M. et al., 2021

REDUCING EMBODIED CARBON

Examples of possible routes for low carbon cement in India

Eliminate use of OPC	• Product stage carbon of OPC= 0.842 kg CO_2e/kg • Product stage carbon of PPC (with 31% fly ash)= 0.582 kg CO_2e/kg
Increase percentage of fly ash and slag in PPC and PSC	• India: Maximum 35% fly ash allowed in PPC • India: Maximum 70% slag allowed in PSC (average 57% current share) • Brazil: Maximum 50% fly ash and 75% BF slag allowed • Canada: 50%–60% fly ash allowed • Europe: 36%–55% fly ash allowed
Use of calcined clay or other materials to replace clinker	• Limestone calcined clay cement (LC3) can reduce CO_2 emissions by up to 40%

Source: Centre for Science and Environment, 2023

REDUCING EMBODIED CARBON

Design with whole life carbon in mind

- While minimizing embodied carbon is vitally important, it must not create adverse or negative outcomes for both operational carbon and whole life carbon. A low embodied carbon building that performs poorly in operation has adverse financial, environmental and social implications
- Action to tackle upfront carbon must be done while designing with whole life carbon in mind. This holistic approach enables a concerted focus on transformational pathways for both net zero embodied carbon and net zero operational carbon

Source: World Green Building Council, 2019

Embodied Carbon in Buildings

Regulations

Image source: https://www.storaenso.com/en/newsroom/news/2022/1/good-for-wood-new-embodied-carbon-

EMBODIED CARBON

Certifications and regulations

Significant improvements have been made in the area of operational carbon since the fuel crisis of the 1970s. Efforts to tackle embodied carbon emissions at a global scale needs to be increased, while continuing to address operational carbon.

One Click LCA in their report, *The Embodied Carbon Review* (2018, updated 2021) studied 156 certification and national regulation systems worldwide that address embodied carbon:

- These embodied carbon reduction systems were largely in the form of voluntary certifications (69%), with regulations (14%), standards like ISO and EN (12%) and guidelines (4%) being the remaining
- 105 included direct measures for embodied carbon, and almost all address it through practices like recycled material use, waste reduction and material efficiency measures
- The highest rates of adoption are in some European regions, and the lowest adoption rates are in Middle East, South America and Asia

Source: One Click LCA, 2018

EMBODIED CARBON REGULATIONS

Typical regulations

- **Carbon reporting:** Calculate the construction project's embodied carbon and report it
- **Carbon comparison:** Compare design options for carbon; e.g., design baseline and proposed designs and show improvements against a self-declared baseline value
- **Carbon rating:** Evaluate carbon performance based on variable scale from best to worst on which a project's carbon is rated, but no effective maximum value applied
- **Carbon cap:** Calculate the project's embodied carbon and prove it is not exceeding the CO_2e limit
- **Decarbonization:** Reduce carbon to a minimum, then compensate all residual emissions by own energy export or buying offsets

Source: One Click LCA, 2018

EMBODIED CARBON REGULATIONS

Incentives for applying carbon reduction policies

- Most common form of incentive is better rating in rating systems or building certifications
- Embodied carbon reduction policies being a funding condition for building
- Provision of density bonus, similar to additional floor area ratio (FAR) provided for green certified buildings in India
- Cash impact in the form of funded carbon offsetting or carbon performance payment
- Being a mandatory criterion for building

Source: One Click LCA, 2018

EMBODIED CARBON

Benchmarks

- A benchmark establishes a reference point to evaluate the relative performance of a building. For example, Energy Use Intensity (EUI) or Energy Performance Index (EPI) benchmarks are used for operational energy
- Benchmarking for building-level embodied carbon and whole life carbon are not yet widely available. Most available benchmarking studies and standards are for European countries. The quality, representativeness, life cycle scope and included building components also vary greatly

EMBODIED CARBON

Benchmarks

Source	Geographic region	Reference study period	System boundary		Embodied carbon benchmarking values ($kgCO_2e/m^2$)				
			Life cycle scope	Physical scope	Building type				
					Residential	Office	School	Industrial	Mixed
CLF	North America	Assumptions unknown	A only	*Foundation* *Structure* *Enclosure* *Interiors*	200–660	270–540	230–460	–	200–640
LETI	UK	Assumptions unknown	A1–A5	*Substructure* *Superstructure* *Façade* *Internal finishes* *MEP*	800	1,000	1,000	–	–
RIBA	UK	Assumptions unknown	A1–A5 B1–B5 C1–C4	*Substructure* *Superstructure* *Finishes / fixed FF&E* *Building services (and associated refrigerant leakage)*	1,200	1,400	1,400	–	–

Source: Lewis, M. et al., 2023

EMBODIED CARBON

Benchmarks (continued)

Source	Geographic region	Reference study period	System boundary		Embodied carbon benchmarking values ($kgCO_2e/m^2$)				
			Life cycle scope	Physical scope	Building type				
					Residential	Office	School	Industrial	Mixed
One Click LCA	Europe	Assumptions unknown	A1–A3, A4 B4–B5 C1 – C4	*Varies*	–	520–680	380–490	500–560	–
Zimmerman et al.	Denmark	60 years	A1–A3, B4, B6 C3–C4	*Substructure* *Superstructure* *Façade* *Building services* *Vertical circulation*	315–425		–	–	–

Source: Lewis, M. et al., 2023

NET ZERO

Actions for embodied carbon

Government

- Deliver education and training
- Provide financial incentives
- Create national roadmaps
- Set low carbon public procurement policy
- Set benchmarks, targets and require disclosure

Investors

- Require a holistic whole life cycle approach
- Provide sustainable financial products to incentivize low or zero carbon products or projects
- Investor groups to agree and set embodied carbon benchmarks and targets
- Collaborate with stock exchanges

Developers

- Use LCA and whole life cycle approach
- Optimize structural design
- Prioritize low carbon materials and require disclosure
- Seek innovative solutions
- Use financial incentives or contractual obligations

Designers

- Educate clients
- Specify low carbon materials
- Use LCA and whole life cycle approach
- Optimize structural design
- Seek innovative solutions

Manufacturers

- Develop product-specific EPDs
- Implement recycling and circularity principles
- Maximize process energy efficiency
- Implement renewable energy sources
- Work with industry to standardize EPDs
- Develop innovative low or zero carbon construction materials and products

NGOs, networks and researchers

- Contribute to collection of embodied carbon data
- Promote findings of key research
- Work with government, public and private sector
- Deliver training
- Certification schemes require disclosure, EPDs, and set measurement and performance targets

Source: World Green Building Council, 2020

Embodied Carbon in Buildings

Case Examples

Microsoft's headquarters in Redmond, Washington

Image source: https://www.archdaily.com/976015/strategies-to-reduce-embodied-carbon-in-the-built-

CASE EXAMPLE

Houston Advanced Research Center

20%

Embodied Carbon Reduction
(structural and enclosure)

0%

Cost Impact
(No cost premium)

Strategies:

- Structural system optimization
- Achieved a lighter overall structural framework
- Reduced the need for extensive foundations by minimizing long-span elements
- Optimized concrete slab thickness, reducing material usage
- Utilized advanced concrete mixes with extended strength development times and incorporated alternative cement materials
- Pursued LEED Platinum certification to meet top-tier sustainability standards

Source: Huynh, T. et al., 2023

CASE EXAMPLE

Toronto Emergency Medical Services Station

30% Embodied Carbon Reduction

0% Cost Impact (No cost premium)

Strategies:

- Utilized low-impact extruded polystyrene (XPS) insulation
- Increased the percentage of supplementary cementitious materials (SCMs) in the concrete mix
- Applied an environmentally-friendly concrete slab sealant
- Incorporated steel with high recycled content
- Substituted traditional concrete masonry units (CMU) with hempcrete blocks
- Employed recycled glass gravel as insulation

Source: Huynh, T. et al., 2023

CASE EXAMPLE

Mixed use mid-rise office building

46% Embodied Carbon Reduction

0% Cost Impact
Premiums due to lower carbon glazing products and strategic procurement of steel

Strategies:

- Used concrete mixes with reduced cement content
- Opted for mixes with extended concrete curing times
- Replaced XPS insulation with polyiso or mineral wool alternatives
- Incorporated steel with a high recycled content
- Substituted standard gypsum sheathing with alternative materials
- Used glazing products with a lower carbon footprint

Source: Huynh, T. et al., 2023

CASE EXAMPLE

SDE1 and SDE3 Blocks, NUS Kent Ridge Campus

Adaptive reuse of old building

Net zero operational carbon

- SDE1 and SDE3 are among the oldest buildings on the National University of Singapore (NUS) Kent Ridge Campus, built in the 1970s
- By adaptive reuse of the building, embodied carbon of the building is to be lower than a third of a similar new construction
- Cost of renovating the buildings is substantially lower than demolishing it and constructing a new building
- By incorporating strategies like extended west façade, hybrid cooling system, and building management system for better operation, it is targeting to achieve net zero operational carbon emissions

Source: National University of Singapore, 2023

Thank you!

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