Issue 01 • July 2023
acumen.architecture.com.au/environment

ISSN 2651-9828

Embodied carbon in buildings

Philip Oldfield

Cover image. Macquarie University Incubator, Sydney, by Architectus. The building was designed to be dismantled and moved to a different site, to extend its life cycle. (Image: Brett Boardman)

Abstract

There has been a tendency to focus on energy efficiency measures when reducing building-related greenhouse gas (GHG) emissions – that is reducing heating, cooling, lighting and ventilation energy needs. However, the GHG emissions related to building materials and construction – known as embodied carbon – are also significant, and likely to be responsible for over half of many new buildings' total life cycle emissions in Australia.

This note outlines what embodied carbon is, the key definitions that inform it, and documents its contribution to building GHG emissions. It presents the main frameworks, methods and data sources used for measuring embodied carbon in Australia. It concludes by documenting key strategies for the design and development team to reduce embodied carbon in practice.

This note provides information and evidence designed to support the 2021 National Standards of Competency for Architects, and the Performance Criteria concerned with embodied carbon and life cycle thinking.

Introduction

Buildings are responsible for 37% of all energy-and-process-related CO2 emissions globally, with total emissions from the world's buildings at their highest ever level in 2021 (UNEP and GlobalABC 2022) (Figure 1). The need to reduce these emissions significantly by 2030, and then eventually to 'net zero', is well established if we are to avoid the negative impacts of climate change.

Broadly, greenhouse gas (GHG) emissions in buildings can be grouped into two categories:

- *Operational emissions:* These are the emissions associated with the day-to-day running of a building, the lighting, heating, cooling and ventilation.
- *Embodied emissions:* These are the emissions associated with the materials, construction, maintenance and eventual demolition, or disposal of the building.

Historically, our understanding of building-related GHG emissions was that operational emissions were by far the most significant, and that embodied emissions were quite small. However, more recently, we've come to understand that this is no longer the case, and that without reducing embodied carbon emissions, we cannot meet our climate goals.

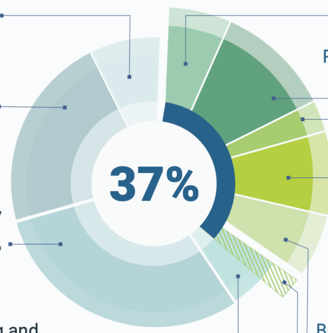


Figure 1. Buildings' contribution to global energy and process GHG emissions in 2021. (Source: UNEP and GlobalABC 2022)

This is a challenge, as while regulations, technologies and design strategies to reduce operational emissions are mature and well developed, our understanding of how to measure and reduce embodied emissions is still evolving.

This note unpacks these issues. It provides an understanding of what embodied carbon is, and the different definitions around this. It also quantifies the importance of embodied carbon over time, documenting how a new building's emissions will change over the coming decades, and the contribution of both operational and embodied carbon. It also presents the different ways of measuring embodied carbon in buildings, and the different tools and frameworks that influence this. In doing so, the broad conclusions are:

1. For many new buildings constructed in Australia, embodied carbon will be the biggest contributor to their total GHG emissions over their lifetime.
2. There are different methods and data sources used to determine embodied carbon, and without care, this can lead to inconsistencies and unfair comparisons between projects.
3. There are simple and effective means to reduce embodied carbon available to architects and the design team. But the most impactful approaches with the biggest savings require action at the start of the planning and design process, rather than at the detailed design stage.

Whole life cycle carbon

Life cycle stages

Buildings contribute to carbon dioxide (CO2) and other greenhouse gas (GHG) emissions throughout their entire life cycle, from the extraction of the raw materials needed for their construction, to the energy needed to power their daily operation, to their eventual demolition, disposal or recycling of their materials in the future.

These emissions can be grouped into five life cycle 'stages' and 17 'modules' as defined by EN 15978:2011 *'Sustainability of Construction Works – Assessment of Environmental Performance of Buildings – Calculation Method'* (European Standards 2012). While this is a European standard, the modules and stages are internationally recognised (see Figure 2).

Let's consider a new building's life cycle over the next 50 years. It may be built from a steel frame, with iron ore extracted from a mine, transported to a factory and then manufactured into steel using either a blast furnace or an electric arc furnace. Emissions from these activities are captured in the 'product stage' and modules A1-A3. The steel is transported to a construction site on a truck powered by fossil fuels, and then lifted into place by a crane. Emissions here are captured at the 'construction process stage', in modules A4 and A5.

During the building's life, some of these materials (such as paint or certain insulations) may emit greenhouse gases directly, while others may need maintenance, repair, replacement or refurbishment.

Emissions from these activities are included in the 'use stage', and modules B1-B5. In addition, the building will need energy to operate for lighting, heating and cooling, be it using direct fossil fuels (such as a gas boiler) or electricity. This is also in the 'use stage', but under module B6. The building will operate over many decades. At the end of its life, it may be demolished, its components transported to landfill or recycling plants. Emissions here are captured under the 'end of life stage', modules C1-C4. Some materials may be reused or recycled providing a 'carbon benefit' to a different building in the future. These benefits are captured in the 'benefits and loads beyond the building life cycle stage', known as module D.

To truly understand a building's GHG emissions over its life, we need to measure across all these stages. This can be time and resource consuming, and is subject to significant assumptions and uncertainties. As such, often building carbon assessments only include some of the above stages.

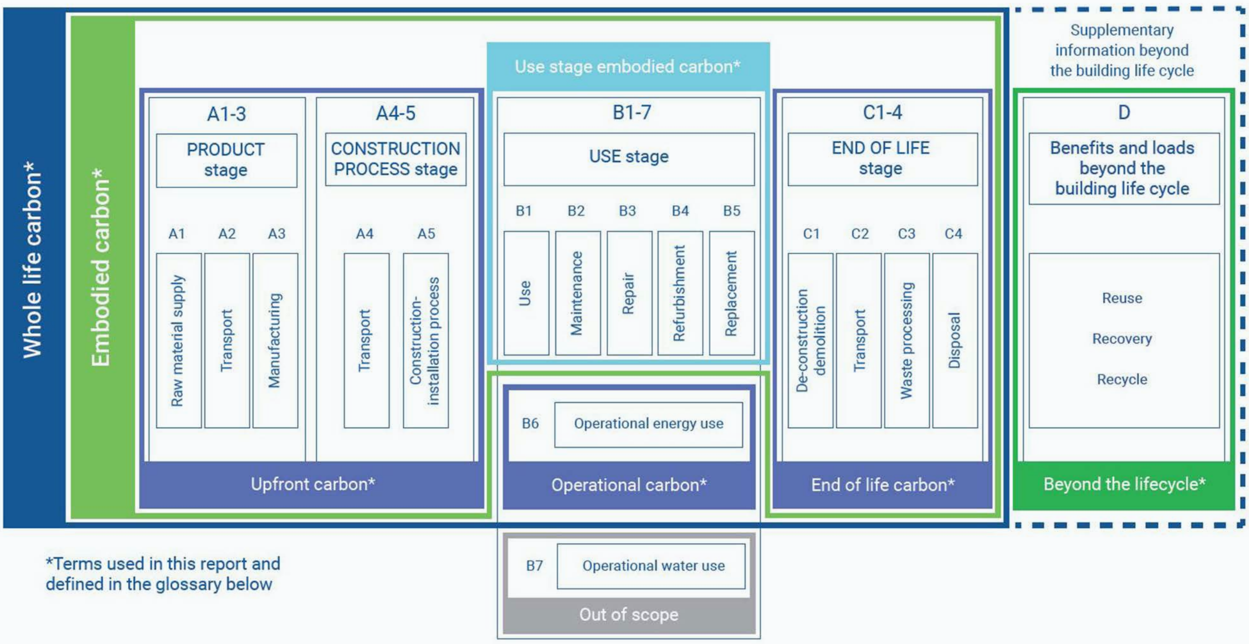


Figure 2. Life cycle stages and modules as defined by EN 15978:2011 (WorldGBC 2019). (Image: WorldGBC)

Defining embodied carbon and other key terms

Using these different stages and modules can allow us to understand different definitions that are commonly used in industry as outlined in the box below.

Embodied carbon

Embodied carbon is the sum of all the GHG emissions associated with the materials, construction and eventual demolition of a building over its life cycle. This includes the share of emissions associated with making the production process equipment to manufacture those materials, their transportation, maintenance and repair over the building's life (Prasad et al. 2023). In its most complete sense then, embodied carbon includes modules A1-A5, B1-B5 and C1-C4 as outlined in Figure 2.

However, this can be complex to determine and simpler versions of embodied carbon are often used including 'Upfront carbon'.

Upfront carbon (sometimes called 'initial embodied carbon')

Upfront carbon is a measure of the emissions caused by manufacturing the materials and the construction of a building *before it is open for use*. This includes modules A1-A5 in Figure 2, across a period of time also known as 'cradle-to-practical completion', as it is a measurement of GHG emissions from the materials leaving the ground, until the building is complete.

Upfront carbon is often used as a measure of embodied carbon as it can be quicker and subject to fewer uncertainties than full embodied carbon measurements that include stages B and C.

Recurring embodied carbon (sometimes called 'use-stage embodied carbon')

Recurring embodied carbon is the emissions associated with the building materials after it is built, but before its end of life. These consist of the repair, refurbishment, maintenance and replacement of materials, and are measured under modules B1-B5.

Some materials, such as the building structure, will last for the entire life on the building – and as such, won't have a recurring embodied carbon. Others such as mechanical, electrical and plumbing (MEP) systems, finishes, fittings, facade etc, may be replaced multiple times, and therefore will contribute to a building's recurring embodied carbon.

Operational carbon

Operational carbon is the emissions associated with the day-to-day running of the building – the lighting, heating, cooling and other energy needs. This is captured under module B6 only.

End of life carbon

End of life carbon emissions are those associated with the building's decommissioning, demolition, transportation of any materials and their disposal. This is captured under modules C1-C4.

Whole of life carbon

A building's whole of life carbon consists of the embodied carbon (upfront, recurring and end of life) and operational carbon combined. This is modules A1-A5, B1-B6 and C1-C4 (with module D reported separately – see below).

Beyond the life cycle

Some materials can be reused, recycled and recovered for future applications. For instance, an aluminium component could be recycled in 50 years, and used in a future building or product which is not yet designed or even envisioned. This potential carbon benefit is captured under module D. Due to the future uncertainty of these benefits, carbon emissions in module D are reported separately to whole life cycle carbon figures (RICS 2017).

Scope of GHG emissions

Greenhouse gas emissions in buildings can also be grouped into three 'scopes' that are recognised internationally. Embodied carbon is considered within 'Scope 3'.

Scope 1: Direct emissions from buildings - Emissions caused by the *direct* release of GHG emissions from a building (eg a gas boiler, release of refrigerants, etc)

Scope 2: Indirect emissions from building energy consumption - emissions from using electricity in a building for heating, cooling, ventilation, etc and any emissions from district heating or cooling systems.

Scope 3: Indirect emissions from other sources - Embodied carbon and emissions from water, sewage and waste sent to landfill (Prasad et al. 2022)

A note on metrics

GHG emissions in buildings are most commonly measured in terms of $kgCO2e/m^2$. This is kilograms of **carbon dioxide equivalence** per metre square of floor area. The term 'carbon dioxide equivalence' refers to the metric including other greenhouse gases (methane, nitrous oxide, HFCs, etc) and converting them to an equivalent value of carbon dioxide based on global warming potential (or GWP). In this sense 'embodied carbon' effectively means embodied greenhouse gas emissions and is not just limited to CO2.

Sometimes embodied carbon is not measured by floor area, and instead considers the whole building, in which case a figure of tCO2e might be used (tonnes of carbon dioxide equivalence).

Finally, the term **embodied energy** is sometimes used instead of embodied carbon. Embodied energy is a different metric. It is a measure of the *primary energy* used in materials, construction and the eventual demolition of a building over its life cycle. Embodied energy is used less regularly in recent years, with most focus on embodied carbon.

Measuring embodied carbon

The measurement of life cycle assessments (of which embodied carbon is included) is governed, at the highest level, by ISO 14040:2006 *Environmental management – Life cycle assessment – Principles and framework* (ISO 2006). This international standard describes the principles of life cycle assessment, and its reporting, but does not prescribe specific methods to follow. As such, a variety of different methods, frameworks and tools exist for calculating embodied carbon in buildings.

At its most basic level, measuring embodied carbon can be quite simple to understand. For instance, to determine the embodied carbon of floor tiles in a building for life cycle stages A1-A3 the following formula could be used:

Material quantity (kg) x embodied carbon coefficient (kgCO2e/kg)

In this case, if the embodied carbon coefficient of floor tiles is 1.3 kgCO2e/kg (as taken from the EPiC database, see Crawford et al. 2019) and 500 kg of tiles were used, the embodied carbon could be determined as:

500 x 1.3 = 650 kgCO2e

If a full list of the building's materials and the processes needed to create it is known, a similar method could be followed to determine the building-scale embodied carbon. However, in the early design stages, when initial embodied carbon measurements and targets are made, it is almost impossible to know the full and complete quantity of materials in a building design. Even at the detailed design stage, a bill of quantities will not include all materials by weight – for instance, how much steel is in an air-handling unit, how much copper is in the building wiring, etc, and will include contingency amounts to cover material uncertainties. This means that embodied carbon measurements can often be incomplete; that is, they exclude certain processes and materials from the measurement.

What's more, different embodied carbon calculations use different methods and data sources, which can mean it's unfair and inconsistent to compare embodied carbon results undertaken by different teams

(Simonen et al. 2017; Prasad et al. 2023). To give an indication of the impact of these different methods and uncertainties, in Australia some data suggests a typical detached house can have an embodied carbon of 228 kgCO2e/m^2 GFA, including the structure, foundations, envelope and roof, across modules A1-A3 (GBCA and thinkstep-anz 2021). Other data suggests the figure can be as high as 1,270 kgCO2e/m^2 NHA when also including internal walls, finishes, fittings, services, preliminaries and site work across modules A1-A5, and measuring the floor area as net habitable area, which is smaller than GFA (Prasad et al. 2023). These two figures cannot be compared, as they include and exclude different elements of the building and measure embodied carbon using different floor area metrics.

When measuring embodied carbon it is vital the design team report transparently on what building elements have been included (and excluded), what life cycle modules are included (as outlined in Figure 2), what methods have been followed, how the floor area is measured and where embodied carbon coefficients have been sourced.

Embodied carbon coefficient data sources

There are three main methods used to calculate embodied carbon (or embodied energy) coefficients for materials. These are called **process analysis**, **input-output analysis**, and **hybrid analysis**. Details on these methods are outlined in the *Acumen* note Life Cycle Energy Analysis (Crawford 2012). Each method has its own benefits and limitations, and each generates different embodied carbon coefficients. For example, figure 3 presents the embodied carbon of double glazing using these different methods.

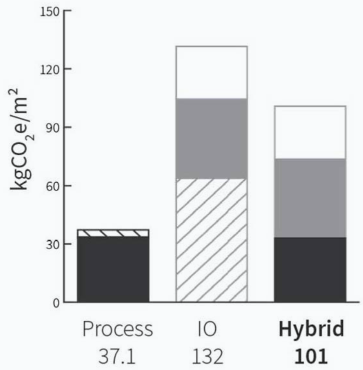


Figure 3. Embodied carbon (indicated as GHG emissions) of double glazing, showing different values using different methods. (Source: EPiC database, Crawford et al. 2019)

Data sources in Australia

In Australia, two common sources for embodied carbon coefficients are 'EPDs' and 'EPiC'.

EPDs: EPDs (Environmental Product Declarations) provide embodied carbon (and often other environmental impacts) of products using process analysis. Different boundaries are used, and EPDs can sometimes include only modules A1-A3, and other times broader A-D data. However, EPD data obtained for modules A4, A5, B4-B7 and C2 should be changed to project specific values – ie an EPD that includes carbon emissions for transport (module A4) should have these transport emissions re-calculated for the specific location of the building (RICS 2017).

EPD Australasia provides a database of EPDs that are independently verified to ISO 14025, and a relevant 'Product Category Rule' (PCR). A PCR sets out the framework and rules for EPDs to follow in a particular category – for instance, the PCR for building products is *EN 15804 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products.*

EPDs have the benefit of being product specific. That is, they can allow architects to choose between different types of the same product to identify which is the most preferable option. However, some concerns exist that they can be inconsistent and challenging to compare due to the different ways they measure environmental impacts, and the fact that key information can be excluded in their publication (Moré et al, 2022; Crawford et al. 2022).

For EPDs in Australia and New Zealand see: https://epd-australasia.com/

EPiC database: The EPiC (Environment Performance in Construction) database contains embodied energy, water and carbon data for over 250 construction materials, across the A1-A3 modules. These have been developed using hybrid analysis which fills in the gaps that process analysis typically suffers. The advantage is the embodied carbon coefficients in the EPiC database can be considered complete, consistent and transparent (Crawford et al. 2019). However, EPiC data is generic for the Australian market, and can't be used to compare the embodied carbon of the same material or product from different suppliers.

To view the EPiC database see: http://epicdatabase.com.au/

Frameworks, tools and software

There are a variety of different frameworks, tools and software available for measuring embodied carbon in buildings. The main examples relevant in Australia are outlined in this section.

NABERS embodied emissions framework

The National Australian Built Environment Rating System (NABERS) are developing an 'embodied emissions tool' to allow for the future rating of building-scale embodied carbon. Underpinning this tool is technical analysis that seeks to develop a consistent method for measuring embodied carbon allowing for reliable comparisons between buildings. The proposed method only considers upfront carbon (modules A1 – A5), but includes the option to expand this to the full building life cycle in the future. In addition, it specifies the building 'cold shell' as the scope of inclusion (ie including structure, facade and HVAC limited to vertical rises – but excluding other elements and materials such as finishes from the measurement). Finally it specifies that embodied carbon coefficients should come from process-based sources, such as EPDs, and ideally not generic material databases (thinkstep 2022).

View the framework here: https://www.nabers.gov.au/sites/default/files/2022-12/NABERS - Embodied Emissions - Technical Report.pdf

BASIX Materials Index (as part of the Sustainable Buildings SEPP)

BASIX (Building Sustainability Index) is a NSW-based rating system that regulates minimum performance standards for energy use, thermal comfort and water usage in housing. As of October 2023, the standard will also include a new 'Materials index' which requires the calculation of embodied carbon of any new housing in NSW (or renovations over $50,000) using coefficients from the EPiC database. This is a major turning point in embodied carbon regulation, and the first large-scale requirement for its calculation in Australia. In the initial stage, no limit of embodied carbon will be implemented. However, the BASIX Materials index could be used to regulate maximum embodied emissions in NSW in the future (NSW Government 2022).

The State Environmental Planning Policy (Sustainable Buildings) SEPP 2022, also requires *all* non-residential buildings in NSW to disclose the quantities of key construction materials (super-structure, substructure and facade) and associated embodied carbon at the development application and construction certificate stages.

View the standard here: https://www.planning.nsw.gov.au/sites/default/files/2023-03/sustainable-buildings-sepp-overview.pdf

GBCA Upfront Carbon Emissions calculation guide

The Green Building Council of Australia (GBCA) Upfront Carbon Emissions calculation guide defines the method for modelling buildings' upfront embodied carbon as part of Green Star assessments. To do so, project teams must compare a 'reference project' with their proposed design; the reference project is the same size, shape, location, floor area and glazing areas as the proposed design, and provides a benchmark against which the upfront carbon can be compared. Any project seeking a Green Star ranking must reduce embodied carbon by 10% (as compared to the reference project), with 20% for 5 and 6 star rated buildings, moving to a 40% reduction target by 2030 (GBCA 2022).

View the interim guide here: https://www.gbca.org.au/get/resources/2156/794DF066980741905C78C3EE5A89D0C3

Race to Net Zero Carbon

This guide proposes a method for embodied carbon measurement that is consistent and complete for Australian buildings. It uses a combined method where known building material quantities are multiplied by embodied carbon coefficients (as outlined before), and unknown quantities and processes are included by multiplying the financial cost by an input-output coefficient for that industry. This means carbon emissions associated with building processes often excluded from embodied carbon measurement (such as preliminaries) can be captured and included. This also allows early stage embodied carbon analysis to be undertaken when bills of quantities are incomplete, as financial data for 'unknown' material quantities can be used. The method is limited to modules A1-A5 and uses net lettable floor area ($kgCO2e/m^2$ NLA) as the metric of comparison (Prasad et al. 2022).

View the guide here: https://www.unsw.edu.au/content/dam/pdfs/unsw-adobe-websites/arts-design-architecture/built-environment/net-zero-guide/2023-01-24-Net-Zero-guide-v1b-online-version.pdf

RICS professional standards and guidance

The Royal Institute of Chartered Surveyors (RICS) Whole Life Carbon Assessment for the Built Environment publication provides requirements and supporting guidance for conducting whole life cycle carbon and embodied carbon assessments of buildings and infrastructure. It provides detailed guidance on all aspects of the building life cycle (across modules A – D), with the aim of providing consistent and reliable measurements. Of note is the suggestion that a minimum of 95% of the cost of each building element should be included in any life cycle carbon assessment, and if this target is not met it should be clearly articulated alongside the calculation results. The method prioritises EPDs as a data source, but also allows embodied carbon coefficients from materials databases (RICS 2017).

View the guide here: https://www.rics.org/profession-standards/rics-standards-and-guidance/sector-standards/building-surveying-standards/whole-life-carbon-assessment-for-the-built-environment

Software

Below is a list of some of the software that can be used to measure the embodied carbon of buildings in Australia.

- eTool
- Fitzpatrick and Partner's Embodied Carbon Calculator App
- GaBi
- OneClick
- Tally
- The Footprint Calculator

The Carbon Leadership Forum provides a longer list of tools and software available to architects, engineers and consultants globally. However, care is required as some software may not have available datasets relevant to the Australian market.

https://carbonleadershipforum.org/clf-architect-toolkit/

The significance of embodied carbon

Our understanding of the significance of embodied carbon emissions has changed in the last two decades. Twenty years ago, it was generally thought that embodied carbon emissions were quite small, as a percentage of buildings' whole life cycle emissions, with estimations of around 20%. However, in more recent years it's become apparent that embodied carbon is often responsible for a much greater percentage of whole life cycle emissions. This change is due to:

1. Increased research on embodied carbon, and the creation of more comprehensive data sets and methods for its measurement.
2. Improved energy efficiency in buildings and the decarbonisation of regional electricity supplies, meaning the relative contribution of operational carbon emissions has decreased.

Case study: A detached Australian house

Research by the University of Melbourne (Schmidt et al. 2020) examined the whole life cycle carbon emissions of conventional Australian detached homes. They measured the initial and recurring embodied carbon, and operational emissions for a 230 m² house built in 2019, to determine the contribution of different life cycle stages by 2050 (a life span of 31 years). The breakdown of a typical house in Victoria is outlined in Figure 4.

As can be seen, embodied carbon contributes just over half of the total life cycle emissions. Houses in other states were found to have similar breakdowns, with embodied emissions around 50% of the whole life cycle emissions.

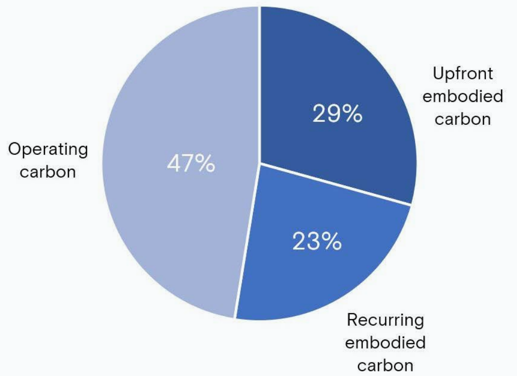


Figure 4. Whole life cycle carbon of a typical detached house in Victoria from 2019 to 2050. (Source: Schmidt et al. 2020)

The impact of a decarbonising electricity grid

An important factor to consider is that upfront carbon emissions happen now, in the present, while operating emissions build up cumulatively over time. This means operating emissions will change as our energy systems decarbonise in the future. This change is subject to some uncertainties, but we can be confident of the broad trends.

In Australia for each kilowatt hour (kWh) of electricity used in buildings, some GHG emissions are released. This amount differs from state to state, and is as high as 0.96 kgCO2e/kWh in Victoria and as low as 0.16 kgCO2e/kWh in Tasmania (Commonwealth of Australia 2021). These figures are likely to fall in the coming decades as our regional electricity mixes move away from fossil fuels to renewables such as solar and wind power.

The result is that operating emissions will not increase linearly across a building's life cycle, and their contribution will likely diminish over time (Figure 5). There is a large increase in emissions in year zero, due to the upfront carbon needed to create the building. Operating emissions increase gradually over time, but reduce as electricity grids are decarbonised in future decades. Recurring embodied carbon appears as small regular jumps, the result of refurbishment and maintenance at strategic junctions in a building's future. Again, these may decrease as material supply chains decarbonise in future decades.

Due to this decarbonisation of future electricity supplies, studies suggest embodied carbon (initial, recurring and end of life) could contribute as much as 50 – 70% of whole life cycle emissions in buildings at the present time (Robati at al. 2020; RICS 2017).
It is worth noting that the World Green Building Council target all new buildings to be 'net zero carbon in operations' from 2030 – that is, all their energy use will be sourced from renewables (either on-site, or off-site). In this case, embodied emissions would effectively be 100% of the building's whole life cycle emissions for every new building from 2030 onwards.

This makes reducing embodied carbon a vital aspect of decarbonising the built environment.

Reducing embodied carbon

Acknowledging the significance of embodied carbon, architects and built environment professionals need to manage its reduction. Different regions, cities, countries and roadmaps have set different targets for embodied carbon reduction. Some of these targets are outlined in Table 1. Consistent among most targets are an urgent reduction of embodied carbon of 40-60% by 2030, and then to net zero embodied carbon by 2040 – 2050. While this may seem ambitious, studies have shown that embodied carbon can be reduced by 50% below 'typical construction' using existing strategies and materials that are available today (WBCSD and Arup 2023).

Given the long run up time typical in building development, architects should be aiming for 2030 targets in current design proposals.

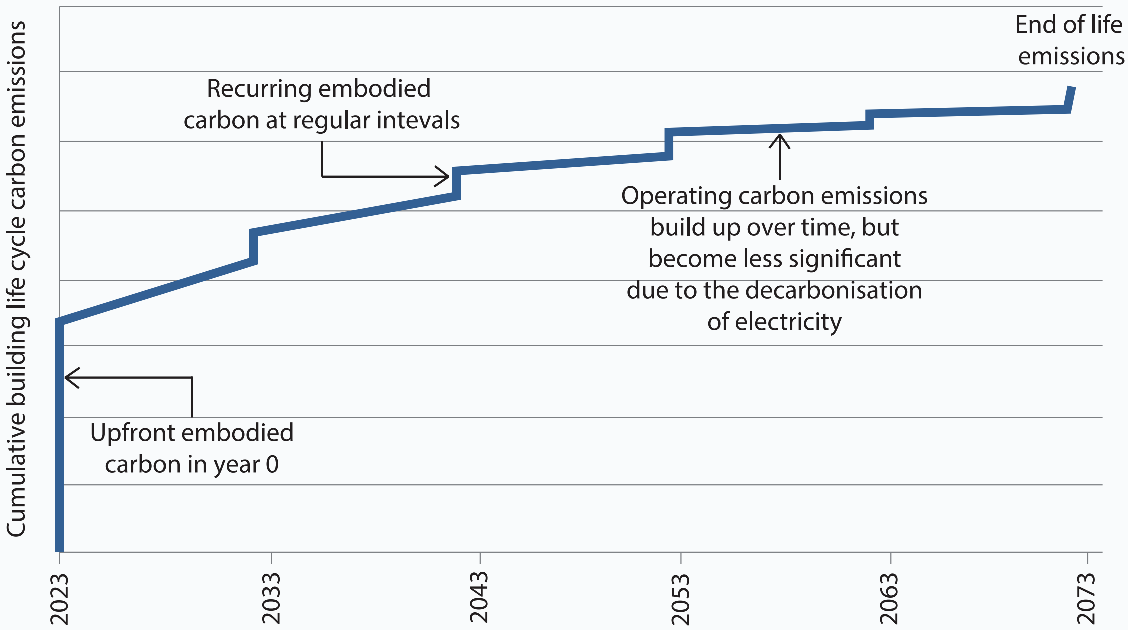


Figure 5. Cumulative whole life cycle carbon emissions of a new building, visualised over 50 years from 2023 to 2073. (Source: Author)

Year	Green Building Council of Australia (GBCA)	Race to Net Zero Carbon, Australia	World Green Building Council (WGBC)	London Energy Transformation Initiative (LETI), UK	Architecture 2030 Challenge, USA
2020	10-20%			30 – 40%	40%
2025		40%			45%
2030	40%	60%	40%	65%	65%
2040		Net zero embodied carbon			Net zero embodied carbon
2050	Net zero embodied carbon (some rated buildings to achieve this from 2023 onwards)		Net zero embodied carbon		

Table 1. Targets for embodied carbon reductions. (Source: Adapted from Prasad et al. 2023)

A variety of design strategies, technologies and materials are available to architects and built environment professionals to reduce embodied carbon. However, a fundamental principle is that the greatest reductions in embodied carbon are informed by decisions made in the earliest stages of a project. Is a new building actually necessary to meet the client or community's needs? Can an existing building be reused, instead of replaced with new construction? How much floor area is really necessary? What height should the building be? (Figure 6). Different procurement methods can also influence this, since they place different emphasis on quality, cost and performance, and when design decisions are made.

Adaptive reuse and refurbishment

One of the most effective ways to significantly reduce embodied carbon is to adaptively reuse existing built assets, rather than build entirely new buildings. Structure and substructure elements typically contribute around 40% of a building's embodied carbon,

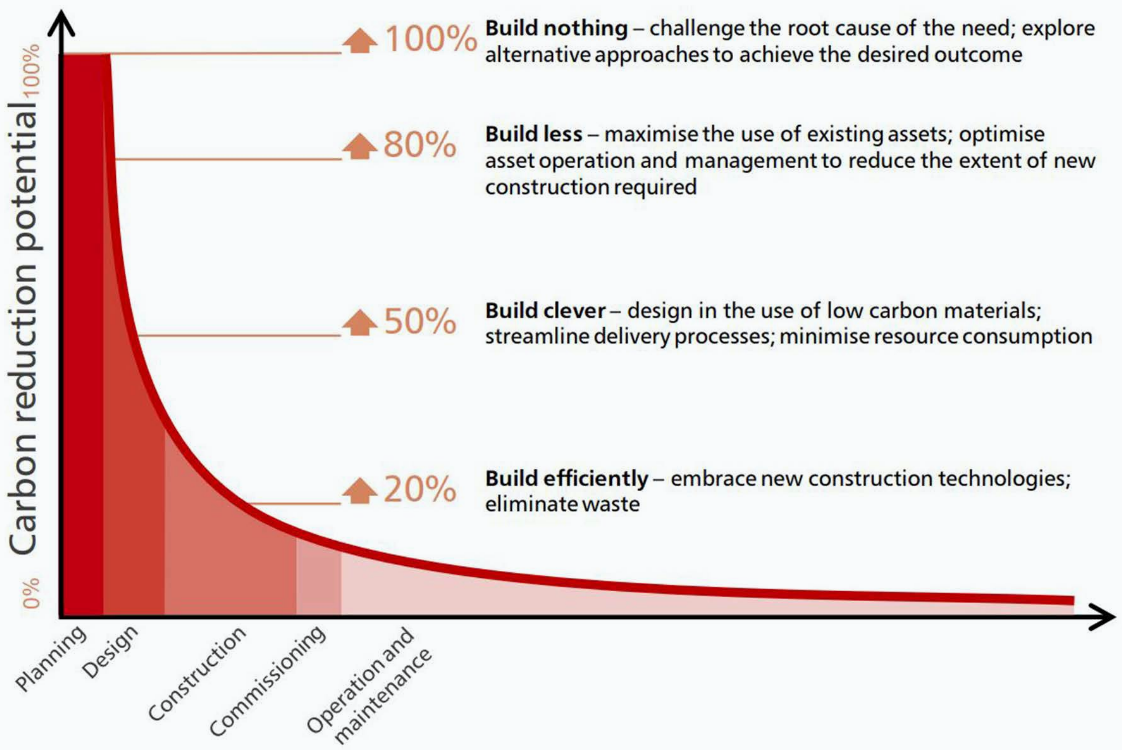


Figure 6. Opportunities to reduce embodied carbon, showing the greatest potential for reductions occur earliest in the project schedule. (Source: HM Treasury 2013)

so even a deep retrofit where the entire facade, systems and finishes are replaced can result in major embodied carbon savings. A study of 103 buildings in the UK found refurbishment projects consistently had lower embodied carbon per metre squared than new builds, making it one of the best ways to reduce embodied emissions (Collings 2020). Other more radical reuse strategies, such as vertical extensions where existing buildings are retained and extended upwards, can also have embodied carbon benefits (GBCA 2023; Julistiono et al. 2023).

Adaptive reuse is not just a strategy for existing assets but also needs to be 'designed in' to new construction as well.

Australia has seen a spate of cultural buildings demolished after short life cycles, meaning the embodied carbon investment in construction is wasted. The Sydney Exhibition Centre was demolished in 2014 after a 26 year life cycle while the Sydney Football Stadium lasted a mere 31 years. To tackle this, architects need to design for uncertain and often unknowable futures in their buildings. Strategies to achieve this include:

1. **'Long-life loose-fit'** First coined by RIBA President Sir Alexander John Gordon in 1972, 'long-life loose-fit' essentially asks architects to design in future flexibility into their buildings, to allow them to be adapted and remain useful beyond their initial function and brief. An example might be in the design of an office building, ensuring floor plates are not too deep as to restrict possible future adaptation to a residential layout. Or, quite simply, ensuring the inevitable future replacement of the MEP systems can be easily managed without the need for demolition of walls or structure that can last much longer.
2. **Design for disassembly** This is a similar approach, where the design and construction of a building is optimised to allow for future disassembly of building elements such that they can be reused and/or recycled at the end of the building's functional life. The Macquarie University Incubator by Architectus (see Cover image) uses reusable steel screw piles and a modular cross laminated timber (CLT) structure fabricated off-site with lighting and services pre-installed (Oldfield 2019). One example might be to use mechanical connection joints that can be easily dismantled, rather than chemical bonds or glues, which would make future separation of materials challenging. Refer to Acumen note [Design for disassembly – themes and principles](#).

Case Study: Quay Quarter Tower, Sydney, by 3XN and BVN Architects

The Quay Quarter Tower consists of the adaptive reuse and extension of the AMP Centre, completed in 1976. The building was 40 years old and nearing what would typically be the end of a commercial building's useful life cycle. Instead of a conventional 'demolish and rebuild', only the northernmost third of the building was demolished. Floorplates were extended increasing their area from 1500 m² to 2300 m². Two thirds of the structure was retained, thus saving around 8000 tonnes of embodied carbon (Oldfield 2022).

Figure 7. Quay Quarter Tower, showing (from left to right) area to be demolished (in grey), area to be retained (white), and new build elements (blue). (Image: 3XN)

Figure 8. Quay Quarter Tower, completed building. (Image: Courtesy of 3XN, ©Adam Mørk)

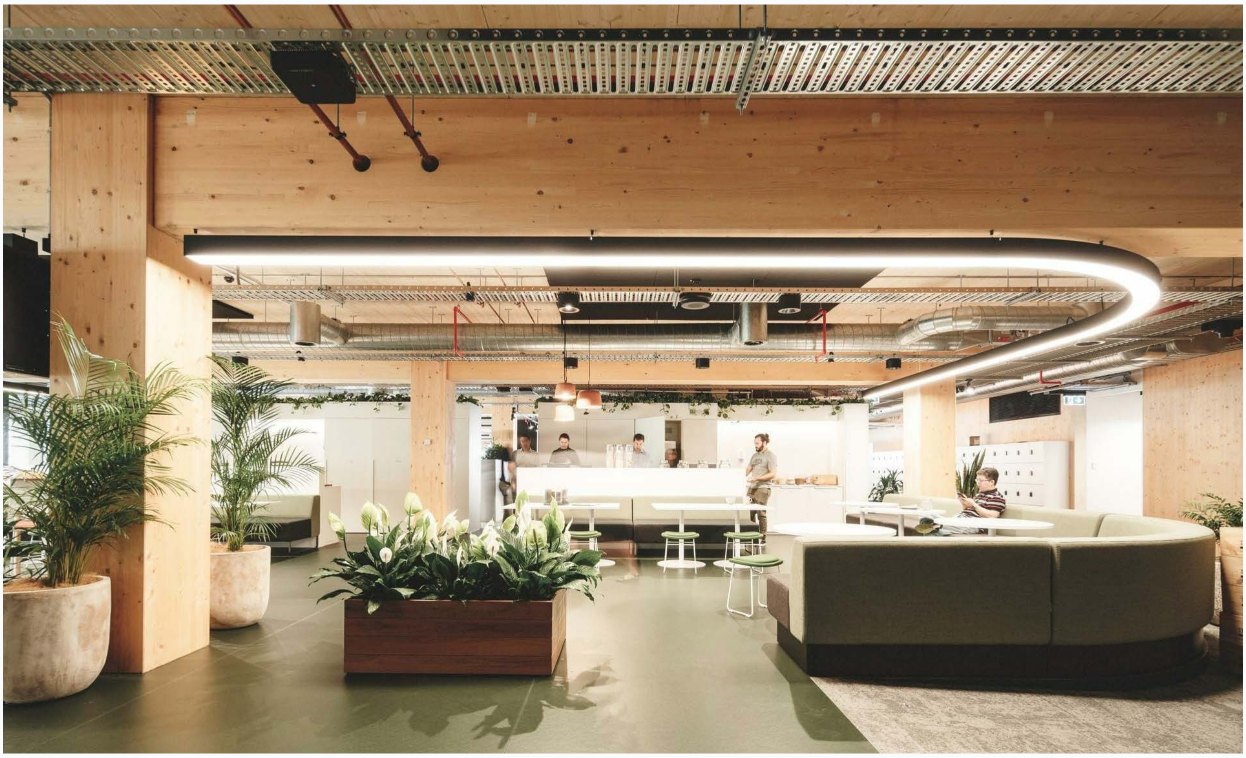


Figure 9. 25 King Street, Brisbane, by Bates Smart and Woods Bagot. The 10-storey office building is built from cross laminated timber (CLT) floors, lift shafts and stairs and glue laminated timber (glulam) beams and columns. The omission of a suspended ceiling would also reduce embodied emissions. (Image: Mark Nilon)

Dematerialisation

Fundamental to reducing embodied carbon emissions is to 'consume less' – that is, to only use materials and systems where absolutely necessary for the building's functionality, or the occupants' or societies' needs.

Dematerialisation then might involve optimising the building structural system to achieve the required safety and performance while using the minimum quantity of concrete (Figure 10). Other dematerialisation strategies include:

- Constructing smaller houses, which still meet the needs of families but with reduced floor area.
- Building efficiently, by reducing 'unnecessary' built area and improving 'net-to-gross' efficiencies (this effectively creates more useable floor area for the same embodied carbon).
- Reduce structural spans. Floor systems are amongst the higher contributors to building embodied carbon, and research has shown that reducing spans from 11m to 7m can reduce the embodied carbon of a flat slab from 265 $kgCO2e/m^2$ to 140 $kgCO2e/m^2$ (a 47% saving) (Figure 11). Such an approach may mean a shift away from 'column free' interiors.
- Make considered facade decisions. While multi-layered fully-glazed facades can allow for greater transparency and integrated shading systems, they typically have a higher embodied carbon than simple-framed facade systems with smaller glazed areas (WBCSD and Arup 2023)
- Creating multi-functional buildings that accommodate multiple societal needs (rather than creating multiple separate buildings that are only periodically used). An example might be a school which is also used as a community centre in the evenings and at weekends.
- Omitting 'unnecessary' finishes and fittings, such as suspended ceilings, carpets, etc where these do not impact the quality of internal space and comfort (Figure 9). Removing suspended ceilings alone can reduce upfront embodied carbon by 38 $kgCO2e/m^2$ (WBCSD and Arup 2023).
- Using passive design principles to reduce servicing requirements. The addition of external solar shading might add some embodied carbon, due to additional materials, but it would also reduce peak heat loads, which would reduce cooling requirements and the size of MEP systems and chillers (which in turn can reduce aluminum, copper, etc).
- Use prefabricated building components and systems built off-site to reduce waste.

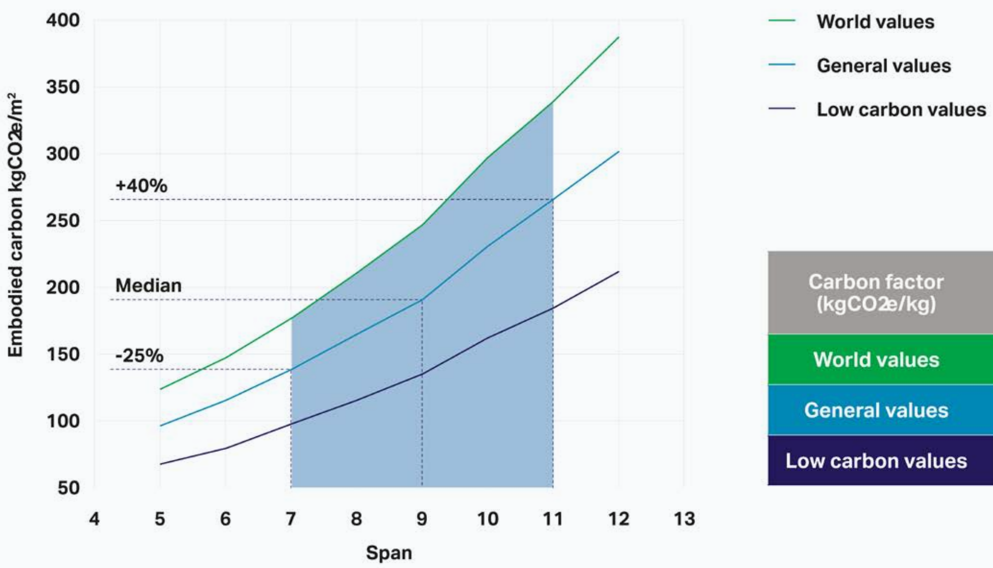
Dematerialisation approaches can also have other benefits, such as reduced cost. However, dematerialisation should not be implemented to the detriment of other performance criteria; for instance, moving from double glazing to single glazing would reduce upfront carbon, but would also increase operational emissions, and diminish occupant comfort.

Low carbon and biomaterials

Replacing carbon-intensive materials with lower carbon alternatives or reusing building components instead of new ones will reduce embodied carbon (Figures 12 and 13). Such an approach requires careful collaboration between consultants, the contractor and subcontractors. For instance, Lend Lease asks suppliers to identify the environmental performance of their product through an Environmental Product Declaration (EPD). If different suppliers offer products with comparable performance and price, the selection of a lower carbon solution could be an important differentiator (Kenny 2022).

A common approach is to utilise a cement replacement material. Cement is extremely carbon intensive, and is responsible for as much as 8% of all global CO2 emissions (Andrew 2018). In a typical concrete mix, cement can be responsible for 87% of embodied carbon emissions across modules A1 – A3 (ICE 2022). Replacing cement with waste materials such as fly ash (a waste product from coal-fired power stations), ground-granulated blast-furnace slag (a by-product of steel manufacture) and silica fume (a by-product of manufacturing silicon) can reduce embodied carbon.

Figure 10. 'BubbleDeck' slabs can reduce the amount of concrete used. In the Mills Park community centre in Beckenham, Perth, the use of BubbleDeck reduced the need for 250m³ of concrete as compared to conventional slabs (BubbleDeck 2018). (Image: BubbleDeck)



Carbon factor (kgCO2e/kg)	Concrete	Steel reinforced
World values	0.19	1.95
General values	0.15	1.5
Low carbon values	0.12	0.76

Figure 11. Graph of span versus embodied carbon for a typical flat slab, showing how shorter floor spans can significantly decrease emissions. (Source: WBCSD and Arup 2023)

Figure 12. Resource Rows, Copenhagen, by Lendager. Resource Rows reused brick facades from abandoned industrial buildings on the site (including a former Carlsberg Brewery). Since modern mortar is so strong, salvaging and reusing individual bricks was not possible. Instead, 1m x 1m segments of brickwork were cut from the demolished buildings and reused in new apartments and row houses, while timber was salvaged from the construction of the Copenhagen Metro and used in facades, terraces and for flooring. In total 9% of the building's materials were upcycled from waste streams, saving an estimated 12% of embodied carbon (WBCSD 2021). (Image: © Rasmus Hjortshøj)

However, this can also influence other aspects of the materials' performance, and as such, it is important all members of the design team and client are involved in all decision making (ICE 2022; Prasad et al. 2023).

A further approach is to use biomaterials, such as timber, straw, hemp, bamboo or even cork to replace conventional building materials (Figures 14 and 15). The advantage of biomaterials is they often require less energy and processing to create building products, contributing to lower embodied carbon emissions. In addition, since these materials are harvested from plants they also store carbon in their biomass (known as carbon sequestration), which is captured through photosynthesis (see note in box below).

Research by UNSW (Robati et al. 2020) found that in an 18-storey mixed-use building in Sydney, with a conventional concrete frame, a switch to a post-tensioned concrete frame would reduce embodied carbon by 8%. However, a switch to a mass timber system with a concrete core, would reduce embodied carbon by 26% (Figure 16).

Figure 13. The Beehive, Sydney, by Luigi Rosselli Architects and Raffaello Rosselli Studio. At this office building in Surry Hills, waste terracotta roof tiles were stacked in a variety of patterns to create solar shading for the western facade.
The same tiles were also used internally to create bookshelves. (Image: Ben Hosking)

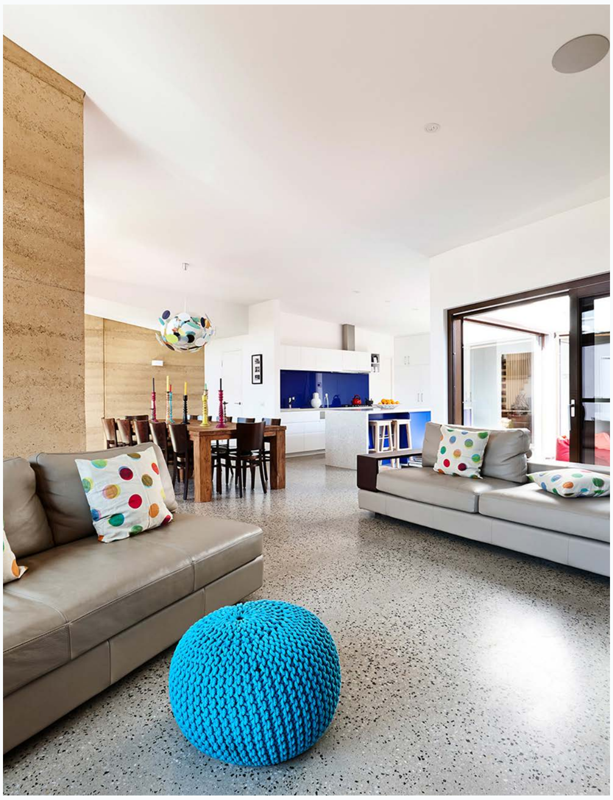


Figure 14. Hemp House, Melbourne, by Steffen Welsch Architects. These two family homes uses a mixture of hempcrete and rammed earth to reduce embodied carbon. Hempcrete is a biocomposite material made up of hemp hurd, lime, water and sometimes sand (Hookham 2022). (Image: Rhiannon Slatter)

Figure 15. Cork House, London, by Matthew Barnett Howland with Dido Milne and Oliver Wilton. Built from stacked cork blocks with interlocking joints means the cork forms the structure, insulation and internal and external surface finishes. The house is estimated to have a whole life cycle carbon of just 15% of a typical new build (Crook 2019). (Image: Magnus Dennis)

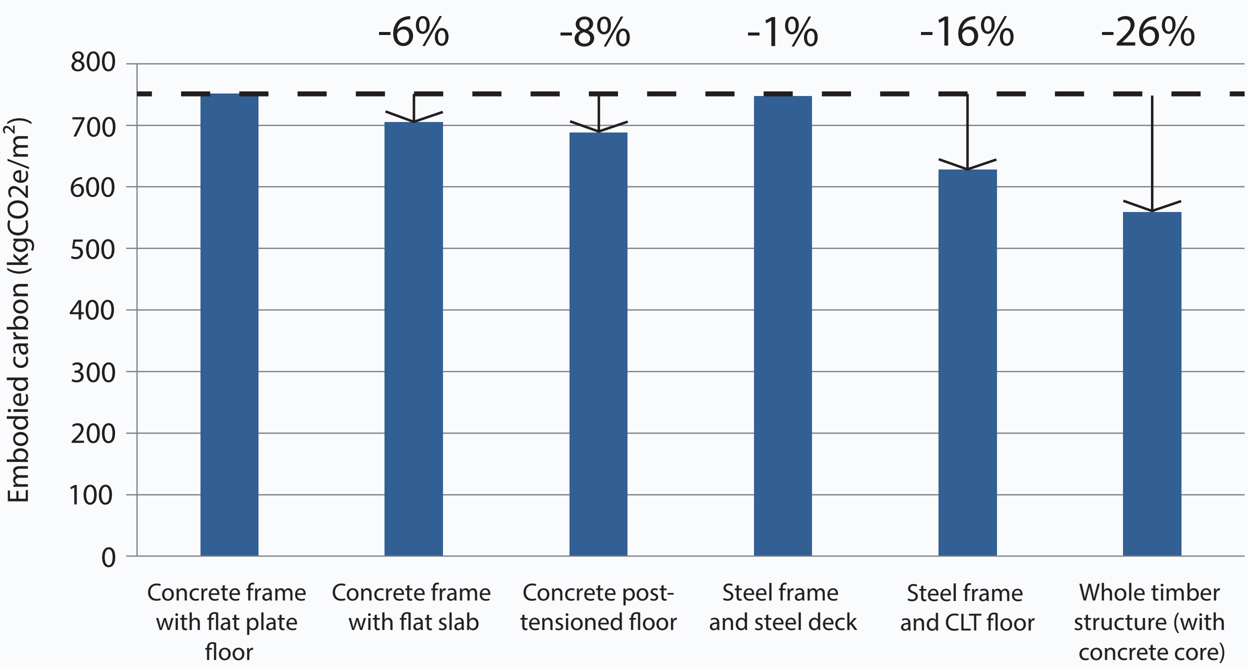


Figure 16. Impact of different material and structural systems on the embodied carbon of an 18-storey mixed-use building in Sydney (A1-A5, B4 and C1-C4, including structure, facade and finishes only). (Source: Data from Robati et al. 2020)

A note on measuring embodied carbon in timber and biomaterials

Accounting for the carbon stored in timber and biomaterials (sequestration) when determining a building's embodied carbon can be complex, and different methods and approaches exist (Robati et al., 2022). Any carbon absorbed from the atmosphere and stored in a building product (eg a timber beam) can potentially be considered a carbon 'benefit' that reduces the building's embodied carbon. However, we need to remember that this carbon will only remain in that product until the end of its life. After this, the timber beam could be burnt and the carbon released back into the atmosphere, or it could be reused, and the carbon stored in the product (and its benefit) passed onto another building or system. Or the material could be landfilled, where it would slowly degrade and release some of the carbon stored in the biomass over decades, or even centuries. Such options and future uncertainties can be challenging to navigate and may require expert input to support robust and consistent embodied carbon measurements.

The RICS whole life carbon assessment for the built environment guidance (2017) notes that the benefit of carbon sequestration should only be included in embodied carbon analysis when:

1. The whole life carbon assessment includes the end of life stages (module C). That is, sequestration benefits should not be included when analysis only considers upfront carbon emissions (A1-A5).
2. Any timber originates from certified sustainable sources, to ensure that its use is not contributing to deforestation.

The relationship between embodied and operational emissions

When developing strategies to reduce carbon emissions, it is important for architects to acknowledge that the different stages of a building's life cycle interact, and approaches to reduce emissions in one phase of the life cycle could actually increase emissions in a different phase.

For instance, improving the building fabric may require additional materials (more insulation, additional layers of glass, etc) which would increase upfront emissions. These additional upfront emissions could be paid back over time by lower operating emissions, due to reduced heat loss through the fabric.

Consider the decision of whether to install double or triple glazing in a refurbished house. A triple-glazed window would have a thicker frame, and an extra layer of glass, with greater upfront emissions. But it would also have a lower U-value, and thus contribute to reduced operating emissions over time. A study in the UK by Craig Jones (2014) has shown that a triple-glazed window could take 20 years for the reduced operational emissions to 'pay back' the increased upfront carbon emissions. This is a timeframe longer than the life of some window systems, meaning that from a whole life perspective, triple glazing may not be the best approach (see Figure 17). However, such results will differ in different climates and regions. Triple-glazing may also provide other non-carbon based benefits, such as improved occupant comfort, reduced noise transmission, etc, that need to be considered.

Actions and targets in practice

Reducing embodied carbon in practice puts an emphasis on different strategies at different stages in the design process. The Green Building Council Australia (GBCA) have documented the roles of different stakeholders in their report *A Practical Guide to Upfront Carbon Reductions* (GBCA 2023). Some key opportunities for architects are also documented below:

Brief stage: This stage provides the greatest opportunity for the most significant embodied carbon savings overall. Conversations with the client and development team can focus on key decisions such as whether the building is needed in its entirety, if refurbishment is an opportunity, if basements can be removed, floor areas reduced or functions merged to achieve the same outcome using far fewer materials. This stage can also be used to identify targets for the ambition of embodied carbon savings and building performance ratings (such as Green Star). LETI provide specific guidance for architects regarding how to talk to clients about embodied carbon in these early meetings, how to set the right tone, and how to manage differing client priorities (see LETI 2020, Appendix 1). Measuring embodied carbon at this stage is challenging, due to uncertainties around materials and quantities, so may be limited to simple calculations (eg considering floor area and typical values for embodied carbon per square metre).

Initial design stage: This stage provides the best opportunity to identify and embed dematerialisation strategies. In particular engagement with structural

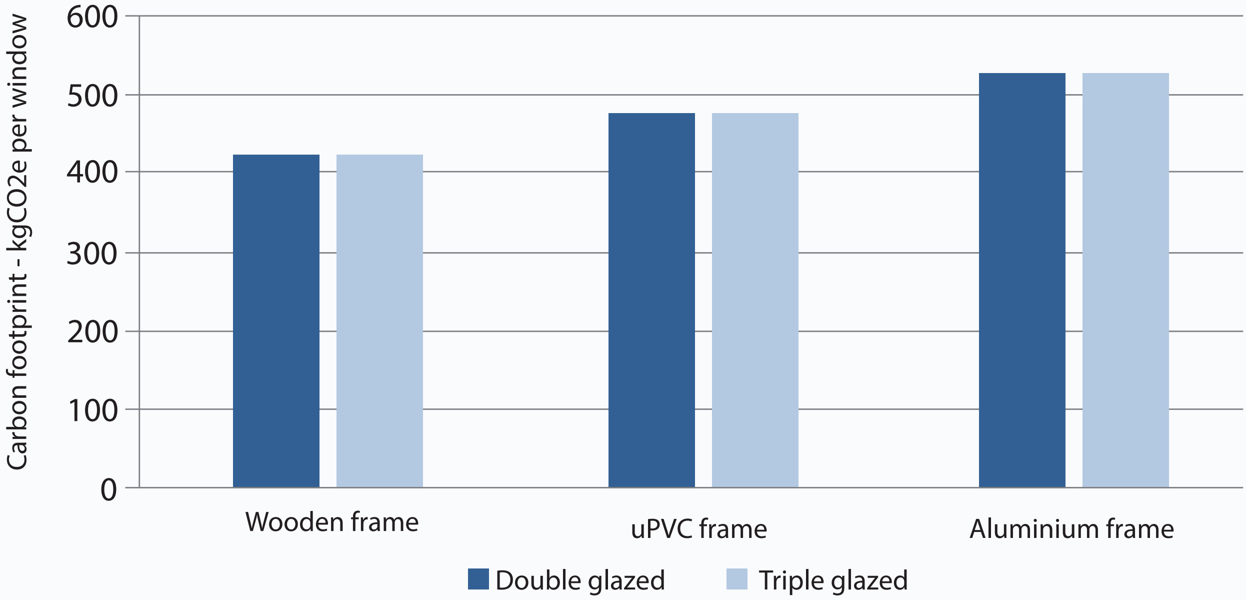


Figure 17. Whole life cycle carbon emissions (embodied and operational carbon) of a double and triple glazed window (1770mm x 1200mm) over 20 years. (Source: Jones 2014)

teams to optimize structural layout and reduce materials are key. Practice has shown that early contractor engagement at this stage can also provide new options to reduce embodied carbon, while identifying potential supply chains for reused materials and components is important (AHMM and UCL IEDE 2022). Embodied carbon measurements at this stage are unlikely to be complete (as a comprehensive list of materials will still be evolving), but comparative tests that measure the embodied carbon of different options to the same level of detail will be vital to inform the design team.

Detailed design stage: This stage provides an opportunity to compare different material suppliers to identify the lowest carbon options. In terms of embodied carbon measurement, a comprehensive Bill of Quantities (BoQ) or detailed BIM model should be available, allowing for more complete embodied carbon measurement to occur.

Post completion: Upon completion of the building it is important to use a final BoQ to determine an 'as built' embodied carbon with the highest level of detail and completeness. Such a measurement is often required for rating and certification (including Green Star and Climate Active certification). This also allows for the design team to compare against initial targets and earlier calculations, to understand how decisions throughout the design process impacted the final embodied carbon. It is vital that any published results are transparent in terms of life cycle modules included or excluded, data sources, and methodology used, to allow for fair comparisons in the industry.

When setting targets for embodied carbon reductions, two approaches are available to the design and development team:

1. **Reference case:** The designed project is compared against a 'reference' building of the same size and shape but using conventional construction methods and materials. This is the current method for Green Star certification.
2. **Comparison against benchmarks:** The designed project is compared against national, regional, or local benchmarks for embodied carbon of comparable building types.

Both these methods have challenges. The reference case requires the 'design' of two projects, while current benchmarks for embodied carbon are immature, and challenging to compare against due to differing inclusions and exclusions in their calculation (as outlined prior). In the future, it is expected that NABERS will develop a series of more comprehensive embodied carbon benchmarks for commercial buildings in Australia, which will make comparisons easier (GBCA 2023).

We can also expect 'science-based' targets for embodied carbon to emerge in the coming years. Science-based targets are different in that they are not based on what is 'typical' in the industry. Instead, they are based on the global carbon budget, and allocate cumulative emissions to different countries and sectors to ensure we stay below 1.5°C of global heating. Science-based embodied carbon benchmarks then will set ambitious targets for reducing embodied carbon based on what we need to do to limit global heating, rather than our current practice (SBTi 2023).

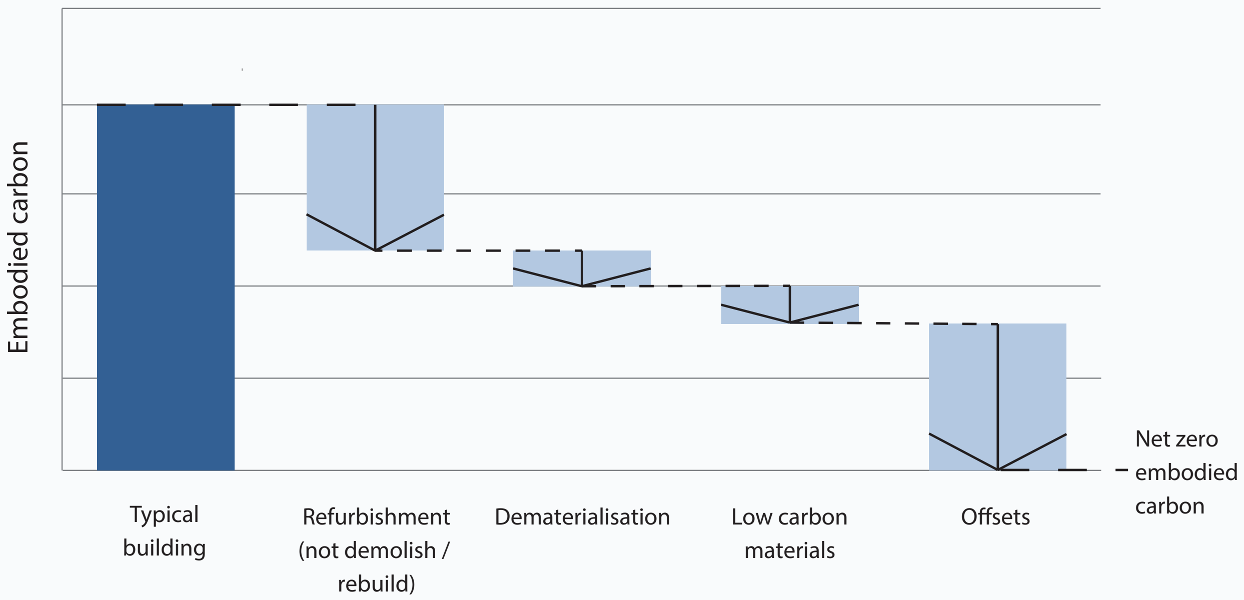


Figure 18. Achieving net zero embodied carbon. (Source: Adapted from a graphic by Caroline Noller and found in Prasad et al. 2023)

Towards net zero embodied carbon

As outlined in Table 1, many organisations have set future targets for net zero embodied carbon. To understand this, we need to define net zero embodied carbon. The World Green Building Council (WGBC 2019) provide the following definition:

> *'A net zero embodied carbon building (new or renovated) or infrastructure asset is highly resource efficient with upfront carbon minimised to the greatest extent possible and all remaining embodied carbon reduced or, as a last resort, offset in order to achieve net zero across the lifecycle.'*

Since most building material supply chains include at least some GHG emissions, such targets are challenging if not impossible to meet without carbon offsets. Offset projects reduce, remove or capture carbon emissions from the atmosphere. Offset schemes include investments in renewable energy systems, revegetation projects, carbon capture projects and more. Carbon offsets can be purchased through certification schemes such as Climate Active, which provides specific guidance for embodied carbon offsets (Climate Active 2023). However, in striving for net zero embodied carbon buildings it is essential that embodied emissions are *reduced to their maximum potential first*, prior to any offsetting (Figure 18).

Conclusion

For many new buildings embodied carbon will be the largest contributor to the total GHG emissions released over the building's life cycle. Embodied carbon is a fast-moving area in terms of measurement, benchmarking and tools, and a growing number of methods and performance criteria are emerging in Australia (and internationally).

There is strong evidence that embodied carbon can be significantly reduced in the built environment, today, using design strategies and approaches that are within the control of architects and broader design and procurement teams. Design teams should be looking at 2030 targets (as outlined in Table 1) and striving to achieve these today.

Fundamental is that decisions made earlier in the design process (eg whether to demolish and rebuild, or adaptively reuse existing assets) have a more significant influence on embodied carbon, and can result in far greater savings, than decisions made towards the detail design stages. As such, embodied carbon is a factor that needs to be considered from the very beginning of any building or infrastructure development process.

Further reading

A variety of resources exist to support architects' knowledge in embodied carbon. Some of these are outlined below.

A Practical Guide to Upfront Carbon Reductions: This guide by the GBCA provides value by outlining the roles different stakeholders have in embodied carbon reduction at different stages in the building life cycle.

LETI Embodied Carbon Primer: This provides a broad overview of the significance of embodied carbon in the built environment, and strategies to reduce this. While the focus is on the UK context, much of the information is globally applicable.

Net Zero Buildings: Halving construction emissions today: This guide sets out how we can halve embodied carbon in construction by 2030, but also suggests that reductions of this magnitude are possible today.

Race to Net Zero Carbon: This guide provides targets and benchmarks for new and refurbished buildings in Australia covering both operational and embodied carbon. The guide's aim is to achieve net zero embodied carbon across Australia's built environment by 2040.

RICS Whole life carbon assessment for the built environment: This provides one of the most comprehensive step-by-step guides for calculating embodied carbon and whole life cycle carbon in buildings.

References

AHMM and UCL IEDE (2022) *Delivering Net Zero in Use: A guide for architects by AHMM and IEDE*, London, UK.

Andrew RM (2018) 'Global CO2 emissions from cement production', *Earth Systems Science Data*, 10:195-217.

BubbleDeck (2018) *News*, BubbleDeck website.

Climate Active (2023) *Guideline: Upfront Carbon for Buildings*, March.

Collings D (2020) 'Carbon footprint benchmarking data for buildings', *The Structural Engineer*, November/December 2020:10-13.

Commonwealth of Australia (2021), *National Greenhouse Accounts Factors: Australian National Greenhouse Accounts*, August, Australian Government.

Crawford RH, Stephan A and Prideaux F (2022) 'The EPiC database: Hybrid embodied environmental flow coefficients for construction materials', *Resources, Conservation and Recycling*, 180, 106058.

Crawford RH, Stephan A and Prideaux F (2019) *Environmental Performance in Construction (EPiC) Database*, The University of Melbourne, Melbourne. doi.org/10.26188/5dc228ef98c5a

Crawford R (2012) 'Life cycle Energy Analysis', *Environment Design Guide*, 71 RC, Royal Australian Institute of Architects.

Crook L (2019) *Recyclable house is built from cork blocks*, Dezeen website.

Kenny C (2022) *I use EPDs every day... and here's how*, EPD Australasia website.

European Standards (2012) *EN 15978:2011 Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method.*

GBCA (Green Building Council of Australia) (2023) *A Practical Guide to Upfront Carbon Reductions. For New Buildings and Major Refurbishments.*

GBCA (Green Building Council of Australia) (2022). *Upfront Carbon Emissions calculation guide – interim. Guidance on calculation methods for the Upfront Carbon Emissions and Life Cycle Impacts credits*, December.

GBCA (Green Building Council of Australia) and thinkstep-anz (2021). *Embodied Carbon and Embodied Energy in Australia's Buildings.*

HM Treasury (2013) *Infrastructure Carbon Review*, London, UK.

Hookham B (2022) *Nature as inspiration: Bio-based materials for sustainable construction*, Architecture Australia website.

ICE (Institute of Civil Engineers) (2022). *Low Carbon Concrete Routemap: Setting the agenda for a path to net zero*, London, UK.

ISO (International Organization for Standardization) (2006) *ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework*.

Jones C (2014) *Double or triple glazing? All pane and no gain?*, Circular Ecology website.

Julistioni E, Oldfield P and Cardellicchio L (2023) 'Vertical Extensions: Stakeholder Perspectives on Development Decisions and Construction Strategies', *Journal of Architectural Engineering*, 29(2).

LETI (London Energy Transformation Initiative) (2020) *LETI Embodied Carbon Primer: Supplementary Guidance to the Climate Emergency Design Guide.*

Moré FB, Galindro BM and Soares SR (2022) 'Assessing the completeness and comparability of environmental product declarations', *Journal of Cleaner Production*, 375, 133999.

NSW Government (2022) *Sustainable Buildings SEPP Overview. The new State Environmental Planning Policy for sustainable residential and non-residential development.*

Oldfield P (2022) 'Upcycling the highrise: Quay Quarter Tower', *Architecture Australia*, September.

Oldfield P (2019) 'Next level prefabrication: Macquarie University Incubator', *Architecture Australia*, March.

Prasad D, Kuru A, Oldfield P, Ding L, Dave M, Noller C and He B (2023) 'Embodied Carbon in the Built Environment: Measurements, Benchmarks and Pathways to Net Zero', in *Delivering on the Climate Emergency: Towards a Net Zero Carbon Built Environment*, Palgrave McMillan, Singapore.

Prasad D, Dave M, Kuru A, Oldfield P, Ding L, Noller C and He B (2022). *Race to Net Zero Carbon: A Climate Emergency Guide for New and Existing Buildings in Australia v1b*. Low Carbon Institute and UNSW Sydney.

Australian Institute of Architects

Robati M and Oldfield P (2022) 'The embodied carbon of mass timber and concrete buildings in Australia: An uncertainty analysis', *Building and Environment*, 214, 108944.

Robati M, Oldfield P, Nezhad AA, Carmichael D and Kuru A (2020) Carbon value engineering: A framework for integrating embodied carbon and cost reduction strategies in building design, *Building and Environment*, 192, 107620.

RICS (Royal Institute of Chartered Surveyors) (2017) *Whole life carbon assessment for the built environment*, RICS professional statement, 1st edn, UK.

SBTi (2023) *A 1.5°C Pathway for the Global Building Sector's Embodied Emissions: Pathway Development Description – Draft*, May.

Schmidt M, Crawford RH and Warren-Myers G (2020) 'Quantifying Australia's life cycle greenhouse gas emissions for new homes', *Energy and Buildings*, 224, 110287.

thinkstep (2022) *Embodied Emissions Technical Analysis*, thinkstep pty ltd, Perth.

UNEP (United Nations Environment Programme) and GlobalABC (Global Alliance for Buildings and Construction) (2022) *2022 Global Status Report for Buildings and Construction. Towards a Zero-Emissions, Efficient, and Resilient Buildings and Construction Sector*, Nairobi.

WBCSD (World Business Council for Sustainable Development) and Arup (2023) *Net-zero buildings: Halving construction emissions today*, World Business Council for Sustainable Development, Geneva.

WBCSD (World Business Council for Sustainable Development) (2021) *The business case for circular buildings: Exploring the economic, environmental and social value*. World Business Council for Sustainable Development, Geneva.

WorldGBC (2019) *Bringing Embodied Carbon Upfront*, World Green Building Council, London and Toronto.

About the Author

Philip Oldfield

Philip Oldfield is Head of School at UNSW Built Environment, Sydney. His research interests are focussed on life cycle thinking, embodied carbon, tall building architecture, and climate literacy in architectural education. He is author of *The Sustainable Tall Building: A Design Primer* (2019) and co-author of *Delivering on the Climate Emergency: Towards a Net Zero Carbon Built Environment* (2023).

Australian Institute of Architects

DISCLAIMER