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POSTbrief

By Helen Freeman,
Lorna Christie

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Reducing the whole life carbon impact of buildings

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For further information on this subject, please contact the co-author, Dr Lorna Christie.

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Summary

Buildings contribute a significant proportion of the UK's carbon emissions and play a key role in the Government's target to reduce net emissions to zero by 2050.

The emissions attributed to a building across its lifetime are known as its 'whole life' carbon emissions and are commonly split into 'operational' and 'embodied'. Operational carbon emissions are those associated with the energy required to run a building (such as the energy used to provide lighting, power, heating, cooling, ventilation, and water services). Embodied carbon emissions are those associated with all the non-operational aspects of a building (such as those from the extraction, manufacture and assembly of a building's materials and components, it's repair, maintenance and refurbishment, and end of life activities).

To date, Government policies for decarbonising buildings have focused on reducing operational carbon emissions. However, many stakeholders, including the Climate Change Committee, have said that to address net zero targets, there needs to be an increased focus on the whole life carbon emissions of buildings, including embodied carbon emissions. However, there are currently no statutory requirements to measure or to reduce the embodied carbon emissions of buildings in the UK. The importance of the emissions from buildings is recognised at COP26, with a day dedicated to 'Cities, Regions and Built Environment'.

Whole life carbon assessments can be used to calculate a building's whole life carbon emissions and identify opportunities to reduce their carbon impact.

Strategies to reduce the whole life carbon emissions of buildings include: considering the need for the construction of new buildings versus repurposing existing ones; adapting the design of a building to reduce the quantity of material used while maximising operational efficiency; selecting alternative materials and construction products that have lower embodied carbon emissions, and; utilising materials that are durable, require minimum maintenance and can be dismantled, reused or recycled.

This POSTbrief discusses the emissions associated with the entire life of domestic and non-domestic buildings, from conceptual design to end of life (which may include repurposing, deconstruction for re-use, demolition or disposal). It presents a broad overview of the available strategies to reduce whole life carbon emissions being adopted by the construction sector and other stakeholders. It also provides an overview of the current and future skills needed for the construction sector to address net zero targets. The scope of this report is limited to the carbon emissions associated with

buildings, and it does not cover wider economic infrastructure such as transport networks and utilities. However, many of the principals around whole life carbon emissions reduction apply to both. Energy efficiency, planning and housing are devolved policy areas, and this briefing focuses on policies in England.

Building and construction stakeholder priorities for reducing the emissions associated with buildings include:

- A focus on reusing and repurposing buildings where possible, to avoid the need for construction of new buildings.[1,2]
- Whole life carbon (in particular, embodied carbon) to be considered in amendments to the building regulations for both new buildings and retrofitting of buildings.
- VAT to be reduced for building refurbishments to be in line with new builds. Repurposing existing buildings is not always cost effective, in part due to the VAT costs associated with refurbishment, which do not apply to demolition and new-build.[3]
- Introduction of a certification process for all construction materials to support better understanding of the whole life carbon impact of buildings.[2]
- Policies to drive more resource-efficient construction and use of existing low carbon building materials.

1 Background

To date, efforts have primarily concentrated on decarbonising operational carbon emissions, such as heating and lighting, in existing buildings. However, many stakeholders have highlighted that to achieve a net-zero built environment, the whole life carbon emissions of buildings need to be considered

In June 2019, the Government introduced a legally binding target for the UK to reach net zero emissions by 2050.[4] In April 2021, the Government updated this commitment with an intermediate goal to reach a 78% reduction in emissions by 2035, compared with 1990 levels.[5]

There is no agreed single figure for the whole life carbon emissions from buildings in the UK. Estimates of the carbon emissions attributed to buildings vary in their scope and are also made more complex due to the inclusion or exclusion of the emissions associated with imported products or services. One estimate found that 30-40% of embodied carbon emissions from buildings are from construction materials and products produced overseas and imported to the UK.[6] Emissions attributable to buildings also cut across multiple different sectors, including energy supply, manufacturing and transport.[6]

The UK Green Building Council's latest calculations from 2018 include both operational and embodied carbon emissions from the built environment, which includes buildings and infrastructure together.[6] These calculations estimated that the emissions associated with the construction, operation, and maintenance of buildings and infrastructure (which account for a proportion, but not all of, the embodied emissions) made up 8% of the UK's total annual emissions in 2018. It also reported that operational carbon emissions made up 20%.[6]

The Climate Change Committee (CCC) reported that the operational carbon emissions of all buildings made up 18% of the UK's total emissions in 2019.[7] It also reported that 13% of UK emissions in 2019 were from the manufacturing and construction sectors, some of which are associated with the embodied carbon emissions of buildings.[7]

To date, efforts have primarily concentrated on decarbonising operational carbon emissions, such as heating and lighting, in existing buildings. However, many stakeholders including the Royal Academy of Engineering and the UK Green Building Council, have highlighted that to achieve a net-zero built environment, the whole life carbon emissions of buildings need to be considered.[1,2]

A whole life approach to carbon emissions reduction would include tackling embodied carbon emissions alongside operational carbon. As such, it would necessitate changes in building design and materials selection, including designing with less material to improve resource efficiency and reduce waste, and selecting materials with a lower carbon impact. Circular economy based strategies, such as reusing materials and designing buildings to be reused or deconstructed, can also contribute towards whole life carbon emissions reductions.[8]

In December 2020, the Government announced a requirement for whole life carbon assessments for all public works projects and programmes.[9] In its 2021 report to Parliament, the Climate Change Committee (CCC) recommended that the Government further develop policies to drive more resource-efficient construction and use of existing low carbon materials, including a substantial increase in the use of wood in construction and finalising a reporting methodology for whole life carbon standards across all sectors.[7]

Construction is forecast to increase globally, with one estimate suggesting a 3.9% annual growth to 2030.[10] In the UK housing sector alone, the Government set a target to build 300,000 new homes per year by the mid-2020s. In its 2020 Budget, it announced a £600billion investment in infrastructure up to 2025, including an increase in housing investment to support its new homes target.[11] 'Greener buildings' was also one of the points featured in the Government's 2020 10 Point Plan for a Green Industrial Revolution.[12] In the plan, it estimated that developing greener buildings (including both new and existing buildings) has the potential to support 50,000 jobs in 2030, create £11billion of private investment throughout the 2020s and save a total of 71 $MtCO_2e$ of operational carbon emissions between 2023 and 2032 (equivalent to 20% of annual UK emissions in 2019).[12,13]

The Government's 2019 Future Homes Standard outlines proposals to reduce the operational carbon emissions of new homes by at least 75% by 2025, compared with homes built to current building regulations.[14] It aims to achieve this through higher energy efficiency requirements and installation of low carbon heating systems (such as heat pumps). As part of the Future Homes Standard, the Government will require homes built from 2025 to be 'zero carbon ready' – in that they should not require further energy efficiency retrofit measures to become zero-carbon (referring to operational carbon). However, the Future Homes Standard does not include any measures to address embodied carbon emissions.

2 Whole life carbon

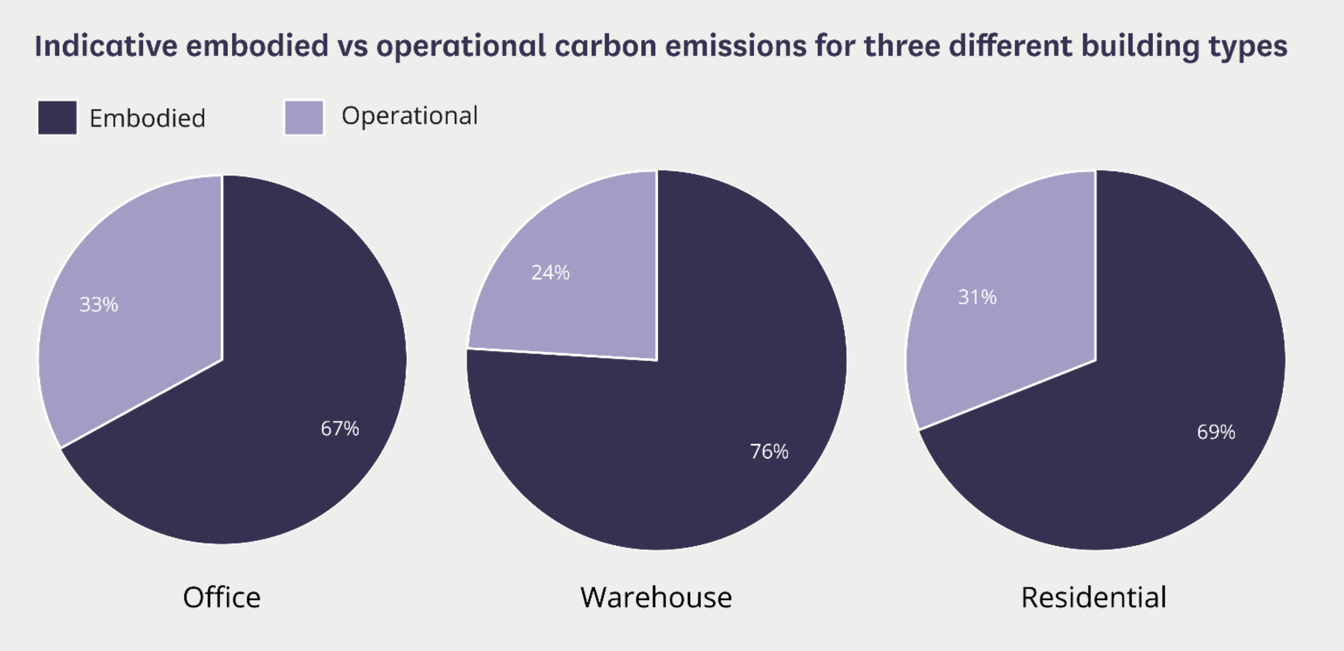
Buildings generate carbon emissions throughout their entire lifetime (which, for the ease of assessing their carbon impact, is usually considered to be 60 years, but in practice may be much shorter or longer).[15] These are referred to as 'whole life carbon' emissions. A building's whole life carbon includes both net operational and embodied carbon emissions, and, depending on scope, can include emissions associated with circular economy activities (for example the recovery of waste via re-use, and recycling from end of life activities).[15,16]

- **Operational carbon emissions** are the net emissions associated with the energy required to run a building, such as the energy used to provide lighting, power, heating, cooling, ventilation, and water services.
- **Embodied carbon emissions** are the net emissions associated with all the non-operational aspects of a building across its lifetime. This includes the emissions associated with energy consumption and chemical processes during the extraction, manufacture, and assembly of the materials and components that make up a structure, as well as the maintenance, repair, replacement and ultimately demolition and disposal of the building. It also includes emissions arising from transportation during building production, such as transportation of construction materials to a building site.[15]

Circular economy principles account for the repurposing of materials and products discarded from the building, or any energy recovered from them beyond the building's life cycle.[15] Potential emissions savings at this stage are due to re-use of components, which can avoid additional emissions from manufacturing an equivalent item from primary materials.[17] This stage of the whole life carbon emissions is usually reported separately in whole life carbon assessments (see later) as there is a high degree of uncertainty around the end of life activities and the future treatment of building components.[15]

The proportion of a building's whole life carbon that is attributed to operational versus embodied carbon emissions differs depending on the building type. Buildings that have good operational energy efficiency or a low requirement for operational energy have a higher proportion of embodied carbon in their whole life emissions. For example, in some cases, around 75% of the whole life carbon of a warehouse is associated with embodied carbon emissions, since warehouses generally have a low operational energy requirement.[15] Figure 1 shows some examples of the proportions of embodied versus operational carbon emissions for different building types.[15] Proportions can vary significantly depending on design, energy supplier and occupants.

Figure 1. An example of the proportions of embodied vs operational carbon emissions for different building types, including: a speculative office building in central London; a typical warehouse shed with 15% office space in the London perimeter and; a residential block with basic internal fit out, in Oxford.



Source: Redesigned with permission from RICS 'Whole life carbon assessment for the built environment' (2017).

2.1 Operational carbon emissions

To date, Government policies for decarbonising buildings have focused on reducing operational carbon emissions by decarbonising the electricity grid, improving the energy efficiency of buildings via changes to building regulations, updating local authority planning requirements, and introducing the sustainability assessment rating schemes for measuring, sharing and benchmarking operational carbon emissions.[18] More detailed discussions of environmental standards for housing can be found in POSTnote 650.[19]

Studies estimate that over 70% of the current UK building stock will still be in use in 2050,[20,21] much of which has been reported to be amongst the most inefficient and oldest in Europe.[22] This is because most of the UK's housing stock was built prior to the 1990s, and was not built to the higher energy efficiency standards that exist today.[23,24] It is estimated that new homes will make up approximately 20% of the total housing stock in 2050.[21]

In its 2021 Budget, the Government committed £3.9billion to ensure buildings in England and Wales are "warmer and cheaper to heat."[25]

The Government has previously established a number of financial support schemes to aid reductions in operational carbon emissions of existing buildings:

- **The 2020 Green Homes Grant** allows homeowners and residential landlords to apply for vouchers that contribute to the cost of installing energy efficient improvements to their homes (such as insulation, thermostats or heat pumps).[26] This scheme ends in March 2022.
- **The Public Sector Decarbonisation Scheme** provides grants for public sector bodies to implement heat decarbonisation and energy efficiency measures in public sector buildings.[27] £75million of funding is available in the 2021/22 financial year.
- **The Social Housing Decarbonisation Fund** supports projects using innovative approaches to retrofitting social housing. Following the 'demonstrator' launch in October 2020, the projects have received a share of £62million and will retrofit over 2,300 homes to bring them up to Energy Performance Certificate (EPC) band C or higher.[28] The Government has announced £160million for 'wave one' which will be followed by series of further funding waves.[29] The 2021 Budget reported that the Fund would be supported with a total of £800million.[25]

In 2025, the Government's Future Homes Standard will come into effect for new homes.[21] This aims to reduce the operational carbon emissions of new build homes through changes to the building regulations (Part L: Conservation of fuel and power), which will require the use of low carbon heating systems and improved energy efficiency measures. The Government has said it will adopt a two-stage approach, with interim measures to achieve a 31% reduction in emissions compared to previous building regulations coming into effect in 2021, followed by measures to achieve a 75% reduction, implemented in 2025.[14] During consultation for the Future Homes Standard, some stakeholders raised concerns that it does not make any provisions for measuring or reducing the embodied carbon emissions of buildings.[14] In response, the Government said that it intends to carry out longer-term work to examine a wider scope around how new buildings can be designed and constructed to be fit for a zero carbon future.[14]

The Future Buildings Standard expands on the Future Homes Standard and sets out ventilation and energy standards for both new and existing non-domestic and domestic buildings in England.[30] It also includes proposals to mitigate overheating in domestic buildings. The CCC's third Climate Change Risk Assessment has highlighted overheating as a "priority risk for urgent further action" (see POSTnote 642).[31,32]

In the Future Buildings Standard, the Government has proposed a two-option approach for new non-domestic buildings, with measures to deliver either a 22% or 27% interim improvement in operational carbon emissions compared to current standards. The latter is the Government's preferred option.[30] For existing residential buildings, the Future Buildings Standard also outlines proposals for new energy efficiency standards for when a new or replacement part of the building is built (including installation or renovation of a building's walls, floors, and roof). The second phase of consultation on the Future Buildings Standard closed in April 2021.[30] It does not currently mention whole life or embodied carbon emissions. The Government has said it will consider consultation responses before regulating later in 2021.[33]

Measures to reduce operational carbon emissions largely rely on decarbonisation of the electricity grid, retrofitting existing buildings (e.g. with insulation) and using low carbon heating such as heat pumps.[34] In October 2021, the Government published its Heat and Buildings Strategy.[35] The strategy provides a roadmap to tackle the operational carbon emissions from homes and businesses and details the proposed policies around replacing gas boilers with heat pumps.[36] The strategy includes an ambition to phase out the installation of new natural gas boilers from 2035 and make strategic decisions on the role of hydrogen for heat by 2026. Heat pumps and improved insulation play a significant role in the strategy. The Government has said it will work with industry to "reduce the costs of heat pumps by at least 25-50% by 2025, and towards parity with boilers by 2030."

Government data show that in the period 1990 to 2018, the operational carbon emissions of residential buildings in the UK reduced by approximately 14%, largely due to decarbonisation of the electricity grid and insulation installation.[37] As the operational carbon emissions of buildings continue to reduce following the rollout of these schemes, embodied carbon emissions will become an increasingly significant proportion of a building's whole life carbon emissions.[17]

2.2 Embodied carbon emissions

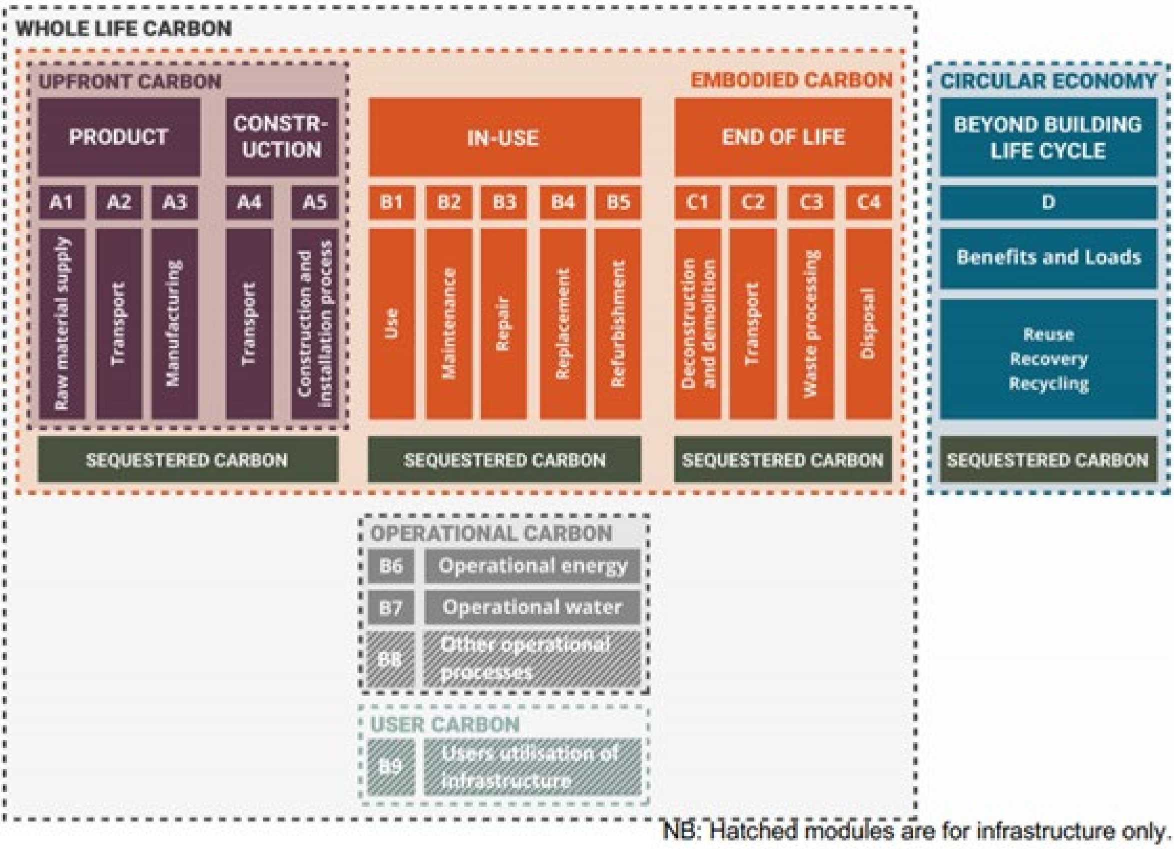
Embodied carbon emissions refer to the total emissions associated with materials and construction processes throughout the whole life of a building.[16] The established European (and British) Standard 'BS EN 15978:2011' sets out the framework for assessing the sustainability of buildings, and splits the building lifecycle into stages. These stages can be grouped into those that constitute a building's embodied emissions and those that include operational emissions (Figure 2). Stages within this framework that comprise embodied emissions include:[15]

1. **Product stage**: includes the supply of raw materials (such as limestone, iron ore and timber), transportation of raw materials to processing facilities, and the processing and manufacture of construction products.
2. **Construction stage**: includes the transport of materials and products to the building site, the physical construction and installation processes, and disposing and processing of on-site waste.
3. **In-use stage**: includes the maintenance, repair, replacement and refurbishment of components. It does not include operational carbon emissions. Note that all operational emissions also occur during the 'in-use' stage.
4. **End-of-life stage**: includes deconstruction and demolition, transport of materials to waste/recycling facilities, waste processing and waste disposal.

As mentioned earlier, the activities that take place beyond the end of a building's lifecycle can also impact its whole life carbon emissions (Figure 2, module D). Some reductions in embodied emissions may be possible through consideration of circular economy principles, such as recovery and reuse of materials and components. However, 'beyond building lifecycle' activities are reported separately in whole life carbon assessments (see later) due to the high level of uncertainty associated with them.[15]

For many building types the majority of embodied carbon emissions occur during the product stage.[17,38] This is due to the large volumes of materials used in current construction practices and the often carbon intensive processes associated with producing them (discussed later). A building's structure often contributes the majority of its embodied carbon (but this varies depending on the building, its lifespan and structure type). For example, a warehouse designed for a short service life of 15 years would have a relatively high proportion of embodied carbon in its whole life carbon, whereas residential buildings, which often have a lifespan of over 100 years, may have a higher proportion of operational emissions.[15]

Figure 2. Diagram showing the life cycle modules that make up a building's whole life carbon emissions, adapted from the standard BS EN 15978. Modules within the orange shaded box show the stages that comprise embodied emissions. Modules shaded in grey represent operational emissions.



Source: Figure reused with permission from 'Improving Consistency in Whole Life Carbon Assessment and Reporting, WLCN, LETI and RIBA (2021)'

Until recently, the embodied carbon assessment of building services has been limited, and therefore often overlooked. However, work is ongoing to improve carbon assessment of these components.[39] In addition, some studies show that other building layers (e.g. façades, internal finishes, external works) can also play a significant role, particularly for buildings with high levels of energy consumption (e.g. hospitals) or heavy use (e.g. schools).[38]

Many stakeholders, including the CCC[40] and the UK Green Building Council[1] have said that in order to address net zero targets, there needs to be an increased focus on the whole life carbon of buildings, particularly embodied carbon emissions.[41–43] This is also reflected in a number of the evidence submissions received as part of the Environmental Audit Committee's ongoing inquiry into 'Sustainability of the Built Environment'.[44–46]

3 Strategies to reduce whole life carbon emissions

There are currently no statutory requirements to measure or to reduce the embodied carbon emissions of buildings

The Government, building industry and other stakeholders have recognised the need to address emissions from buildings, including their underpinning construction processes. The following sections give an overview of some of the approaches being taken.

Government initiatives

In the National Infrastructure Strategy, the Government committed to transforming the construction sector to make it more sustainable, including through better use of data and modern approaches to construction (discussed later).[47] However, there are currently no statutory requirements to measure or to reduce the embodied carbon emissions of buildings. While the technologies for improved operational efficiency are currently available, reducing embodied emissions is considered more of a challenge due to the current reliance on construction materials and processes with unavoidable process emissions (discussed further in 'Product stage' section).[42,48]

Many stakeholders, including the UK Green Building Council and the Institution of Structural Engineers, have recommended that the most effective solution is to avoid constructing new buildings, and instead focus on re-purposing existing buildings.[8,48,49]

The Green Construction Board represents the sustainability workstream of the Construction Leadership Council and includes government officials from the Department for Business, Energy and Industrial Strategy (BEIS), the Ministry of Housing, Communities and Local Government (MHCLG), the Department for Environment, Food & Rural Affairs (Defra), the Infrastructure and Projects Authority (IPA), Innovate UK and Treasury, as well as industry experts from the construction and built environment sectors. They produce guidance and roadmaps (for example 'Zero Avoidable Waste in Construction' and 'Low-Carbon Concrete') and respond to Government publications.[50–52] The Construction Leadership Council's CO_2nstructZero Initiative, a response to the Government's 10 Point Plan, has worked with key stakeholders to develop a list of priorities around decarbonising buildings and construction.[12,53]

Voluntary initiatives

Various voluntary initiatives, guidelines and targets for whole life and embodied carbon reduction have been established, driven by campaign groups and professional institutions. These include the World Green Building Council's Whole Life Carbon Vision, the Royal Institute of British Architects 2030 Climate Challenge, the London Energy Transformation Initiative, the

Architects Climate Action Network, the Institution of Structural Engineers Embodied Carbon Tracking scheme, the Construction Declares movement and guidance from the Royal Academy of Engineering's National Engineering Policy Centre.[2,17,42,54–57] The UK Green Building Council is one of ten European Green Building Councils in the Building Life project which aims to create 'the first region-wide response to the vision of a net-zero embodied carbon built environment'.[58] In 2020, the World Green Building Council set a target to reduce embodied carbon emissions by 40% by 2030.[48]

Building sector and industry initiatives

Many leading UK construction companies have set their own targets and roadmaps for achieving net zero emissions. These strategies often include changes to building design, manufacturing processes and use of materials to reduce embodied or whole life carbon.[59,60] However, several of these targets only cover operational emissions. To go beyond these targets, it is recognised that collaboration with broader stakeholders, beyond the construction industry (such as planning authorities and materials and products suppliers) is needed from the outset of a construction or retrofit project.[61,62]

Through the 'Construction Declares' movement, the UK construction sector has made a commitment to "take positive action in response to climate breakdown and biodiversity collapse".[55] Its scope includes a range of both operational and embodied carbon reduction strategies. Since May 2019, over 6,000 architectural, structural, civil, and building services engineering practices, landscape architects, contractors, and project managers in the UK (and internationally) have signed the declaration. However, the signatories are not held to account and are part of the movement on a voluntary basis.

In July 2021, whole life carbon experts, with the support of representatives from the construction industry, published a report that proposed amendments to the Building Regulations 2010. The proposals were described by the authors as a 'proof-of-concept', to demonstrate how embodied carbon could be incorporated into UK regulation and were termed 'Part Z'. The proposals outline requirements for the assessment of whole life carbon emissions, and limiting of embodied carbon emissions, for all major building projects.[63]

Local authority initiatives

Some local authorities have started to consider whole life and embodied carbon in their local plans. As of February 2021, 74% of the UK's District, County, Unitary and Metropolitan Councils have declared a Climate Emergency.[64] However, limited emissions reduction targets have been published. For those that have set targets to reduce building emissions through local development plans, the majority focus on operational carbon. Few local authorities have made commitments around whole life or embodied carbon. Below are examples of those that have:

- The Greater London Authority's London Plan states that major new developments and developments involving major refurbishment should be net zero-carbon.[65] Such projects should calculate whole life carbon emissions through a nationally recognised methodology and demonstrate actions taken to reduce emissions. The exact methodology is being decided through public consultation and is expected to be published in this year.[66]

- Eastleigh Borough Council's 2011-2029 Local Plan states that all new residential developments, and non-residential developments over 500m^2 must "use recycled, low embodied carbon, low environmental impact and locally sourced materials in construction where possible".[67] However, it does not quantify such targets.
- Bath and North East Somerset's 2011-2029 Local Plan requires that new developments must address "efficiency in materials use, including the type, life cycle and source of materials to be used".[68]
- The inclusion of embodied carbon and whole life carbon assessments (see next section) have been introduced (and in some cases subsequently removed) in the city plans of other local authorities, such as Dundee (2019),[69] Leeds (2011),[70] and Manchester (2020).[71]

Box 1. Strategies to address whole life and embodied carbon in other nations

Internationally, some whole life carbon and embodied carbon regulations exist in Europe and the United States. For example:

- **Netherlands**. Since 2013, the 'Building Decree 2012' requires new residential and office buildings larger than 100m^2 to have whole life carbon calculations and carbon mitigation cost estimates using a national methodology.[72]
- **France**. From early 2022 the new 'RE2020' will require whole life carbon calculations for all new housing projects with an emphasis on the use of wood in construction.[73] Reduction targets will be set incrementally to achieve carbon neutrality by 2050. The scheme has been running since 2016 on a voluntary basis to build a database and upskill the sector.
- **Finland.** From 2025 the measurement and reporting of both operational and embodied carbon emissions will be required for all new buildings using a national whole life carbon calculation methodology.[74] Emissions targets will be set according to building type.
- **California**. The 'Buy Clean California Act' applies to infrastructure projects and public buildings and sets out 'Carbon Intensity Limits' on certain construction materials.[75]

The Government's 2020 Construction Playbook requires whole life carbon assessments for all public works projects and programmes (including buildings).[9] Contracting authorities are advised to work with the wider supply chain to ensure that solutions put forward by potential suppliers are accompanied by a whole life carbon assessment. This is mandatory on a 'comply or explain' basis for all contracting authorities within central Government departments and its arm's length bodies such as their agencies, and public bodies.

In July 2021, the Infrastructure and Projects Authority (the Government's centre of expertise for infrastructure and major projects) updated its Best Practice in Benchmarking Guidance to provide a structured approach for organisations introducing whole life carbon assessments in their data collection and reporting practices.[76] Despite this, experts are still calling for the Government to change approaches to procurement, at central, devolved and local levels to reflect broader definitions of whole life carbon performance.[2] They are also calling for increasingly stringent carbon reduction targets for all buildings, including targets for both embodied carbon and operational carbon emissions.[2] Some other countries have put in place regulations for whole life and embodied carbon emissions of buildings (Box 1).

Reducing emissions at each lifecycle stage

Prior to implementing carbon reduction strategies for a building or retrofit project, it is important to have a good understanding of a building's whole life carbon impact. This can be achieved through carrying out a Whole Life Carbon Assessment (WLCA).

The following sections give an overview of WLCAs, followed by a more detailed discussion of strategies to reduce whole life carbon emissions at each stage of a building's lifecycle (as outlined in Figure 2). Strategies for emissions reduction include factors such as:[77]

- Assessing the need for a new building and the options for repurposing existing assets. Many stakeholders including the Royal Academy of Engineering have said that the priority at the end of life stage should be to reuse buildings where possible, to avoid the need for construction of new buildings.[1,2]
- Considering the design of a new building to minimise both operational and embodied carbon emissions; for example, through reducing the quantity of material used while maximising operational efficiency, reducing waste, and enabling building-use adaptability.
- Optimising the materials and products used and their associated whole life emissions.
- Minimising the distance travelled by materials and products, especially those of high mass.
- Considering the construction process, including the emissions from on-site activity and construction waste.

- Assessing the embodied carbon of materials and products for maintenance and retrofit versus their potential to reduce operational carbon.
- Considering demolition and waste-material processing.
- Considering circular economy principles including the reuse, recovery, recycling potential of materials and energy recovered from materials.

By reducing whole life carbon emissions, these strategies minimise the residual emissions that may need to be reduced by carbon capture technologies (Box 2) to meet the 2050 net zero Paris Agreement.

Box 2. Carbon capture technologies

Carbon capture technologies can reduce emissions by capturing CO_2 from fuel combustion or industrial processes and transporting it for either permanent underground storage or use as a resource for products or services.[78] Such technologies include carbon capture utilisation and/or storage (CCU, CCS or CCUS) (see POSTbrief 30 and POSTnote 618).

In the 2020 National Infrastructure Strategy, the Government said that CCUS will be essential to decarbonise large parts of the construction industry.[47] However, the Government and other stakeholders have also recognised that industrial scale carbon capture technologies require further development to reduce any financial and technical risks.[12] To address this, the Government has pledged to invest £1billion in four CCUS clusters by 2030 and set an ambition to capture 10 $MtCO_2$ per year by 2030 (less than 2% of annual UK emissions).[47] These investments were reaffirmed in the 2021 Budget.[25]

The CCC has recommend that final investment decisions are made on the first industrial carbon capture projects by mid-2022 to ensure at least two CCUS clusters are established in the mid-2020s.[7] The steel and concrete sectors have also identified carbon capture technologies as a critical technology in their net zero roadmaps.[79,80] However, they also recognise that these technologies are not yet ready for deployment at scale and have asked for support from Government to ensure competitiveness is maintained during the transition to net zero.[81]

Some stakeholders have said that carbon offsetting may also play a role in certain sectors as they work to decarbonise.[82] Offsetting happens when a business compensates for its emissions by paying for emissions reductions (offsets) to occur elsewhere. Some examples of greenhouse gas removal techniques that are used in offsetting schemes include tree planting and direct air carbon capture and storage (see POSTnote 549 for more information on greenhouse gas removal techniques).

The Oxford Offsetting Principles provide four recommendations for how offsetting should be approached to ensure it helps achieve a net zero society, the first of which is to minimise the need for offsets in the first place.[83] In the construction sector, both the Institution of Structural Engineers and UK Green Building Council (UKGBC) have provided guidance around carbon offsetting.[82,84]

The CCC has recommended that the use of offsets should be minimised and suggests that in the buildings sector, it would not be appropriate to rely on offsets by 2050.[85] It also recommends that in the manufacturing and construction sector, offsetting should only be considered for residual emissions from CCS on process emissions by the 2040s (more on process emissions can be found in the 'Product stage' section).

3.1 Whole life carbon assessment

Whole Life Carbon Assessments are not currently a national statutory requirement for building projects, however many professional bodies and some local authorities encourage them

A life cycle assessment is a method used to assess a range of environmental impacts of a product, process or service across its lifetime.[86] A 'Whole Life Carbon Assessment' (WLCA) is a type of life cycle assessment, which specifically aims to provide an overview of the carbon emissions associated with each stage of a system's life. Part of carrying out a WLCA for buildings involves compiling an inventory of all the materials and processes used in the construction and lifetime of the building and assessing the total environmental impact.

A building WLCA can identify opportunities to reduce both emissions and costs and gives an overview of the different proportions of operational versus embodied carbon emissions that exist for different building types (for example see Figure 1). WLCAs are not currently a national statutory requirement for building projects, however many professional bodies and some local authorities encourage them (see previous section).

There are various frameworks available for measuring whole life carbon emissions, however the most widely used method in the UK is the 2017 Royal Institute of Chartered Surveyors (RICS) 'Whole Life Carbon Assessment for the Built Environment' methodology.[15] The RICS methodology is based on the British Standards Institution's 'BS EN 15978:2011', which defines the framework for appraising the environmental impacts of the built environment and describes the key stages of a building's life (as outlined in Figure 2). Other standards that are relevant to carrying out WLCAs are outlined in Box 3.[87] The RICS methodology is endorsed by key stakeholders including the Royal Institute of British Architects (RIBA)[42,88] and Chartered Institution of Building Services Engineers.[39] The RICS methodology is also an integral feature of the Greater London Authority's London Plan.[65] Guidance on using this methodology has been published by organisations including the UK Green Building Council,[87] the Institution of Structural Engineers (IStructE)[89] and London Energy Transformation Initiative (LETI).[17]

The scope of a WLCA often varies between projects, but to be robust it should ideally cover each of the lifecycle stages outlined in Figure 2. However, as mentioned earlier, 'BS EN 15978:2011' and the RICS methodology state that the 'circular economy' stage (also referred to as Module D) should be reported separately as it bears "high inherent uncertainty regarding the future treatment of building components".[15]

Box 3. Standards relevant to carrying out a whole life carbon assessment

There are a number of national and international standards for assessing environmental impact and performance that are relevant to carrying out a life cycle assessment (and whole life carbon assessment).[87] Some of these are applicable to all sectors, and others are specific to buildings and/or construction. Examples of these include:

- **BS EN 15978:2011** provides the requirements for undertaking a compliant building life cycle assessment and sets out the principles for environmental performance and life cycle assessment of buildings (see Figure 2).[90]
- **BS EN 15804:2012+A2:2019** provides the requirements for producing Environmental Product Declarations (EPD, see above) for construction products that are used in BS EN 15978:2011.[91]
- **BS EN ISO 14040:2006+A1:2020** describes the principles and framework for life cycle assessment.[92] BS EN 15978 is also based on this standard.[90,93,94]
- **Publicly Available Specifications (PAS)** are commercial standards from the British Standards Institution (BSI) which define good practice for products, services, or processes in the UK. For example, PAS2035 provides guidance on assessing domestic energy efficiency retrofit projects.[95]

The accuracy of WLCAs rely on the input of data on the carbon impacts of building materials, products, processes, and equipment. The RICS methodology cites five carbon data sources that are permitted for use in their whole life carbon assessments.[15] These include Environmental Product Declarations (EPD) which provide a standard way of declaring the impacts of products through life cycle assessments.[96] By the beginning of 2021, globally over 10,000 EPD were verified to 'BS EN 15978:2011', 360 of which covered UK-produced products covering a wide range of construction applications.[96] There is no statutory requirement in the UK for EPD.

There are a number of other databases that provide carbon impact data. For example:

- **The Inventory of Carbon and Energy (ICE)**, developed by the University of Bath, is a database of embodied carbon and energy values for a variety of construction materials.[97] It only includes the emissions associated with the product stage (see Figure 2).
- **The Ecoinvent Database** is a commercial life cycle inventory database that supports various types of sustainability assessments. It contains around 18,000 datasets (each is attributed a geographic location) covering a range of sectors, including construction.[98]
- **The GaBi Software** is a commercial life cycle inventory database that contains around 13,000 datasets, including 1,000 plan models.[99]
- **The RICS Building Carbon Database** captures embodied carbon data for whole buildings (launched in 2019 and formally known as the Waste & Resources Action Programme (WRAP) Embodied Carbon Database).[100] It includes the emissions associated with all stages of a building's life cycle.
- **The Wood for Good Lifecycle Database** provides carbon emissions data associated with timber, timber products and panels and includes end of life data. It also includes separate data for beyond end of life activities, (Module D, (see Figure 2).[101]
- **The 'SteelConstruction.Info' Database** provides emissions data associated with brick, concrete and steel and includes end of life data. It also includes separate data for beyond end of life activities, (Module D, (see Figure 2).[102]
- **The Mineral Products Association** provides information on the embodied carbon emissions of UK cement and concrete products.[103–105]

Despite these resources, there remain some challenges that limit how widely WLCAs are currently used.[106] These include, but are not limited to:

- **Uncertainties**: WLCAs usually involve many assumptions, including assumptions about what will happen to the building at the end of its life and the extent of refurbishment that the building may require. This is an area of active research between academic and industry partners.[107] The RICS Professional Statement on Whole Life Carbon includes some default assumptions to help ensure consistent assessments.
- **Scope**: Carbon assessments often vary in scope, with some accounting only for the product stage, others for the product and construction stage, and some for the whole life (see Figure 2).[108] The scope of an assessment is decided by the individual/organisation performing the analysis.
- **Data:** The availability and quality of data on carbon impacts for each stage of the building lifecycle can vary significantly.[106,109,110] Experts have noted that there is a wide range of available figures for the embodied carbon impacts at certain lifecycle stages, and that the choice of data

used could make a big difference to the result of a carbon assessment.[106,109]

- **Carbon storage and release:** The carbon stored in building materials and the carbon released at the end of life can be complex to account for accurately. For example, some academics and other groups have reported that there is significant variation in how biogenic carbon (the carbon removals associated with carbon sequestration into biomass, as well as any emissions associated with this sequestered carbon,[16] is accounted for in WLCA assessments, although standards address how this should be assessed.[15,91,108] This may be significant for buildings that use timber (see later).[108,111]

Although the use of life cycle assessments and WLCAs for buildings is not currently regulated, they are now incorporated into some environmental certification schemes. For example, The Building Research Establishment's Environmental Assessment Method (BREEAM) is the main global sustainability assessment method for infrastructure and buildings. In 2018, BREEAM changed its environmental assessment of buildings and now uses life cycle assessment at a whole-building level rather than assessing the individual elements of the building.[18] Experts are calling for the Government (supported by industry) to introduce a certification process for all construction materials.[2]

3.2 Design stage

If a new building is deemed necessary then considering the whole life carbon during the design stage presents opportunities to reduce both operational and embodied carbon emissions.[56] These include designing:

- with less material and/or decreased complexity to improve resource efficiency and reduce waste.[112]
- with materials/products that have low embodied carbon (see 'Product stage' section).
- for energy efficiency and low carbon heat to minimise operational carbon emissions.[113]
- with a consideration of the construction (and deconstruction) process (see 'Construction stage' section).
- using materials and products that are durable and require minimal maintenance to reduce emissions during the 'in-use' stage (see 'In-use stage' section).
- for adaptability, to allow buildings to be repurposed through refurbishment and extension in preference to demolition and replacement with a new building, and/or for disassembly, so that materials and products can be re-used (see 'End of life stage' section).

Some experts have called for whole life carbon (in particular, embodied carbon) to be considered in amendments to the design aspects of building regulations for both new buildings and retrofit

Some experts have called for whole life carbon to be considered in amendments to the design aspects of building regulations for both new buildings and retrofitting of buildings.[14,56] Experts have highlighted that a whole life carbon approach to building design can help to ensure that low operational carbon design does not inadvertently increase embodied carbon and vice versa.[43]

The whole life carbon approach relies on collaboration between multiple stakeholders, including those involved in manufacturing low operational carbon products and building designers.[62] To facilitate this, new sustainable design tools and guidance are available to assist with whole life carbon calculations of different architectural forms and performance enhancing technologies.[114,115] For example the PANDA tool uses software that can generate and analyse many different building designs at concept stage and determine which have the lowest embodied carbon emissions.[114] Other tools include ECCOlab,[116] iCIM,[117] AutoBIM,[118] Concept[119] and H\B:ERT.[120] There are also commercial tools used in the UK, for example OneClickLCA[121] and eToolLCD,[122] in addition to many in-house embodied carbon tools. For additional reading, the International Energy Agency's 'Annex 57' and 'Annex 72' projects analysed a variety of case studies to curate a detailed list of design strategies and calculation methods.[123,124]

Resource efficiency

Resource efficiency reduces the demand for new materials by maximising the use of a material or component and creating minimum waste (see POSTnote 646). Creating more value with fewer resources has the potential to reduce the embodied carbon emissions of buildings.[8,125] The UK Green Building Council and Institution of Structural Engineers report that components, including the above- and below-ground structures and assemblies (such as floors and walls), typically have the highest material volumes, masses and embodied carbon contributions in a design.[87,126] Various studies suggest that these components are currently consuming more material than necessary.[49,127] 'Lean' design is a principle that aims to minimise the amount of materials used in buildings and address some of the most significant and achievable carbon reductions.[87,125,128] This can be achieved by:

- **Streamlining the building form.** For example by reducing floor spans, reducing finishes and linings, using standardised structural grids for columns and beams and standardised layouts for electrical cabling, service pipes, and ventilation ducts.[125]
- **Avoiding over-engineering of the structure.** For example one study found that certain buildings could be designed with around half the steel currently used without compromising safety and service levels.[127]
- **Specifying locally sourced materials.** This can reduce the carbon emissions associated with transportation, particularly for high mass materials.[129]

- **Reducing waste.** For example through designing out waste, reducing excess construction materials and improving the storage and management of materials.[50]
- **Maximising material re-use.** For example, increasing reuse of materials from demolition, designing a building for deconstruction rather than demolition at the end of its life and designing a building for reconfiguration during its life.[2,50,125]

Stakeholders including the UK Green Building Council and Royal Academy of Engineering encourage lean design and resource efficiency to be considered at the early stages of a construction project when the design and choices of materials can be influenced.[2,87] Practical guidance has been published by the Institution of Structural Engineers on how to produce designs that make efficient use of materials to reduce their environmental impact.[49,57] Construction material manufacturers are also looking to improve resources efficiency; for example, Tata Steel have developed a higher strength steel to reduce the volume of steel required.[130]

Repurpose and adaptability

An average building will commonly change owners (and occupants) multiple times during its standard lifespan of 60 years (as defined by RICS).[15] Each owner or occupant is likely to have different building requirements.[15]

Adaptability is a design principle that involves designing buildings in a way that meets the needs of the present, but also considers how those needs might change in the future. It considers how to accommodate these changes through periodic remodelling, reconfiguration or modification.[8] This can reduce whole life carbon through introducing circular economy principles and discouraging demolition.

However, adaptability could increase the upfront carbon emissions (emissions released caused in the materials production and construction phases, before the building is used) and cost of the building, and it may be difficult to account for future needs.[129] Despite this, some stakeholders have highlighted that the long term cost and carbon savings can be significant due to the reduced need to refurbish.[8]

Further discussion regarding repurposing buildings and reusing their components can be found in the 'End of life stage' section and a case study of building repurpose is detailed in Box 6.

3.3 Product stage

The most widely used materials and products in construction globally are concrete, timber, steel, and masonry. In addition to this, building services (the provision of power, heat, and water) use plastics and metals (such as copper) for piping, cables, and fixtures.

The embodied carbon of these materials varies depending on the source of raw materials, the production and installation process, the volume of material used, and the opportunities for re-use/recycle. Concrete, steel, and timber are amongst the most widely used building materials in the UK, so there is a particular focus on environmental optimisation for these categories. Experts recommend that comparisons between building materials should be made using a 'functional unit', rather than comparing emissions per unit mass.[109,110,131] This allows for functionally equivalent structures to be compared, and accounts for the embodied carbon emissions per unit mass as well as other factors such as the lifetime, maintenance requirements, material density and durability of the material.[131]

In the CCC's Sixth Carbon Budget, recommendations were made for the manufacturing and construction sector to meet net zero targets.[132] The CCC advised that "Government should set targets for ore-based steelmaking and cement production in the UK to reach near-zero emissions by 2035 and 2040, respectively".[132] The following sections summarize the existing sustainability achievements, challenges and targets for the concrete, steel, and timber sectors.

Concrete

Globally, concrete is the second most widely used commodity after water, with over 10 billion tonnes produced every year.[133] The UK has around 1,000 concrete production facilities with an annual output of 90 million tonnes, providing 95% of the UK's concrete demand.[79] The mineral products industry (of which the concrete sector is part of) contributes around £18billion to UK GDP and directly employs 74,000 people.[79]

Concrete is a popular building material due to its longevity, fire resistance and low maintenance requirements. Due to its high thermal mass and low conductivity, it can absorb heat in warmer weather and release it slowly in cooler temperatures.[134] This means it has the potential to reduce the energy required to heat and cool buildings, and reduce the risk of overheating.[135–139]

Cement is one of the key ingredients of concrete, the production of which is largely responsible for concrete's carbon footprint. Estimates suggest the global cement industry contributes around 8% of annual global CO_2 emissions.[133] In the UK, the Mineral Products Association report that concrete and cement production contributes around 1.5% of total annual CO_2 emissions.[79] While some other construction materials (such as steel) have higher carbon footprints per unit mass,[131,140] the emissions per functional unit (see above) and large amounts of cement consumed worldwide makes it a considerable contributor to CO_2 emissions and therefore a key focus for emissions reduction.[141–143]

The traditional form of cement is called ordinary Portland cement (OPC, also termed 'CEM I') and is the most widely used globally. Around 90% of the CO_2 emissions of cement production arise from the production of an ingredient of Portland cement known as Portland 'clinker', which is used as a binder in concrete. Ordinary Portland cement is made up of over 95% clinker.[144,145] Clinker is produced by heating up a mixture of limestone and clay in a kiln up to 1,450°C. Around two thirds of the emissions from clinker production are a result of unavoidable CO_2 being released during this chemical reaction (known as 'process emissions').[79] Further CO_2 emissions arise from the burning of fossil fuels needed to heat up the kiln.[79] Since CO_2 is an inherent by-product of the chemical reaction that produces clinker, strategies to reduce process emissions involve innovations in product formulation.

In the UK, Portland cement is often blended with other cementitious material to lower the Portland clinker content

In the UK, Portland cement is often blended with other cementitious material to lower the Portland clinker content (and hence its embodied carbon) and re-use waste products (see later).[146] According to the Mineral Products Association, in 2019 Ordinary Portland cement accounted for 51% of UK cement sales, with other cement types accounting for the remainder.[147]

According to a 2020 analysis by the Global Cement And Concrete Association, the amount of CO_2 emitted per tonne of cement produced globally has reduced by 19.2% since 1990.[148] However, this has been matched by a rise in global demand, mainly in developing nations.[133]

The UK concrete and cement industry, represented by the Mineral Products Association, has recognised the need for decarbonisation of all aspects of production, supply, and use. It reports that the industry has reduced its carbon emissions by 53% since 1990 through fuel switching, changes in product formulation, and energy efficiency.[79] Government data shows that more recently, the emissions reductions trajectory has been less pronounced, with a 10% reduction in total emissions from the manufacture of cement between 2008 and 2019.[149]

The Mineral Products Association's net zero roadmap outlines several ways in which the sector can further reduce the carbon emissions associated with cement production, and the sector's ambition to achieve net negative carbon emissions by 2050, with carbon capture technology making up a significant proportion of the planned reductions (see bullets below).[79] UK based professional institutions and building-related organisations, such as the UK Green Building Council, have also provided guidance and tools to help inform specifiers and designers of best practice design to reduce carbon emissions when using cement and concrete.[87,125,150] CEMBUREAU (the European trade association for cement manufacturers) and the IEA provide a European and international perspective, respectively.[151,152] Different approaches are favoured depending on the stakeholders developing the strategies. Strategies include, but are not limited to:

- **Reducing the volume of concrete and cement required** through more resourceful material use in building design and reducing the amount of cement in concrete via the addition of aggregates.[146,153]

- **Reducing the amount of clinker used in cement**.[152,154] This can be achieved through the use of substitutes (known as 'secondary cementitious materials'), such as fly ash (residual material from coal combustion) and blast furnace slag (a by-product of iron and steel production). The availability of both these substitutes is limited as they are by-products of processes which are either being phased out (coal) or replaced (steel) in the UK.[133,151,155] However, alternative binders such as calcined clay or powdered limestone could be used in their place.[133,151] Since the 1980s, clinker substitution has contributed on average to a 20-30% decrease in CO_2 emissions per tonne of cement produced globally.[133] In the UK, commercial cements are already produced with a significant proportion of clinker substitute.[156] For example, in 2018, 26.2% of the total cementitious materials used in the UK were secondary cementitious materials.[146] Examples of reduced clinker cements include CEM II cements, which contain up to 35% clinker substitutes such as calcined clay, limestone powder or fly ash, and CEM III cements which contain between 40-95% blast furnace slag as a clinker substitute.[144,154,157] Combining clinker substitutions can allow for higher clinker replacement levels.[133] 'Ternary blended cements' are those that contain Portland clinker and two other secondary cementitious materials. An example of a recent innovation in this area includes limestone calcined clay cement (LC^3), which contains up to 60% clinker substitutes of blended calcined clay and limestone.[158] Studies show that the clinker substitutions lead to reduced embodied carbon emissions compared to conventional Portland cement.[154] Cements containing clinker substitutes can have different properties depending on the type and proportion of substitute material. Some clinker substituted cements may be suitable for specific applications, referred to as 'niche' cements, as opposed to 'general use'. The British Standards Institution specify cements that are suitable for general use.[144] The International Energy Agency has set has set a global target for cements to reach an average of 40% clinker substitutes by 2050.[151] Experts have highlighted that increasing the use of secondary cementitious materials further is a significant challenge that will require regulatory and technical changes, as well as material and process innovation, particularly as the supply of certain substitutes, such as fly ash, will reduce following industrial decarbonisation.[133] It is also important to note that there is a limit to the proportion of clinker substitution that can be used.[159]
- **Using alternative fuels**. Cement kilns have historically relied on coal or coke (a solid product formed by heating coal to high temperatures in the absence of air) as their main fuel, however, in recent years cement producers have employed the use of alternative fuels including biomass.[79] In the UK, the latest figures from the Minerals Products Association show that 43% of the kiln fuel is now from waste-derived alternatives to traditional fossil fuel (such as waste packaging, processed sewage pellets, waste textile fibres or rubber tyres).[160,161]
- **Use of carbon capture and storage (CCS)** to reduce unavoidable process emissions. The Mineral Products Association's net zero roadmap places significant emphasis on CCS, estimating it will account for 61% of

the sector's planned direct emissions reductions to 2050.[79] However, as noted earlier, most CCS technologies are still at the early stages of development. Some stakeholders, including the CCC and IEA, have highlighted the risk associated with relying on CCS when it is still in infancy.[40,133,151] See Box 2 for a discussion of carbon capture technologies.

- **Using 'novel' cements.**[133,162] In addition to the clinker-substituted cements mentioned above, there are a variety of other types of lower carbon cement, which are generally non-Portland clinker based. These are produced using non-traditional alternative materials to limestone and are often referred to as 'novel' cements.[133,157,162,163] While some novel cements are commercially available, others are at earlier stages of development. Some examples are given in Box 4.

As some of these solutions approach a practical threshold (such as complete decarbonisation of the grid and maximising the use of clinker substitutions without requiring changes to production facilities), the need for technological developments in carbon capture technologies, and lower carbon cements (see Box 4) will become increasingly critical.

Despite the developments in novel low carbon cements, their large-scale uptake has been limited. Many of the standards, design codes and testing protocols for cement are based on traditional cement, creating a barrier for the application of novel products.[164] Access to materials may also be an issue for some novel cements, for example alkali activated cements rely on fly ash and blast furnace slag, for which there is a limited or diminishing supply.[133,155]

In addition, novel cements tend to also have more specific applications (known as 'niche' cements), meaning there is not one single replacement for Portland-based cements. In some cases niche cements can undergo rigorous UK-specific validation testing to provide the evidence base needed to approve them for general purpose applications.[165] Experts suggest that a better understanding of the required performance properties and adopting a toolbox approach using multiple cements can avoid over engineering and encourage resource efficiency.[133,166]

In addition to the above, the concrete and cement industry has called for 'carbonation' of concrete to be included in emissions accounting.[162] Carbonation is a natural process in which the exposed surface of concrete absorbs atmospheric carbon dioxide over its lifetime (and in secondary applications beyond its end of life). Carbon dioxide penetrates and reacts with the concrete, producing mainly calcium carbonate. Studies estimate that the amount of CO_2 absorbed by concrete in this way is around 10-15% of the total CO_2 emitted during concrete production.[167] This may be greater depending on what happens to the concrete at the end of its life (for example, if it is crushed after use in a building, it can absorb more CO_2 as it has a greater exposed surface area).[162,168]

Box 4. Innovations in cement

Novel low-carbon cements are non-Portland based and use alternative ingredients that provide similar properties traditional cement, but release fewer emissions during production.[145,162] Several cement producers have released products based on various different technologies. Some examples of innovations in this area include:

- **Alkali-activated** or geopolymer cements contain 90% secondary cementitious material as clinker substitutes (including fly ash, blast furnace slag or clay) that react readily in the presence of alkalis and water.[157,169] Their embodied carbon can be up to 90% lower than traditional Portland cement.[169] Short and unpredictable setting times have been a challenge for on-site use, although improvements are being made. These cements are available commercially on a relatively small-scale (including in the UK, Australia, US and China) and are used mainly for non-structural applications.[170,171] The use of these cements has been demonstrated for both on-site and pre-cast products.[169,172,173] The Association of Alkali-Activated Cementitious Materials (A3CM) is a UK-based industry body for manufacturers of alkali activated cements.[174,175]

- **Calcium sulpho-aluminate (CSA)** clinker contains ye'elimite as the main constituent, which reduces process emissions by around 40% compared to traditional Portland cement.[151] It has been commercially produced for more than 30 years, primarily in China, with recent developments making it more competitive with Portland cement for large scale applications.[151,157,169,176]

- **Magnesium-based** cements use a binding material derived from magnesium silicates and have the potential to counterbalance all process emissions while curing.[151] However, due to their early research stage, their industrial scale costs, energy demand, concrete properties and applications are not fully understood.[133,151]

- **Graphene additives** are another innovation being explored.[177] The addition of small amounts of graphene to cement has the potential to increase the strength of concrete, reduce the clinker content and improve durability of products.[178] Commercial use is yet to be demonstrated.

- **Carbon cured cements** absorb CO_2 as they set and harden which is stored permanently in the concrete.[133] Since these cements require a CO2 rich environment, they are often suited to pre-cast components. While current sources of CO_2 for this method are typically a by-product of crude oil cracking, it is hoped that CCUS technologies can be incorporated into the cement production process to reduce the carbon emissions of this process.[169] However, studies suggest emissions from the capture, transport and utilization of CO_2 are still significant.[179] As such, embodied carbon savings are still relatively low. Several products and processes are in development for specific applications but not yet implemented at industrial scale.[180–182]

The Mineral Product Association's net zero roadmap reported that carbonation of concrete has the potential to contribute to a 12% CO_2 reduction in the sector's total emissions.[79] However, the 2018 Global Carbon Budget Report (produced as part of a global research collaboration) stated that there is insufficient evidence to support inclusion of carbonation from the cement life cycle.[160]

The European Commission has plans for a new Carbon Border Adjustment Mechanism to be phased in from 2023. This would apply a levy on the carbon content of products imported into the EU market and will initially only apply to selected products including cement, iron and steel. The proposals are still being developed, and would need to comply with World Trade Organisation requirements.[183] The CCC has recommended that the UK develops longer-term options to apply its own border carbon tariffs or minimum standards for imports of emissions intense products.[184] In its February 2021 'Growing Back Better' report, the House of Commons Environmental Audit Commitee also recommended that the Government should investigate the merits of a Carbon Border Adjustment Mechanism.[185]

Steel

Globally, more than half of all steel is used in construction, of which 60% is used in buildings.[127] In the UK, 95% of all single-storey industrial buildings and 65% multi-storey non-residential buildings are framed in steel.[186] In 2020 the global steel industry produced 1,860 million tonnes of steel and contributed around 8% of annual global CO_2 emissions[187] and 2% of annual UK CO_2 emissions[149] (figures similar to the concrete sector). The UK steel industry produces 7.2 million tonnes of crude steel per year,[188] less than half of current UK demand, and directly employs approximately 34,000 people.[189]

The integrated steel works in Scunthorpe and Port Talbot are the two largest industrial sources of UK carbon emissions, emitting 10.4 $MtCO_2e$ in 2018.[37] Together, they manufacture 78% of UK-produced steel. A detailed report on the current status of the UK steel industry can be found in Commons Library Briefing 7317.[190]

Steel is typically produced by heating iron ore, coke and lime in a blast furnace. The coke is used as both a raw material in the reaction (to reduce the iron ore to iron, which is subsequently mixed with other components to form steel) and a fuel for heating the blast furnace.[190,191] The chemical reaction of reducing iron ore in the blast furnace leads to process emissions of CO_2. Most steel produced in the UK and globally is via the blast furnace technique.

Steel can also be produced in an electric arc furnace where scrap steel is used as the raw material and the furnace is heated using electricity. Electric arc furnaces typically emit less carbon because the process of melting scrap steel has a lower energy demand, and the furnaces do not use coke (instead using electricity as their source of power).[192] Since the process of producing steel via an electric arc furnace does not produce process emissions of CO_2, it is potentially a low carbon way to produce steel that does not require carbon capture.

However, although electric arc furnaces are efficient recyclers of steel scrap, they require large amounts of electrical power and water cooling, and their low carbon credentials rely on decarbonization of the electricity grid. There are also issues around steel recycling (see next section).

Options that are being explored to reduce carbon emissions from steel production include:[190,193]

- **Switching to lower carbon fuels and reducing agents** for blast furnace production, as alternatives to coke (for example, hydrogen).
- **Using carbon capture technologies** alongside blast furnace production to sequester emissions from continued coal use.
- **Improving the energy efficiency** of both blast furnace and electric arc furnace steel production processes.
- **Increasing the recycling rates** of other steel products (for example steel packaging) to increase the availability of scrap metal.[194]

In its 2021 Industrial Decarbonisation Strategy, the Government stated that two of the major decarbonisation options considered for iron and steel production sites in the UK include deployment of CCUS and use of electric arc furnaces

In its 2021 Industrial Decarbonisation Strategy, the Government stated that two of the major decarbonisation options considered for iron and steel production sites in the UK include deployment of CCUS and use of electric arc furnaces.[61] However, the Government and other stakeholders have also recognised that industrial scale carbon capture and hydrogen production technologies require further development to reduce their associated financial and technical risks.[12] In addition, increased use of electric arc furnaces requires increased availability of high quality scrap steel.[195] In its Sixth Carbon Budget, the CCC recommended that funding mechanisms are established to support the costs of both electrification and hydrogen-use in manufacturing.[132] It also recommended continued support for innovation and demonstration of fuel switching and CCS technologies.

To manage the transition to low carbon industries and protect jobs in traditionally high-carbon industry regions, a number of industrial decarbonisation projects have been established: The Zero Carbon Humber project aims to build a net zero industrial cluster in the North East by developing CCUS and low carbon hydrogen technology to support steel production; The South Wales Industrial Cluster will develop technologies and skills to support net zero targets including circular economy innovations, hydrogen production and CCUS, and; the SUSTAIN Future Manufacturing Research Hub explores a range of decarbonisation strategies for the steel sector, including digitalisation and energy efficiency.[196–198]

In 2019 the Government released a consultation on the Clean Steel Fund with the aim to identify the barriers to decarbonising the steel sector and the technology options required for clean steel.[193] Responses to the consultation highlighted that one of the main barriers was electricity prices.[193] They also highlighted that the three main decarbonisation technologies (switching to lower carbon fuels such as hydrogen, use of carbon capture technologies, and improving energy and material efficiency) required further development to reduce the financial and technical risks. The consultation reported that in the short term, more immediate decarbonisation gains can be made by maximising recycling and re-use capabilities.

Steel recycling

Steel is one of the most recycled materials. According to Tata Steel, 85% of global steel is recycled, and in the UK, 94% of steel is recycled when a building is demolished.[130,199] There is debate about the extent to which recycled steel can meet current global demand.[190,193,200] Some forecasts suggest that with today's rates of new steel production, along with recycling capabilities, the amount of scrap steel available globally for recycling will treble by 2050.[192] A 2018 OECD study predicted that the proportion of iron and steel produced through recycling (termed 'secondary production') will not change before 2060 due to growth in overall demand for metals (including from primary production) and growth in the amount of scrap metal avaliable.[194]

Scrap steel recycling uses electricity, and decarbonising of the electricity grid gives the potential for a virtually net zero steel recycling process.[201] However, industry experts have highlighted that the relatively high industrial price of electricity in the UK can act as a deterrent to the industry switching to a greater use of scrap recycling.[193] For example, in a 2021 report, UK Steel (an organisation that represents the UK Steel industry) said that options to decarbonise steel production all involve higher electricity consumption, and that the high electricity price is a substantial barrier to reaching net zero.[202] In its Sixth Carbon Budget, the CCC made recommendations around carbon and electricity pricing for decarbonisation in manufacturing, including that industrial electricity pricing should be reformed to reflect the much lower costs of supplying low carbon electricity in the mid-2020s and beyond.[34]

A further challenge with steel recycling is with the process itself; current recycling technologies using electric arc furnaces cannot remove some impurities such as tin and copper, which degrade the performance of the recycled material.[192] As a result, much of the steel recycling from cars (which contain copper) is largely downcycled to a material of lower quality and functionality. Industry and academic experts have highlighted that innovation is needed in recycling technologies to enable better recycling.[192] This can be partially addressed through novel sorting methods, 'CE markings', and the use of material passports (see later section on Modernising the construction process').[192]

Steel reuse

Steel products, particularly those used in construction, can be designed for direct reuse. Since reuse involves minimal reprocessing, the opportunities for net zero are higher than for recycling. The concept of 'Design for Manufacture and Assembly' is making reuse of steel components increasingly feasible by having standardised parts and designing structures that can be dismantled and repurposed (more information in 'End of life stage' section). Steel reuse is not yet common practice in the UK,[203] however the UK Government and UK steel sector are exploring this route, with work being led by the Infrastructure and Projects Authority, BEIS and companies such as Tata Steel.[130,204] One of the main barriers for steel reuse is the collection, storage, testing and certification of used steel components.[203]

The World Steel Association recognises that the production of steel is a carbon and energy-intensive activity.[187] It has said it intends to reduce emissions by increasing resource and process efficiency, maximising use of scrap, improving resource efficiency through circular economy principles, and investing in low carbon steel making technologies and CCUS (Box 2). The International Energy Agency's 2020 Iron and Steel Technology Roadmap analyses the impacts and trade-offs of different technology choices and policy targets for the industry to be in line with the goals of the Paris Agreement.[80] It provides key actions for Governments, industry, NGOs and financial institutions and states that the industry's direct CO_2 emissions must fall by more than 50% by 2050, relative to 2020. More information on decarbonisation of the steel industry can be found in section 5.5 of the Commons Library Briefing 7317.[190]

Timber

Timber is a commonly used building material in the UK, with 28% of new build homes using timber frames.[205] The CCC has recommended that the use of timber in construction grows to 40% by 2050 to increase carbon storage capacity three-fold.[205,206] Globally, around 3 billion cubic metres of timber is harvested from forests every year.[205] The UK imports over 60% of the 17 million cubic metres of timber it consumes annually, largely from Europe.[207] In construction, over 80% of the timber used is imported.[208] Most global production of timber comes from North America, Russia, China and Brazil and it is increasing over time to meet rising demand.[205] However, the World Bank estimate that global timber demand will quadruple by 2050, which may create challenges for sustainable timber production.[209] The IPCC state that deforestation is still one of the main human causes of climate change and advocate for sustainable forest managment.[210] The CCC has recommended that the Government develops a UK policy roadmap on the use of timber, including policies to support sustainable UK wood supply chains.[7]

Some of the most common wood-based products used in the structure of buildings are solid timber beams and engineered products such as joists, panels and trusses.[211] Modern timber products, such as cross laminated timber (CLT, a product made from perpendicularly stacked lumber board layers), have been developed to have a high and predictable strength and to be relatively light in comparison to other building materials.[212,213] Lower quality wood from forestry and sawmill residues is used to make wood-based panels such as chipboard and plywood.

Studies show that the production emissions from harvesting, drying and sawing the wood are less than those for steel and cement (for a functionally equivalent structural frame) and the carbon absorbed by the tree and stored within the wood can be greater than the production emissions.[141,142,205]

Construction systems using timber have also been reported to be time saving, which is considered the most significant benefit and biggest cost saving, although the cost of the raw material is often higher than other materials.[212] A 2018 study of 100 projects using CLT showed the overall construction time of a CLT scheme was 20% faster than an equivalent scheme in reinforced concrete.[212] However, this study did not cross compare the potential time saving measures of modern construction techniques that use concrete and/or steel (for example off-site construction of precast concrete and prefabricated steel modules).

The Institution of Structural Engineers has reported that timber must be used efficiently and be sustainably sourced (with replanting) to realise the potential embodied benefits of timber over concrete and steel.[142] It also recommends that the life of timber structures are prolonged, and end-of-life timber components are reused or recycled into new materials to keep sequestered carbon from being let out into the atmosphere.[142] The Institution of Structural Engineers also endorses forest certification schemes (discussed below). The CCC has reported that sustainably harvested biomass can play a significant role in meeting long-term climate targets, where it is used to store carbon from the atmosphere while also providing a useful energy service or product.[205]

The Timber and Timber Products Placing on the Market Regulations and UK Forest Law Enforcement Governance and Trade regulations outline the rules for importing and exporting timber products in Great Britain.[214] These regulations ensure harvesting practices are legal, encourage sustainable harvesting practices and support global forest governance.[215] The UK's Timber Procurement Policy was announced in 2000 (with periodic amendments) and specifies that UK public authorities are required to purchase legal and sustainable timber products or recycled products.[216 217]

Global certification schemes are available that can be used to demonstrate that timber products originate from forests that are managed in a sustainable and responsible way.[217,218] The two main certification schemes that the UK Government has approved as meeting its legality and sustainability criteria include the Forest Stewardship Council (FSC) and the Programme for Endorsement of Forest Certification (PEFC).

In its Clean Growth Strategy[219] and 25 Year Environment Plan[220] the UK Government committed to increase the use of timber in construction. Defra has also committed to providing financial support to:

- develop innovative timber products through the Forestry Innovation Fund;
- develop a policy roadmap on use of timber in construction;
- increase public demand for sustainably sourced timber;

- work with Homes England to increase timber use in the delivery of housing programmes, and;
- encourage research into barriers to the uptake of timber.[221]

Using more timber in construction is likely to require greater land use for timber production. There are several challenges associated with the creation of woodland, including economic viability, land tenure, and values and financing challenges

Although increased use of timber presents opportunities for carbon emissions reduction, there are several challenges associated with its use in construction. These include:

- **Land-use:** Using more timber in construction is likely to require greater land use for timber production. There are several challenges associated with the creation of woodland, including economic viability, land tenure, and values and financing challenges (see POSTnote 636).[222] There are also challenges associated with harvesting wood such as biodiversity loss.[223,224] In the England Trees Action Plan the Government outlined plans to protect and improve trees and woodland.[221] It also committed to support the use of timber in construction, including via provision of financial support to help develop innovative timber products. The CCC has said that strengthened governance is needed to manage the risks to sustainable production of biomass (which includes timber), as markets scale up.[205] Tree planting in the UK is discussed in Box 5.
- **Skills gaps:** Structural engineers and construction teams are only recently being trained to design and build with timber.[225] For example, a better understanding of the opportunities of using timber at scale is needed.[225] National skills in the management of hardwood forest and forestry wood science are in decline due to increasing levels of imported timber.[226,227]
- **Materials safety:** Following the 2017 Grenfell fire, a ban was introduced in 2018 on combustible materials in the external walls of residential buildings with a floor above 18 m,[228] which restricts the use of structural timber. Some stakeholders have said this has affected the uptake of timber in construction as the proposed ban does not differentiate between external cladding and the building's structural wall, causing technical specification problems.[229,230] Materials safety perceptions have also affected the availability and cost of insurance for timber framed buildings.[231–233] In 2020, the Government launched a consultation on proposed amendments to the combustible materials ban, including expanding it to hotels, hostels and boarding houses, and lowering the height threshold of the ban to 11 m.[234] The consultation closed in May 2020 and the Government response has not yet been published. In its 2021 Progress Report to Parliament, the CCC recommended that the Government clarifies the position of structural timber in the ban on combustible materials, underpinned by further research where needed to ensure there are no barriers to the safe use of timber in buildings.[7]
- **Whole life carbon assessments:** There is a difference in the way carbon sequestration (the process by which CO_2 is removed from the atmosphere and incorporated into the wood) is reported in whole life carbon assessments, depending on which stages are included in the calculations.[16] According to the RICS Professional Statement, if the assessment does not cover the end of life, then carbon sequestration

cannot be included when reporting the embodied carbon emissions for the product stage. If the assessment covers the full life cycle, then it can be included in the reported figures as sequestration in the product stage and emission at the end of life stage.[15] This is because the carbon stored by the wood will be re-released or transferred to the next product system during the end of life activities.[89,108,142,235] According to The Institution of Structural Engineers such activities may include recycling (which in 2017 was reported to be 55% by mass), incineration with energy recovery (44%), and landfill (1%)).[142,235]

Box 5. Tree planting in the UK

Sustainably managed woodlands can capture CO_2 from the atmosphere and store it as a component of the wood. The CCC has recommended the UK plants 30,000 hectares of broadleaf and conifer woodland per year until 2050 to support net zero targets.[236] In response, the Government has committed to delivering the CCC's recommended target by the end of this Parliament, spending over £500million of the £640million Nature for Climate Fund on 30,000 hectares of trees and woodlands in England between 2020 and 2025 as part of the England Trees Action Plan.[221] The England Trees Action Plan will also provide new UK Forestry standard practice guidance to minimise unintended damage to the environment from tree planting around the principle of 'the right tree in the right place' to 'deliver benefits for people, wildlife and the economy'.

Elsewhere in the UK, Scotland has a target to plant 18,000 hectares of trees per year by 2030 and Wales and Northern Ireland each have their own aims to plant at least 2,000 hectares of trees per year from 2020.[237–239] According to the latest figures from Forest Research (an executive agency sponsored by the Forestry Commission) between March 2020 and March 2021, 13,410 hectares of new woodland were created in the UK; 79% took place in Scotland, 16% in England, 2% in Wales and 2% in Northern Ireland.[240] As such, all nations are currently below their targets.

3.4 Construction stage

Reducing the carbon emissions associated with the construction stage of a building's life involves reducing the emissions associated with transport and construction machinery. In addition, there is increasing interest in achieving emissions reductions through new construction approaches and making better use of digital tools.

Embodied carbon calculations of buildings are usually based on the initial structural design, initial amount of materials ordered for a project, and the transportation associated with delivery. There may be certain issues that arise in the construction pipeline that are not accounted for in these initial estimates. For example, additional emissions can arise due to:

- Changes to design on-site, which result in the use of more material and/or higher embodied carbon materials.
- Materials waste from measurement error, over ordering of materials, or delivery rejects.
- The construction of temporary works such as offices and utilities.
- Rework to address design changes, errors and omissions, poor quality construction, or failing to initially meet building standards or client requirements.
- Materials supplied from a longer distance than originally calculated.

Some stakeholders (including the National House Building Council and Royal Institute of British Architects) have suggested that modern approaches to construction can partially help to address these issues.[241–243] However, other groups (such as the Green Construction Board) have highlighted concerns that some Modern Methods of Construction (MMC) approaches may increase overall resource use and therefore increase embodied carbon emissions.[50]

Transport and machinery emissions

The Green Construction Board estimate that the direct CO_2 emissions from construction transport (of people, equipment and products) and construction processes make up around 30% of a building's total embodied carbon.[244,245]

Construction vehicles and machinery, such as excavators, are typically powered using diesel. While opportunities for construction equipment to be powered by electricity and hydrogen cells are emerging (such as equipment produced by Hyundai,[246] Caterpillar,[247] JCB,[248] and Volvo[249]), there has not yet been a significant move to alternatives due to the high capital investment in existing conventional engine-based equipment. In addition, while the electricity grid is decarbonising, and electric vehicles emit fewer emissions than diesel, the carbon footprint of electricity and hydrogen production is not yet zero (almost all hydrogen production currently uses fossil fuels and results in the release of CO_2, see POSTnote 645).[250]

Some organisations, including BAM, Barratt Developments, and Taylor Wimpey, have included targets in their sustainability plans to reduce diesel use in construction equipment and use more efficient equipment.[251–253] As part of its targets for improving air quality, the Government looked at how to encourage users of diesel-powered mobile machinery in urban areas to switch to cleaner altneratives.[254,255]

London's 'Low Emission Zone' also includes emissions-reduction targets and standards specifically for construction equipment.[256] The standards will get progressively tighter over time until January 2040, when only zero emission machinery will be allowed.[256] In Oslo, Norway, the first zero-emission construction site launched in 2019 through the use of electric machinery, and the city requires all construction sites achieve zero-emissions by 2025.[257,258]

Modernising the construction process

Modernising the construction process includes using off-site manufacture and digital technologies to increase productivity, improve resource efficiency, and contribute towards reducing whole life carbon.

Unlike the UK manufacturing and services sectors, the construction sector has not seen a significant increase in productivity since 1995.[242] It is anticipated that modernisation of the construction process will improve productivity in this sector.[242] The Cambridge Centre for Smart Infrastructure and Construction has said that modern approaches to construction have the potential to make a significant impact on the efficient use of existing infrastructure as well as new builds. It has estimated that this presents an opportunity worth up to £4.8trillion globally.[259]

The Government has made various previous commitments to support modernisation of the construction sector. For example, in its 2017 Budget, the Government said that five central Government departments would support off-site construction of publicly owned assets to drive the modernisation of the construction sector.[204,260] As part of this commitment it launched the Transforming Infrastructure Performance programme, which aimed to improve the performance and delivery of publicly owned infrastructure assets.[261]

More recently, in its 2020 National Infrastructure Strategy, the Government stated its intention to “transform the construction sector” including through better use of data and Modern Methods of Construction (MMC, see below).[47] The Government’s 2020 Construction Playbook also supported off-site construction and digitalization technologies for public sector building works and programmes.[9,47]

The use of MMC is a broad field that encompasses a variety of off-site manufacturing and on-site construction techniques, often underpinned by digital technologies such as Building Information Models (BIM), Digital Twins, and material passports (see below). The use of these digital technologies is not exclusive to MMC approaches, and they can also be used alongside traditional building methods. Experts have said that digital design approaches should play a more central role in construction.[204]

- **Modern Methods of Construction (MMC)** is a term that refers to a range of innovative off-site manufacturing and on-site construction techniques that provide alternatives to traditional building methods. The Government has broad support for MMC. The Ministry of Housing Communities and Local Government’s MMC Joint Industry Working Group defines seven categories of MMC, which cover a range of techniques from pre-manufacturing of 2D and 3D structural systems (such as floor panels) to 3D printing or pre-casting building components (such as staircases).[262]

When used appropriately, MMC has the potential to improve resource efficiency, build quality, environmental performance, and the predictability of delivery timescales. MMC can also be well suited for alternative sustainable building products which require precision engineering and provides the opportunity for made to order products. The Waste and Resource Action Programme (WRAP, a sustainability charity) have estimated that MMC can reduce energy use in the construction process by 67%[263] and on-site waste production by 70–90% compared to traditional construction methods.[264] However, some studies show that MMC can increase overall resource use due to the need for stronger structures to enable transport and lifting.[265] Other groups have also raised concerns that the materials and systems adopted by MMC are largely imported and undermine the British masonry industry as well as other traditional construction skills groups.[266] Some experts highlight that more investigation is needed to consider the impact of transporting pre-fabricated components to site compared with standard on-site alternatives.[129] Other challenges include a lack of robust supply chains for MMC homes and a lack of data on their long-term durability in the UK. This is a barrier to housing industry stakeholders engaging with MMC schemes. Several reports have also noted negative public attitudes towards MMC, due to perceptions based on historic projects that MMC-based products are of lower quality.[267–269] This may also be a barrier to greater uptake of MMC.[264] In 2017, the National House Building Council (NHBC) launched an online MMC hub to support house-builders using MMC, and in March 2021, Homes England launched a research study to assess the impact of MMC on the delivery of news homes, which included research into its embodied carbon impacts.[270]

- **Platform approach to Design for Manufacture and Assembly (P-DfMA)** is a process that uses digitally designed building products and components that can be used across multiple types of buildings. Standardised design minimises the need for bespoke components and can enable large-scale automated manufacturing, which takes advantage of economies and efficiencies of scale. In a 2020 consultation, the Government outlined plans to adopt P-DfMA in public sector infrastructure projects.[204] However, during the consultation some experts raised concerns over intellectual property of products using P-DfMA, and the future of procurement pipelines for P-DfMA components.[204]
- **Building Information Models (BIMs)** are digital representations of every aspect of a built asset that include physical and functional characteristics.[271] BIMs can be shared between stakeholders involved in a building project to facilitate design, construction, and operation processes and form a reliable basis for decision making throughout a building's life cycle. The UK's BIM Framework sets out the overarching approach to implementing BIM and provides tools and resources.[272]
- **Digital Twins** are digital representations of physical objects; for example a BIM of a physical building acts as a digital twin.[273] Data from the physical building can be fed into the digital twin to enable better operation, maintenance, planning and delivery of buildings.

- **Material Passports** are electronic data sets containing the physical and environmental characteristics of building materials and products. They may include information on tensile loading, Environmental Product Declaration (EPD) data, and biodegradation and can be updated over the life of a building. Data contained in material passports can help construction companies make decisions about whether and how a building material or product should be reused or recycled. They can help to reduce waste and facilitate a circular approach to construction. Material passports may be used alongside BIMs and digital twins. The Office for National Statistics is leading on the National Materials Datahub initiative (alongside BEIS and Defra). The project is developing the data infrastructure necessary for a circular economy.[274] The first objective is to understand critical supply chains, with the ultimate goal of tracking all stocks and flows of materials in the UK and their embodied carbon.[275]

3.5 In-use stage

The in-use stage of a building accounts for the carbon emissions associated with the use, maintenance, and repair of a building, as well as the refurbishment and replacement of components (see Figure 2). While the operational carbon emissions are also relevant at this stage, this section focuses on the embodied carbon emissions during a building's use. Some strategies to reduce operational carbon emissions were discussed in the earlier section on 'Operational carbon emissions'.

Use, maintenance, and repair

The carbon emissions resulting from the use, maintenance, repair, refurbishment, and replacement of building components are also classed as embodied carbon emissions. Depending on building typology, and material choices, these can make up 10-45% of a building's embodied carbon emissions.[41] For example, estimates suggest that for a small house, 14% of the embodied carbon emissions arise from maintenance and replacement activities, compared with 45% for commercial offices.[41] The building components that typically contribute to the embodied carbon emissions at this stage include (but are not limited to): mechanical, electrical and plumbing (MEP) systems; finishes; furniture, fixtures and equipment (FF&E), and; retrofit products such as the fitting of insulation and on-site renewable energy systems. The London Energy Transformation Initiative reports that these components are typically replaced 2-3 times during the 60 year lifespan of a building.[41]

A wide variety of materials are used for in-use building components, including copper for pipes, plastic for electrical cables, textiles for soft furnishings and timber for fitted furniture. The Chartered Institute of Building Service Engineers (CIBSE) has recently published an embodied carbon calculation methodology for MEP systems, which includes guidance on using Environmental Product Declarations (EPD).[39]

To reduce embodied carbon impacts at the in-use stage, the UK Green Building Council recommends the following:[1]

- Select materials with high levels of durability and low through-life maintenance.
- Design to allow easy reconfiguration/remodelling of the building to meet changing needs.
- Design to allow the easy replacement of components when required.
- Develop a proactive maintenance, servicing, and repair strategy.

Replacement and refurbishment

As mentioned earlier, it is predicted that around 70% of the total UK building stock will still be in use in 2050,[20] much of which has been reported to be some of the most inefficient and oldest in Europe.[22] Around 15% of the UK's total carbon emissions come from heating homes.[37,276]

It is predicted that around 70% of the total UK building stock will still be in use in 2050, much of which has been reported to be some of the most inefficient and oldest in Europe

Retrofitting involves the addition of components not included in the original construction process, which are incorporated to update a building and make it more energy efficient. Retrofitting can also improve a building's ventilation, safety, security and accessibility.[277] Retrofitting may also be necessary to meet climate change adaptation requirements such as reducing risk of overheating, storm damage or improved flood resilience.[7,278] Retrofit projects can vary significantly, but may include installation of insulation, installation of double or triple glazing, improving air tightness and the addition of renewable energy systems such as solar panels or solar thermal heating. As well as often improving a building's operational carbon emissions, retrofitting can achieve embodied carbon savings by making buildings more suitable for re-use and preventing the need to demolish and re-build. Various stakeholders including the Architects Climate Action Network[56] and the UK Green Building Council[8] have advocated for prioritising retrofitting of existing buildings over demolishing, where possible.

The materials and processes required to retrofit a building also have their own associated embodied carbon emissions. A whole life carbon approach to retrofit identifies the best combined opportunities for reducing whole life carbon by avoiding any unintended consequences by accounting only for operational carbon emissions.[276] This is achieved by calculating a 'payback time' for retrofit products. This refers to the number of years the product would have to be used until its upfront embodied carbon emissions are balanced by the savings in operational carbon emissions. For example, a study into solid wall insulation of the Victorian housing stock in England showed that the carbon payback time of all eight insulation materials measured was less than 23 years in the worst-case scenario, and less than one year in the best-case scenario.[279] Both are considerably shorter than the service life of the insulation materials and are therefore a viable option for carbon savings. For other retrofit products, such as some solar photo-voltaics[280] and triple glazing,[276] the embodied carbon associated with their manufacture and installation can be greater than the operational benefit they offer.

To tackle operational carbon emissions, the UK Government is aiming to install 600,000 heat pumps per year by 2028 (this includes retrofitting existing buildings and including heat-pumps in new builds).[12] In the 2021 Budget, the Government pledged continued support for heat networks in England, with £338million of funding to encourage private investment.[25] To reduce heating demand, the new Future Homes Standards (discussed earlier) outlines plans to improve the minimum insulation requirements of new buildings.[14] In the Future Buildings Standard the Government has stated its preferred option for reducing operational carbon emissions of non-domestic buildings also involves improved insulation requirements.[30] The Royal Institution of Chartered Surveyors recommends that low carbon technologies are supplied simultaneously with an energy efficient building fabric to be both effective in cost savings and emissions reductions.[276] A study assessing the importance of whole life carbon in the use and selection of heat-generation equipment (such as air source heat pumps) also recommended that measures to reduce heating demand should be introduced alongside heat pumps.[281] Other retrofit strategies to reduce operational carbon emissions are discussed in the 'Operational carbon emissions' section.

3.6 End of life stage

When a building has reached the end of its life it can be retained for re-use, repurposed, disassembled or demolished. Opportunities for introducing carbon savings for all options are being explored by the building sector. Many stakeholders including the Royal Academy of Engineering and UK Green Building Council have said that the priority at the end of life stage should be to reuse buildings where possible.[1,2] The Royal Academy of Engineering has also said that there should be more consideration of the carbon benefits of retrofitting during a building's planning stage.[2]

The UK Green Building Council recommends that existing buildings are retained, new buildings are designed for repurpose and/or disassembly, waste materials from demolished buildings are diverted from landfills, and energy efficient demolition equipment is used.[1] It has also published circular economy guidance for construction companies to try and reduce the significant volumes of waste generated by the industry.[8] There are an increasing number of projects looking into implementing circular economy principals.[282] For example, the European Project BAMB (Buildings As Material Banks) demonstrates how flexibly designed buildings can contribute to a circular economy by reducing waste and using fewer raw materials.[283]

In 2018, 138 million tonnes of waste was generated from construction, demolition and excavation in the UK – equivalent to 62% of the UK's total annual waste.[284] The Resources and Waste Strategy for England aims to eliminate all avoidable waste (including waste from the construction sector) by 2050.[285] In July 2021, the Green Construction Board, supported by Defra and BEIS, published a Routemap for Zero Avoidable Waste in Construction.[50] The report outlines opportunities for waste reduction at all stages of the construction lifecycle, and identifies actions for construction sector stakeholders, including the Government.[50] Currently, over 90% of all construction and demolition waste is recycled or recovered (for example as recycled aggregate).[284] Excavation waste is often used to restore quarries and other mineral sites.[284,286]

However, there are challenges associated with maximising the value of demolished materials, and this is an active area of research and development.[287] An example of a recent innovation in this area includes 'smart crushing' of demolished concrete, which can extract clean aggregate and sand. Chemical processing of these products ensures the resultant cement paste can absorb and store CO_2.[287] Steel from demolition projects can be reused through design for disassembly methods (see later). Many stakeholders, including the Institution of Structural Engineers, suggest that material reuse with minimal re-processing is a promising strategy for improving the material efficiency of the built environment.[2,8,49,203] They also recommend that to keep sequestered carbon out of the atmosphere, the life of timber structures are prolonged, and end-of-life timber components are reused or recycled into new materials, rather than incinerated with energy recovery (which in 2017 was reported to be 44% by mass).[142]

To enable effective disassembly, a building must be designed in such a way in that each component can be removed and re-used. Digital twins can capture the loading forces throughout the life of a component, and material passports (if regularly updated and maintained) can provide an up-to-date digital record of the material properties of individual building components (see 'modernising the construction processes' section). Together, these enable different parts of a building to be recovered, recycled, and reused. In the Netherlands, tax incentives exist for developers who register material passports for their buildings, in line with its ambition to achieve a circular economy by 2050.[288] In the UK, The London Plan requires planning applications for buildings in London to include a circular economy statement, which demonstrates how the building components can be disassembled and reused.[65]

Many experts have highlighted that since the majority of the embodied carbon of a building is associated with the structure, there are significant carbon saving opportunities for repurposing buildings, rather than demolishing them.[126] Hence materials with a long design life may offer significant carbon savings. A case study of a building repurposing project is outlined in Box 6. Refurbishments that replace a building's façade can update its appearance and improve operational carbon emissions, however they are not always cost effective. This is in part due to VAT costs associated with refurbishment, repair and maintenance, (which do not apply to demolition and new-build, including housing).[289] Some campaign groups and professional institutes are calling for VAT exceptions on building repairs and alterations.[3]

Box 6. Circular economy in construction case study: 1 Triton Square, London

The 1 Triton Square refurbishment is a private sector led project that aimed to use circular economy principles to repurpose a six story 1990s office building, at 1 Triton Square in London. It has achieved a BREEAM Outstanding rating by maximising retention and reuse of the existing structure and façade and is due to open in mid-2021.[290]

Structural reuse and strengthening strategies were made possible through the existence of extensive building information records. This enabled three additional storeys to be added to the existing building and the central atrium to be partially filled which increased the floor area by 70% and diverted 99.5% of building waste.[290] The embodied and operational carbon savings are estimated to be 56% and 43% respectively, compared to a typical commercial new build.[291] Analysis of the project found that it was more cost and time effective than a demolition-and-rebuild alternative.[292]

4 Skills

Meeting net zero targets in the building and construction sector requires innovation, increased efficiencies, and a mix of new skilled jobs. Some stakeholders have raised concerns that there is likely to be a skills shortage in the building and construction sectors.[293,294] For example the Construction Industry Training Board estimate that the equivalent of 350,000 new construction-related roles need to be created by 2028 in order to achieve net zero emissions by 2050[295] (in addition to the 2.7 million already employed in the sector).[294] Some experts have also highlighted that there is likely to be increased demand for skills in the supply chain for construction materials, products and assemblies, and professional services such as management, architecture, engineering, and surveying.[294]

To address this forecast skills gaps, the Construction Skills Network (part of the Construction Industry Training Board, an executive non-departmental public body that reports on the UK construction economy and labour market) has said that sustained Government investment in skills is needed to support the industry.[293] It has also emphasised the need for greater certainty on the pipeline of work for economic and social infrastructure and has recognised that the industry must present clear pathways of entry and progression.[293]

Existing Government support for construction sector skills includes the Construction Leadership Council's Talent Retention Scheme, which was conceived to help individuals showcase their expertise and help businesses find the skills they need.[296] The scheme provides a portal through which candidates can register their CV and search for vacancies and businesses can promote opportunities.

The Green Jobs Taskforce forms part of the Government's plan to achieve net zero emissions by 2050 and create 2 million green jobs by 2030.[297] Between November 2020 and July 2021 the taskforce gathered evidence on the skills needed in the green economy and reported back with a set of recommendations for how government, industry and the education sector can meet the identified challenges.[298] 15 recommendations were made across three key themes:

- Driving investment in net zero to support good quality green jobs in the UK;
- Building pathways into good green careers;
- A just transition for workers in the high carbon economy.

BEIS has granted £6.4million to the Green Homes Grant skills training competition to support training opportunities for energy efficiency and low carbon heating supply chains to deliver works and scale up to meet additional consumer demand.[299] 18 organisations made successful applications and are now delivering training.

As part of its ‘Lifetime Skills Guarantee’ programme, since April 2021 the Government is offering adults without any A level qualifications or equivalent to undertake a fully funded ‘level 3’ qualification (equivalent to A level qualifications) from a choice of courses, including qualifications in building and construction.[300]

The Government’s 2021 Budget highlighted that green jobs will play a key role in meeting net zero targets and support the levelling up agenda.[25] However, the Commons Environmental Audit Committee (EAC) has warned that inconsistent Government policy on green jobs, a lack of an agreed definition of a ‘green job’ and a knowledge-gap in necessary skills are resulting in missed opportunities.[301] The EAC has called for the Government to produce a detailed, actionable delivery plan.

The Royal Academy of Engineering’s Education and Skills Group is working to change the way that professional engineering institutions accredit university courses. Proposed changes will ensure that accredited courses include teaching on whole life carbon.[302] Professional institutions are also raising awareness of whole life carbon by updating their chartership schemes and many organisations are providing courses on life cycle assessments and environmental product declarations (see ‘Whole life carbon assessment’ section).

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