Whole Life Carbon Guidance for Offsite Construction

Report from the Supply Chain Sustainability School Offsite Leadership Group

Foreword

Forget all our other day to day challenges, it is climate change that we must focus on. The business case is clear and with investors, clients, building regulations and public policy all going in one direction it is down to us as an industry to take action.

Why us? Simply put, the buildings and infrastructure that we build and operate are significant contributors to the climate emergency, with direct control over 25% and influence over 42% of the total carbon footprint of the UK. We need to become part of the solution rather than just being the problem. In my opinion if we continue to build as we always have done, we'll get the same results.

Modern methods of construction (MMC) offer an opportunity to build differently and this report aims to pull together evidence on how the use of MMC can help us tackle the climate emergency. The first step for me, though, is that our industry needs to collect the data of the carbon embodied in the materials we use. This seems at first sight an easy task, and it's certainly easier to do in a manufacturing unit than on a construction site, but challenges remain in getting details from the supply chain. Seemingly it is only a few offsite manufacturers who routinely collect this information.

Once we know our carbon footprint, we can design and procure out carbon in a process I would call 'carbon engineering'. With the growth of renewables, the in-use emissions from the buildings we manufacture is falling dramatically, subsequently increasing the focus we need to place on embodied carbon.

This does not mean we should ignore emissions from buildings when occupied. Again, we need to collect data to ensure that the assets we build perform as intended and plug that into our design processes. With the switch to renewables, operational carbon will reduce over time, but energy costs are high so our buildings must be much more energy efficient.

The good news is we can do this. This report provides you with examples of where our industry is making a difference and that begs the question "should you act now and make a difference or be left behind as your customers transition to a low carbon economy?".

Ian Heptonstall,
Director, Supply Chain Sustainability School

How to use this document

This guidance is framed around the life cycle assessment modules described in BS EN 15978:2011, also utilised for other construction industry guidelines such as the RICS Whole Life Carbon Assessment. This breaks the construction lifecycle down into stages and modules to enable environmental impacts to be assessed and allocated to each.
A full definition of the terms that we use is available in the Glossary on page 22.

This document is intended to bring together experience and evidence from the offsite sector on carbon reductions into one place. There are many technical documents which can aid in designing out, measuring and reporting carbon which we signpost throughout.

We have developed this guidance to provide support to both building and infrastructure projects, however not all the interventions we describe will be applicable across the board. Similarly, we have endeavoured to cover multiple MMC categories and systems and have indicated differences which might arise between them in terms of their carbon reduction potential.

Out of scope of this report, but extremely important in building and infrastructure design fit for our time, are the planning elements which enable zero carbon access such as charging points; proximity to public transport connections and walkability; landscaping for biodiversity and natural flood protection; and installation of on-site renewable energy generation. We have omitted these considerations here as they are not materially affected by the choice of construction method.

Acknowledgements

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Contents

Executive summary

Stage	No.	Opportunity
PRODUCT STAGE A1-A3	1	**Reduced material needs** – through designing out waste, better procurement, and optimising the use of materials
	2	**Process improvement** – a repeated process allowing manufacturers to drive efficiencies
	3	**Decarbonising factories** – currently more straightforward than on a construction site
	4	**Use of innovative low carbon materials** – examples of good practice exist
CONSTRUCTION STAGE A4-A5	5	**Faster build** – can lead to 30% less site energy use
	6	**Fewer vehicle movements** – can lead to 20% reduction of transport for materials, building elements and worker transport
IN USE STAGE B1-B5	7	**Design for maintenance** – maximising the asset life of the systems and structure of the building or facility
OPERATIONAL CARBON B6-B7	8	**Better performing buildings** – up to half the energy use compared to traditional buildings
	9	**Industrialisation of retrofitting** – re-use of existing buildings is inherently a lower carbon solution. Industrialisation of retrofit solutions has proven to provide significant emissions savings

ENABLERS

Key actions for clients, designers, manufacturers, and assembly teams to take advantage of these opportunities.

- Leadership and Strategy
- Designing and procuring out carbon
- Effective collection and use of data
- Encouraging and applying carbon reduction techniques
- Collaboration and knowledge sharing

Our research has revealed that nine significant opportunities exist for the offsite sector to help drive decarbonisation in construction projects, both new build and in the retrofitting of existing assets.

Evidence exists of clients, design teams, contractors and manufacturers reducing carbon using offsite methods, but this is far from consistent across the industry. To take advantage of these opportunities we have identified key enablers for organisations: to show leadership, design and procure out carbon, advocate for carbon reductions across the project life cycle, collect and use data effectively, and collaborate across roles.

There are some specific features of offsite projects which may result in increases in embodied carbon, which project teams should consider and work to balance with savings elsewhere. These include:

- Elements having superfluous material mass for their specific use due to a standardised rather than tailored approach
- Additional structural elements being added to enable the transporting and lifting of units
- Need for careful planning of logistics. If lacking; double handling, the transportation of air, storage and damage, and extensions in build time result in carbon increases

Data is key in informing the business case for offsite construction and optimising designs at the early stages of the project. Manufacturers and contractors should collect and communicate activity data (materials, fuel use, energy consumption) in the first instance, be prepared to share this with clients and main contractors, and work towards the use of EPDs for communication of embodied carbon.

In summary, there is evidence that offsite construction can provide whole life carbon reductions, support retrofit efforts, and produce good quality assets which perform to high energy performance standards. However, there is significant room for improvement around collection and sharing of data, integrating this back into designs, and taking full advantage of opportunities to design with a focus on circularity.

End of life (C1-4, D)

Although there are examples of projects which have been designed for disassembly, and theoretically the opportunity is clearer for manufactured buildings, this represents an opportunity for carbon savings in the long term; outside of the short timescale in which we need to reduce emissions. There are also few real-world examples of offsite buildings which have been disassembled and reused, besides temporary buildings. We recommend developing disassembly plans and enabling a thread of digital information to be shared, but do not include this as a specific carbon saving opportunity for the offsite sector.

1. Introduction

1.1 Carbon in the built environment

Buildings and infrastructure are a significant contributor to the climate emergency, with direct control over 25% and influence over 42% of the total emissions footprint of the UK[1]. In recognition of this, the United Framework Convention on Climate Change has stated that globally by 2030 all new buildings should be net-zero carbon in operation, and embodied carbon must be reduced by at least 40%.

Understanding whole life carbon is crucial to mitigating the impact of built assets and the standard approach to categorising life cycle impacts is shown in Figure 1.

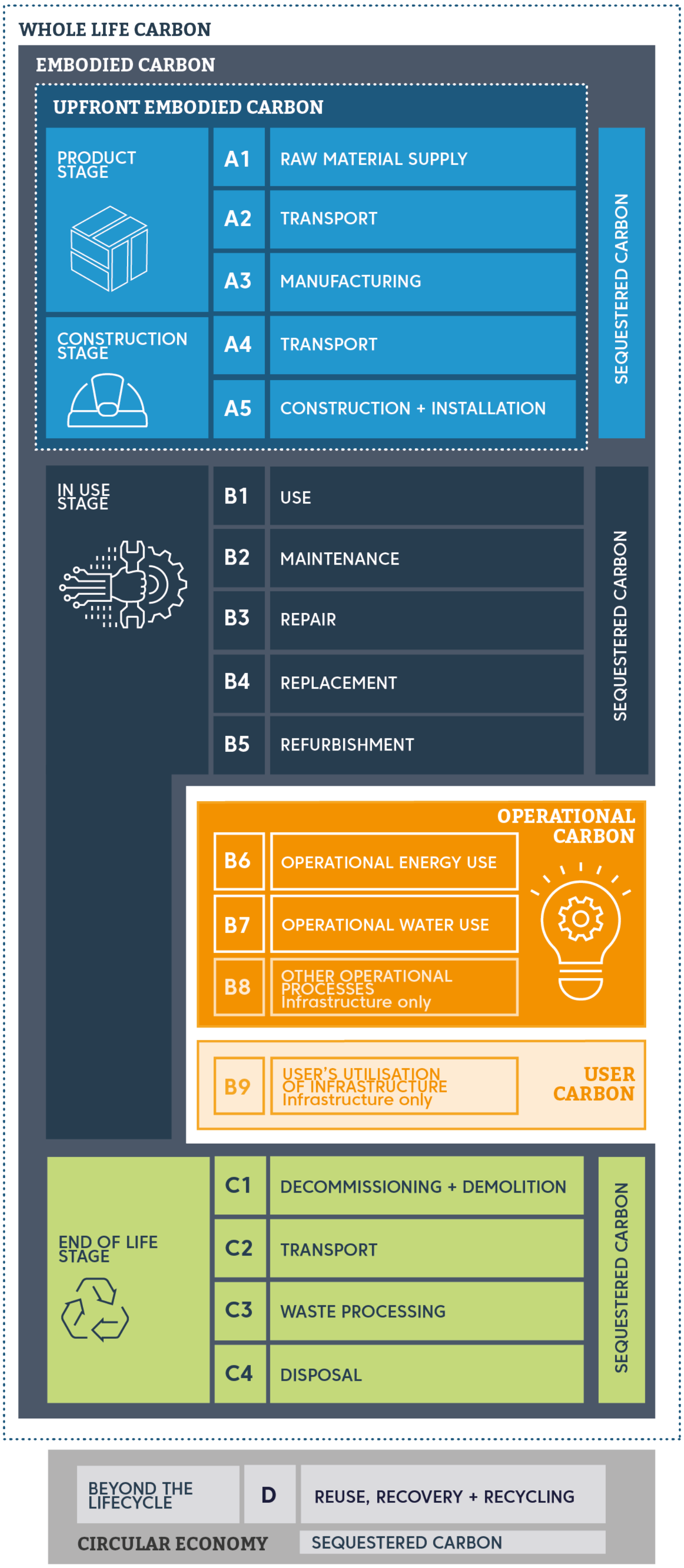


Figure 1: *System Boundaries, Life Cycle Assessment Stages and Modules, from LETI Carbon Definitions for the Built Environment, Buildings and Infrastructure[2], adapted from BS EN 15978 and PAS 2080 (for infrastructure)*

1 *UKGBC, 2021, Net Zero Whole Life Carbon Roadmap, available here*

2 *LETI, WLCN and RIBA 2021, Improving Consistency in Whole Life Carbon Assessment and Reporting, available here*

At present, operational carbon is the biggest contributor to emissions for average buildings compared to embodied carbon (Figure 2). For infrastructure, the carbon emitted by users during operation of the asset (UseCarb) is most commonly the biggest hotspot, responsible for between 75-98% of the whole life carbon of water, energy and transport assets[3].

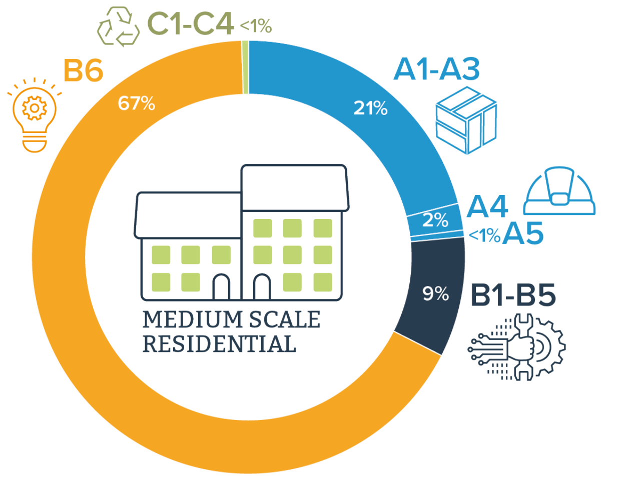


***Figure 2:** Breakdown of whole life carbon by life cycle stage for a typical medium scale residential project build to Building Regulation levels of operational energy. From LETI Embodied Carbon Primer.*

However, a huge amount of carbon is also emitted in the production, construction and maintenance of built assets. For a building designed to best practice energy performance standards, embodied carbon can contribute over 75% of whole life carbon[4]. The significance of embodied carbon will become more common as standards for operational energy and carbon performance in buildings increase and the grid decarbonises.

This pattern is also seen in the infrastructure sector, with emissions from building and maintaining assets (capital carbon, or CapCarb) increasing by 60% in absolute terms between 2010-2018, while operational (OpCarb) and UseCarb emissions fell. For certain infrastructure assets, such as flood defences, CapCarb is already a primary hotspot.

Focusing on this embodied carbon, Figure 3 illustrates the life cycle hotspots of key building typologies and elements. The product stage (manufacture of building materials and elements) and the in-use stage (when elements are replaced or maintained) are typically the most carbon intensive. Transport and construction (A4, A5) emissions usually account for just 5% of the embodied carbon of a building[5].

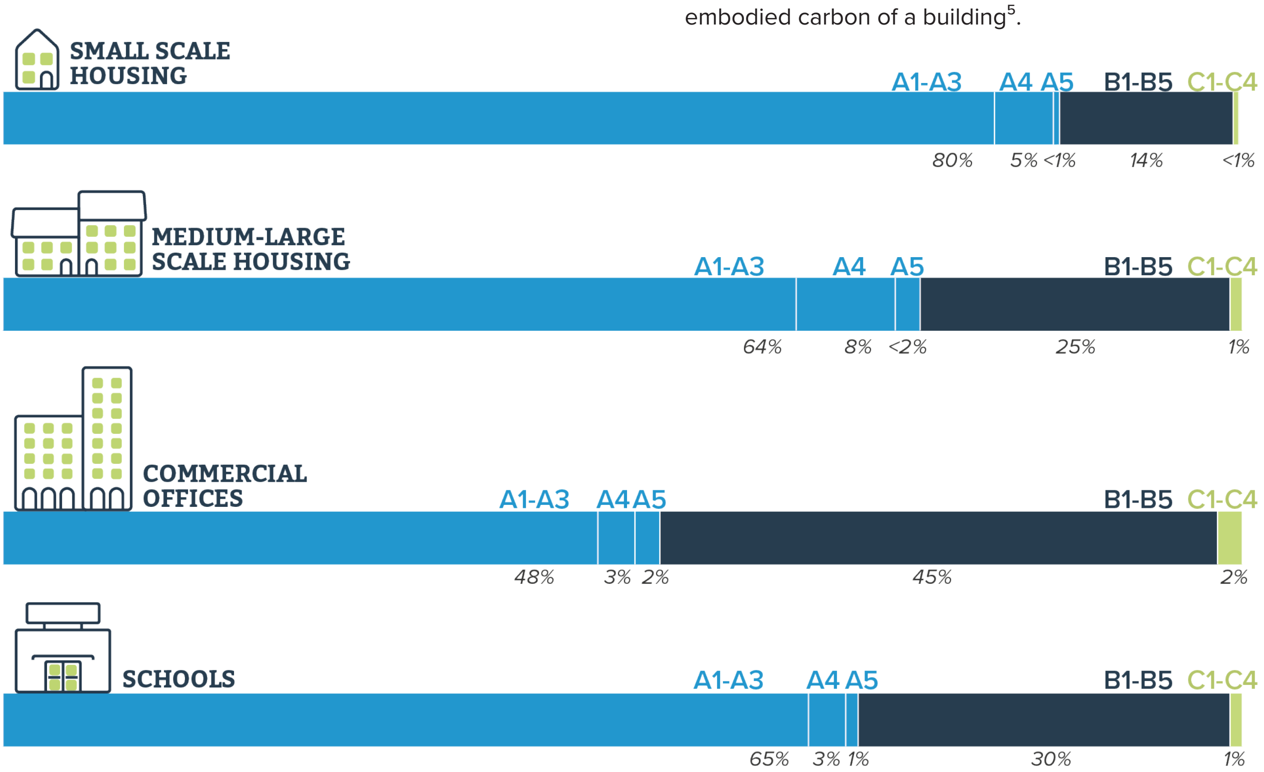


***Figure 3:** Where are the hotspots for embodied carbon?*

3 *Institution of Civil Engineers, 2020, Infrastructure Carbon Review 2020 Data Update, available here*

4 *LETI, 2020, Embodied Carbon Primer, available here*

5 *LETI, 2020, Climate Emergency Design Guide, available here*

So how can we reduce the carbon footprint of the built environment? The concept of the carbon hierarchy is a good place to start and underlies a number of low-carbon guides, including LETI Climate Emergency Design Guide and UKGBC Advancing Net Zero materials[6]. This emphasises the importance of avoiding use of energy and materials in the first instance (i.e. does the building need to be built?), then minimising and decarbonising any necessary energy or material use. Applied to operational carbon in buildings, taking a 'fabric first' approach illustrates the avoidance of energy use at the outset. This entails maximising air-tightness, increasing insulation and optimising natural ventilation, heat and lighting.

Because the range of available choices diminish as projects develop, the decisions we make at the design and procurement stages have a significant impact on both the embodied emissions and the operational energy use of the building, or asset, over its lifetime.

Although the construction industry has a significant role to play in meeting national carbon reduction targets, industry actions are influenced by an ever-changing landscape of grid decarbonisation, technological progress and regulatory change. Although some promising legislation to regulate embodied carbon seems on the horizon, through the Carbon Emissions (Buildings) Bill[7], possible consultation on whole life carbon assessments[8] and industry proposals to amend Building Regulations[9], at present it is clients and design teams that are best placed to drive best practice in whole life carbon reduction. Innovative materials suppliers and manufacturers must support these efforts by making low carbon building technologies available.


Photo credit: HTA Design, Tide Construction and Vision Modular Systems


Photo Credit: ZED PODS Ltd

Photo credit: Fourfifteen & Nordan, for Roderick James Architects

6 *UKGBC - Advancing Net Zero, available here*

7 *Carbon Emissions (Buildings) Bill, available here*

8 *Environmental Audit Committee, 2022, 'Carbon assessments of buildings and targets to boost low carbon construction could come within years', available here*

9 *Part Z, available here*

1.2 Offsite and modern methods of construction

This report discusses carbon reduction in the context of construction industrialisation, that is in utilising manufacturing and digital technologies to improve efficiency, supplementing and sometimes replacing traditional on-site construction methods. We define offsite construction as methods where elements that make up built assets are prefabricated and assembled rather than constructed onsite.

The term modern methods of construction (MMC) encompasses offsite construction, but extends to include site-based materials and process innovation. Typical material genres used in MMC include mass engineered timber, timber frame, light gauge steel frame, hot rolled fabricated steel, and precast concrete. The MMC Definition Framework details the different categories which can be used in designs from 3D and 2D primary structural systems (Categories 1 and 2) to non-structural assemblies and sub-assemblies (Category 5) to site-based productivity aids like workface robotics and drones (Category 7)[10].

Including the manufacturing of building elements in projects impacts the distribution of carbon across the construction life cycle and changes the way carbon can be managed. Firstly, increasing the proportion of elements of a building which are made away from the site in manufacturing facilities (prefabrication) shifts material and energy inputs to the product stage and away from the construction stage. Hence, the construction stage is shortened and is influenced more (and potentially more easily measured) by the manufacturer/supplier.

Secondly, another important difference when planning to use offsite manufacture (OSM) is the need for designs to be agreed and manufacturers to be involved early in the project. Late design changes are more difficult to accommodate than with traditional build. This earlier engagement should be beneficial for carbon data collection and management, increasing the robustness of early carbon estimates.

However, there are many similarities between 'modern' and 'traditional' construction methods, and often projects will incorporate elements of both. Hence, some important carbon mitigation actions apply to all projects. These include:

- Material choices, which have a big impact on the embodied carbon of the asset due to their distinct carbon intensities
- The need to design for high levels of air tightness and excellent energy performance
- Installation of renewable technologies to enable low or zero carbon in operation
- Use of low or zero carbon plant and equipment on site, and providing training for operatives to use them efficiently

10 *Cast Consultancy, Introducing the MMC Definition Framework, available here*

2. Reducing whole life carbon through offsite

What interventions can the offsite industry invoke when trying to minimise the whole life carbon of an asset? In this section we will give some examples broken down by life cycle stage and discuss trade-offs that might need to be considered.

The life cycle of a construction project, shown in Figure 1, is commonly broken down into four main stages. These include:

- **the product stage,** including raw material extraction, transport of materials, manufacturing and fabrication (A1-3),
- **the construction process stage**, including transport to project site and the construction, assembly or installation process (A4-A5)
- **the in-use stage,** including maintenance, repair, replacement, refurbishment and operational energy (B1-B5)
- **the end-of-life stage,** including deconstruction, demolition, waste processing and disposal of materials (C1-C4).

An additional module, D, covers carbon benefits and emissions beyond the life cycle of the asset, for example reuse, recycling and/or other recovery potentials.

2.1 Product stage (A1-A3)

For all buildings and infrastructure projects, this stage is a hotspot for emissions and should be a focus of decarbonisation efforts.

Opportunities

Embodied carbon in materials is one of the biggest contributors to whole life carbon in construction projects. All raw materials have emissions associated with their extraction, transportation, and fabrication into finished elements, which cannot be drawn down again within the short timescales we have to avoid warming of no more than 1.5°C.

The carbon hierarchy provides a framework for prioritising emission reductions in materials:

- Avoid the need for the material entirely,
- Reduce the need by using less in the design,
- Reduce the amount of virgin materials required by reusing existing ones, or those with high recycled content,
- Or use carbon-sequestering materials.

Designing for manufacture and assembly, rather than fabrication on-site, can encourage optimal use of materials, bringing about emissions savings in the product stage. For example, offsite fabricated timber and steel frame homes have been found to create around 80% less waste compared with conventional homes, with a greater proportion of the remaining waste being recycled or used as an energy source rather than sent to landfill[11]. Modular homes have been found to generate even smaller amounts of waste. A recent study of six modular manufacturers found that volumetric homes produce 90% less waste during manufacturing and assembly than traditional homes during construction[12], at 2% versus a 20% baseline[13].

11 *Tavares et al 2021, Prefabricated versus conventional construction: Comparing life-cycle impacts of alternative structural materials, Journal of Building Engineering 41:102705, available here*

12 *Make UK, 2022, Greener, Better, Faster: Modular's Role in Solving the Housing Crisis, available here*

13 *Savills, 2021, Embodied carbon and construction, available here*

There are three main explanations given for these resource efficiency benefits.

Firstly, materials can be procured exactly to meet design requirements, rather than being sourced by multiple subcontractors and brought to site.

Secondly, designs can also be manipulated and optimised more effectively, removing mass and elements which don't add value. Life cycle assessments of two Tide Construction modular developments found embodied carbon savings of 41% and 45% when compared to conventional designs[14], due to more efficient concrete slabs being used and the steel frames being optimised for low carbon.

Thirdly, manufacturers can optimise the use of materials within a controlled setting. Materials can be precision cut or poured, and any unused materials can be utilised for other elements. There is a lower likelihood of damage to materials and elements, as they are not exposed, which minimises the need for rework. Furthermore, any waste which does occur can be sorted easily for reuse or recycling. Unfortunately, public reporting of waste data, and carbon emissions from waste, appears to be limited in the manufacturing space. There are examples of good practice however, including TopHat, which reports zero waste to landfill for two years from operations, and Robertson, which reported a 99% diversion of waste from landfill in 2021/22[15].

Comparing offsite manufacturing to other manufacturing sectors, continual improvement of processes to optimise material and energy use should be a big opportunity for the industry, a concept promoted by Make Modular in its recent report[16]. However, we did not find sufficient data to evidence continual improvement for emissions in the manufacturing process at this time.

The shift in activity (and emissions) from construction site to factory presents another opportunity for whole life carbon reduction because, with the current technologies available, manufacturing facilities can be more easily decarbonised than construction sites. Manufacturers should grasp this opportunity by installing renewable energy at their facilities, procuring green energy, and monitoring and improving energy efficiency.

14 *Infrastructure Intelligence article available here*

15 *Robertson ESG Annual Report 2021-2022 available here*

16 *Make Modular, 2022, Greener Better Faster, available here*

Finally, the ability for manufacturers to develop their supply base and develop expertise in the use of innovative materials may help them unlock low carbon design options. If designers collaborate with manufacturers and utilise their expertise, they can have greater confidence in incorporating novel systems. An example of this is the composite timber and concrete solution from CREE Buildings utilised by Buro Happold in the EDGE Suedkreuz project, Berlin, Germany[17]. Using this hybrid system resulted in a 180-230 $kgCO_2e/m^2$ upfront embodied carbon value for the sub- and super-structure. Without the expert knowledge CREE Buildings had on the performance, cost, and safety of the system, it is unlikely the structural designers at Buro Happold would have incorporated this technology. Buro Happold and CREE have since collaborated on a rapid prototyping tool which can enable application of the system to different types of projects, whilst returning data on materials, embodied carbon and assembly times[18].

Other examples of best practice in minimising product stage emissions include:

- The Valentine (HTA Design), optimised design for reduced embodied carbon[19]
- The Forge (Bryden Wood), where a 22% reduction in embodied carbon was achieved compared to a 'business as usual' scenario, including a 22% reduction in superstructure and façade embodied carbon, and 40% reduction in substructure. Optimised design choices include 4% less steel tonnage in the frame and 13% reduction in concrete against business as usual, high GGBS mix concrete, specification for high recycled content in steel and façade, omission of suspended ceiling and partitions to create open plan offices, adaptable design through reversible components, procurement of local stone, steel and concrete, and reduced material waste on site.
- TopHat low embodied carbon homes. Upfront embodied carbon for one product type is 360.5 $kgCO_2e/m^2$, very close to LETI 2030 design target of 300 $kgCO_2e/m^2$, excluding carbon sequestration from timber. The whole life embodied carbon, including sequestration was found to be 221 $kgCO_2e/m^2$, an A+ rating in the RIBA banding.
- Merkinch Primary School, Inverness, achieved a whole life carbon reduction of 62% due to lighter foundations – generating 437 $kgCO_2e/m^2$ of embodied carbon, below the RIBA 2030 target[20].

17 *Buro Happold EDGE Suedkreuz project, available here*

18 *Buro Happold, A collaboration to drive a net zero construction industry, available here*

19 *The RIBA Journal, Modular schemes slash embodied carbon by over 40%, article available here*

20 *Robertson decarbonisation brochure, available here*

- Portlands Place (Hawkins\Brown) achieved upfront embodied emissions of 755 $kgCO_2e/m^2$, performing better than business-as-usual models (775 $kgCO_2e/m^2$), attributed in part to prefabrication of façade panels and bathroom pods[21]

IMPACTS OF SYSTEM & MATERIAL

- Because low carbon concretes can take more time to cure, pre-casting offsite can be more efficient than pouring on site, waiting for each layer to harden before pouring the layer above. If casting on-site is necessary however, systems can be designed bespoke to avoid programme delays (e.g. propping used during construction of The Forge to enable the GGBS concrete to cure whilst building moved upwards).
- Around 80% of timber consumed in the UK is from overseas, and there are currently no UK-based suppliers of mass engineered timber. Transport emissions from materials delivery can be significant, so should be included in embodied carbon calculations for design choices to be compared effectively. One recent demonstrator project has utilised Scottish-sourced mass timber for a housing unit, so there may be scope for local sourcing to increase.[22]
- Timber structures are relatively lightweight, so can bring about significant reductions in the amount of (high embodied carbon) material needed for substructure, as well as vehicle movements for groundworks.

Drawbacks and considerations

Although there are opportunities for optimisation of designs using Design for Manufacture and Assembly (DfMA), trade-offs may exist between repeatability of elements or modules and material efficiency. For example, in high rise buildings, elements which are not load bearing may be designed to the same specification as the elements which support the highest loads on lower floors. Whole life carbon assessment at the design stage allows these trade-offs to be assessed.

Another consideration regarding product stage embodied carbon is that mass may need to be added to structural elements to resist temporary stresses during transportation, lifting and assembly. These elements are typically made from metal, which can be carbon intensive. Sometimes, this can be avoided by using temporary supports and bracing during transport, which can be lifted and reused.

21 *Arslan, D. et al, 2023, Carbon Analysis, Life Cycle Assessment, and Prefabrication: A Case Study of a High-Rise Residential Built-to-Rent Development in the UK, Energies 16:973, available here*

22 *COP 26 Homegrown demonstrator, available here*

2.2 Construction process stage (A4-A5)

Emissions in this stage relate to transport of materials and building elements to site, as well as onsite fuel and energy use. Together, these activities are only responsible for a small fraction of the whole life carbon of a project (see Table 1), but should still be considered, especially by main contractors who oversee the process and can collect and report data relatively easily.

Opportunities

One of the clearest and most widely acknowledged benefits of premanufacture of built assets is the increase in build speed and associated reduction in the energy and fuel use on site. Assets which utilise OSM have been found to take around 50 to 60% of the time to build[23] compared with traditional construction methods, as well as requiring significantly fewer operatives. This efficiency translates to reductions in energy use from lighting, welfare, generators and tools. Even with factory energy consumption considered, reduced emissions from energy use of around 30% for modular projects have been found[24]. Lower emissions across the construction stage were also estimated in a recent comparative study between timber frame and conventional brick and block homes[25]. The emissions savings in this case were between 30-40% for the open and closed panel homes versus brick and block, attributed to shorter duration on site as well as reduced transport emissions.

When components are manufactured offsite, fewer vehicle movements are required overall to bring people and materials to site, resulting in lower carbon and less air pollution. Contractors report this as one of the biggest opportunities for carbon reductions through OSM. In the comparative study mentioned earlier, emissions savings of 60% from reduced material and worker transport to project site were found, reducing to 20% savings when worker transport to factory was included.

There are also opportunities to optimise these carbon savings through sourcing from local manufacturers wherever possible, an approach taken by Kier using its MMC database. The recently launched MMC Market[26] is also a useful searchable source of supplier information.

There is clear room for improvement in the sector on the reporting of site and transport emissions. Currently, mileage and fuel consumption seem only to be estimated for projects and comparative studies.

As construction activity on site is minimised, waste generation on site is dramatically reduced for premanufactured assets. Again, though, reporting of waste figures and associated emissions needs to improve.

Examples of best practice include:

- Kier's Choice Factory, using local manufacturing bases and encouraging carbon reductions through procurement[27]

IMPACTS OF SYSTEM & MATERIAL

- MMC Category 1 systems have to be transported in large vehicles to site with limited potential for optimising the space available. For this reason, the greatest environmental savings in logistics are often achieved by panelised systems. Last-mile assembly hubs can be used to optimise logistics for volumetric.
- Conversely, MMC Category 1 systems are thought to be the most efficient in terms of on-site installation, as assembly is quicker with little waste generation.
- Using precast concrete minimises the need for timber formwork on site, reducing waste.
- Volumetric is the most efficient in terms of on-site installation, but a trade-off may exist in high rise with embodied carbon as design standardisation will reduce.
- Closed panel systems performed marginally better for emissions in the construction stage than open panel systems in a recent comparative study[28], however these savings were balanced by higher emissions from the product and end of life stages.

23 Tavares et al., 2021, Prefabricated versus conventional construction: Comparing life-cycle impacts of alternative structural materials, Journal of Building Engineering 41:10275, available here

24 Quale et al, 2012, Construction Matters: Comparing Environmental Impacts of Building Modular and Conventional Homes in the United States, Journal of Industrial Ecology 16(2): 243-253

25 AIMCH, 2022, Work Package 11: Whole Life Carbon Assessment

26 MMC Market, available here

27 Kier, The Choice Factory, available here

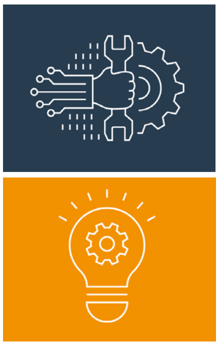
28 AIMCH, 2022, Work Package 11: Whole Life Carbon Assessment

Drawbacks and considerations

Current databases for materials cater primarily for conventional construction processes, so emissions savings in this stage achieved by prefabrication can be missed. This is a challenge which should be considered in life cycle assessment data collection.

Maximising the potential carbon savings through OSM and assembly requires careful planning of logistics to avoid temporary storage and/or double-handling. Any resultant damage in transit will require energy and material expenditure which dilutes savings made elsewhere. Weather damage during transit or during assembly is a major risk for timber components and assemblies, which impacts on quality and thermal performance. Manufacturers and contractors must work together to organise logistics so that deliveries carry materials efficiently and in the fewest trips possible.

2.3 Use stage (B1-B7)



This stage includes both embodied carbon from the maintenance and replacement of elements, and the energy use in operation of the built asset. In terms of embodied carbon, modules B1-5 are often a significant hotspot, second only to products and materials (A1-3) in average building typologies (Table 1). The benefits of premanufacture here are on the whole potential, rather than demonstrated, and this should be a focus of more attention.

Opportunities

Simplifying the maintenance and replacement of building components while minimising disturbance means fewer materials are used, less waste is created, and emissions are reduced. DfMA should enable this kind of approach, for example optimising the location of services and ensuring easy access, making sure panels covering M&E services can be easily removed and replaced, or designing windows to be replaced without damage to panels. These design features can be supported by digitalisation, providing a thread of building information and service requirements to operators and residents. The use of digital twins in support of carbon and circularity goals is being explored currently by the Apollo Protocol[29]. Where modular design is used in an infrastructure context, damaged components can be swapped out for new ones.

Mitigating emissions from heating, lighting and powering buildings is rightly a key focus of the construction sector, and with current energy performance requirements and the makeup of the grid, on average the biggest hotspot for emissions of typical buildings (between 40-60% of whole life carbon emissions[30]). Operational emissions can be minimised in building design through passive design, including improvements in air tightness, low U-values, material insulation and optimal orientation, and supplying any remaining energy needs through renewable technologies such as solar panels and heat pumps. Another important action is to ensure the building performs to or exceeds its modelled standard, minimising any performance gap.

The offsite sector recognises this and a common assertion is that manufactured elements of a building result in higher quality, including improved ease of achieving best practice energy performance through excellent air-tightness, consistent insulation, and systems performing closer to specifications. This makes logical sense, with factories providing a dry, quality-controlled environment, compared to the complexity and unpredictability of the site. Building Information Modelling can also be used to resolve design issues prior to manufacture so that units can be fabricated to fit together precisely.

In terms of specified energy performance, only 2% of homes in the UK are currently being built to EPC Band A, whilst modular homes manufacturers are producing thousands of homes to B and A and above[31]. For example, Ilke homes is currently able to produce homes which cost nothing to heat or power. An assessed product from TopHat was found to have over half the energy use intensity and operational carbon over 60 years of a typical home, closer to RIBA and LETI 2030 Net Zero performance targets than business as usual.[32]

Although post-occupancy data to confirm the benefits is difficult to obtain, we understand that this is an active area of work for some clients and manufacturers, so we expect data to improve. We are also aware that SAP and air tightness data should be available, either from Building Control Authorities or from house-builders themselves, to compare with in-use data. Performance data should also become available from premanufactured test builds within Energy House 2.0[33] at the University of Salford in the coming months.

29 The Apollo Protocol, available here

30 LETI, 2020, Climate Emergency Design Guide, available here

31 Make Modular, 2022, Greener Better Faster, available here

32 TopHat WSP report

33 Energy House 2.0 Project, available here

Note: the process of converting operational energy into operational carbon is complicated by the changing emissions intensity of the grid. LETI recently proposed a methodology to deal with this[34].

Examples of best practice include:

- Post-occupancy data for the Hope Rise development (ZedPods), detailed energy use intensity close to the LETI 2030 target and operational carbon footprint of 170 $kgCO_2e$[35]

IMPACTS OF SYSTEM & MATERIAL

- Steel reinforced concrete requires carbon intensive repairs during the lifetime of the asset if the steel corrodes. There are innovations available which can protect this embodied carbon and which are well suited to integration in precast concrete designs.[36]
- Thermal bridging occurs around interfaces in buildings where the primary structure is steel or concrete, including volumetric modular buildings. This should be considered and minimised during the design stage.

Drawbacks and considerations

As with any building, it's important to consider thermal mass and how this balances out with the embodied carbon of materials. For example, concrete has high thermal mass, but high embodied carbon. In contexts where natural ventilation is being used, it may benefit any in-use emissions to have higher thermal mass elements.

34 *Operational Carbon in Whole Life Carbon Assessments, Executive Summary available here*

35 *ZED PODS, 2022, Hope Rise Post Occupancy Evaluation Year 1 (2020/21), available here*

36 *Buildoffsite and CIRIA, 2022, Achieving sustainable resilience in new precast concrete structures*

SPOTLIGHT ON RETROFIT

Retrofitting existing buildings should be prioritised over the construction of new buildings wherever possible, following the carbon and energy hierarchy. Manufactured elements and digital technologies can be applied to make the process of retrofit more efficient, as well as lowering the embodied carbon of the physical elements needed to improve energy and carbon performance. Some of the technologies that can be used include:

- Volumetric modules being added to roof tops
- MMC Category 2 panelised systems for insulation can be premanufactured and installed
- Structural concrete frames may be reconditioned and repurposed using modularised structural healthcare systems
- Buildings can be digitally scanned and the data used to inform panel design and manufacture for external insulation and interior refurbishment
- Bespoke components can be 3D printed following scanning
- Within Category 5, M&E pods, utility cupboards, flat pack bathroom pods and wall cassettes can be manufactured and installed
- Onsite process improvements within categories 6 and 7 include utilising roofing finishes with integrated solar panels, digital scanning and robotics such as QBot to install cavity insulation

Home retrofits using the Energiesprong model include a performance guarantee, with finance recuperated from savings on energy bills. Because of this, performance reports are generated and information fed back to manufacturers of elements. In its most recent report, energy savings post-whole house retrofit were 70% on average. One particular project, delivered by Melius Homes, utilised full storey height wall panels prefabricated off-site, which included insulation and double-glazed windows and were fitted to a non-structural timber frame. The non-invasive system allowed residents to remain at home throughout the one-week retrofit.[1]

On top of the inherent performance improvements and in-use carbon reductions that are derived from retrofitting, the embodied carbon reduction opportunities for new build through premanufacturing also apply to retrofit, such as reduced waste, less time on site, and predictability of outcome. A key non-carbon benefit of OSM for retrofit solutions is the reduced disruption to occupiers, which along with the performance guarantee, can improve the likelihood of take-up.

1 *Energiesprong UK, 2021, Transforming social housing in Nottingham, available hereavailable here*

2.4 End-of-life stage and circular economy (C1-C4, D)

To calculate emissions at the end-of-life of an asset, a linear system is assumed where materials are sent to landfill, meaning that the value of actions taken to reuse, recover and recycle materials can be obscured. However, the ways we dismantle and process building elements and materials at the end of the asset's life are important as they affect the upfront embodied carbon of the next generation of assets. Interventions made to improve the recoverability and reuse potential of materials in this stage will reduce the overall footprint of the sector considerably.

Currently, the recovery rate of metals is high (96% for steel and aluminium), whereas RICS suggests an energy recovery rate for timber of 75%. Concrete, ceramics and stone make up the greatest waste volumes in construction, being typically crushed and downcycled for uses such as backfilling.

Opportunities

In most cases, the end-of-life fate of the asset and its materials is unknown, so assumptions will need to be made, based on the average recycling and disposal rates for different materials[37]. However, the nature of offsite construction means assets are designed for assembly, which should simplify disassembly. Indeed, modular temporary building suppliers commonly keep stocks of recycled units for reconfiguration and reuse. Manufacturers and designers should take the opportunity to design for disassembly and enable reuse of components, with a deconstruction plan created at the project outset and be maintained. This could both reduce the energy requirements of disassembly, and increase the opportunity for gains in module D.

Manufacturers and designers should also ensure that digital information on material specifications and their reuse or recycling potential can be transferred to the asset owner. Integrating this kind of information into BIM models through materials passports will help maximise the potential for repurposing and reuse and is an active area of research. Manufacturers have the greatest knowledge of the system components and the best chance of repurposing them effectively, so should lead on these efforts.

Examples of best practice include:

- Innovaré design panel systems to be easily dismantled at end-of-life and the components of each panel recycled
- COP26 House[38] (Roderick James Architects) has been disassembled and reconstructed in a college to be used for educational purposes
- The Forge (Bryden Wood) was designed using standard parts with reversible joints, meaning the building can be dismantled in pieces, extending component life[39]
- A number of projects on the Buildings as Material Banks programme used prefabricated elements which were reused[40]
- Some initiatives are working on innovative leasing models for building assets and its parts, such as a cladding system leasing for a facade developed by TU Delft[41]

IMPACTS OF SYSTEM & MATERIAL

- RICS guidance suggests assuming 75% of timber is incinerated and 25% goes to landfill, however it has been suggested that up to 95% of timber can be reused
- When not reused, timber releases carbon at end-of-life, so modelled emissions in this stage can be higher for systems using timber than standard brick and block houses[42]
- Steel recycling can reduce end of life carbon emissions, but this does not negate the currently high embodied carbon of the material. A best option for steel is reuse wherever possible.
- Concrete and bricks cannot be as easily reused, but there are examples of good practice. Concrete frames can be reused in situ, or concrete aggregates can be incorporated into new concrete mixes. Often concrete is downgraded into fill and road sub-base.
- At end-of-life, prefabricated steel and wood buildings have been found to present higher recyclability rates than both prefabricated concrete and non-prefabricated buildings[43]
- The use of timber for high-rise developments is currently banned in some regions due to fire safety concerns
- Steel framed volumetric modules can be re-located, re-used or, depending on their age, re-fitted to meet extant thermal performance and fire safety standards.

37 E.g. RICS, 2017, Whole Life Carbon Assessment for the Built Environment, available here

38 COP 26 House, available here

39 The Forge project, available here

40 BAMB 2020, available here

41 TU Delft Facade Leasing Pilot, available here

42 AIMCH, 2022, Work Package 11: Whole Life Carbon Assessment

43 Pons, O and Wadel, G, 2011, Environmental impacts of prefabricated school buildings in Catalonia, Habitat International 35 (4): 553-563, available here

3. Carbon data management

Robust measurement and effective communication of carbon data are crucial to optimising designs, identifying priorities for action, and quantifying benefits and trade-offs. These principles are also important for benchmarking and public transparency.

Understanding the whole life carbon impact of projects involves collecting numerous types of data from multiple sources. At the outset of a project, it is to be expected that whole life carbon assessments will involve a high degree of estimation, but this should not dissuade design teams from carrying out assessments as early as concept design stage. It's recommended that carbon is assessed at multiple intervals in the project; once manufacturers are selected, estimations will inevitably improve in accuracy.

To understand best practice and set benchmarks, targets from RIBA, LETI and the GLA are useful:

- RIBA embodied carbon: target 1,100 $kgCO_2e/m^2$, best practice 500 $kgCO_2e/m^2$
- LETI embodied carbon: baseline 1,000 $kgCO_2e/m^2$, best practice <600 $kgCO_2e/m^2$for office buildings
- GLA embodied carbon: BAU 950 $kgCO_2e/m^2$best practice 500 $kgCO_2e/m^2$. whole life BAU 1,400 kgCO2e/m2, aspiration 850 $kgCO_2e/m^2$
- RIBA / LETI operational energy use 2030 target of 55 kWh/m^2 for non-domestic buildings

To enable continual improvement and to build confidence in designs, post-occupancy energy performance information should be collected where possible by clients and communicated to the design team and manufacturers. This is particularly useful for offsite construction, as findings can feed back into manufacturing processes and potentially improve performance for many new projects.

Manufacturers, especially modular, have an interest in understanding the real operational energy performance of their products and designers also need to understand how well they have been utilised. This continuity could be an asset of the offsite construction sector, with more effective communication between clients, designers and the supply chain enabling continual improvements in carbon and energy performance.

3.1 Challenges in measurement

Industry practitioners working across the project life cycle have reported common challenges in data collection, management and reporting. Most of these challenges are not unique to the offsite construction sector, and all will require collaboration to overcome.

Data collection and accuracy

There are two main kinds of data needed to understand carbon footprints of products, organisations and projects: activity data and carbon factors. Activity data includes material quantities, fuel and energy use, and mileage; carbon factors indicate the amount of emissions associated with the production of a certain amount of material or unit of energy. During research, representatives from organisations across the value chain reported difficulties in collecting both activity data and carbon factors for building elements.

In terms of activity data, the main challenge reported was around the collection of fuel use and mileage information for deliveries to site. With good communication of expectations and guidance shared between contractor and subcontractors, this is expected to become less of a problem. The tagging and tracking of prefabricated components and assemblies from factory to site will help with this.

In terms of carbon factors, a common practice in calculating embodied carbon is to use generic data on carbon emissions based on categories of spend. This is not the same as the actual carbon in the materials bought. For example, virgin aluminium manufactured using fossil fuels will have a much higher carbon footprint than that manufactured using renewables. It also obscures improvements made to processes or materials by suppliers. For this reason, specific factors should be sought where possible.

Environmental Product Declarations (EPDs) are increasingly being requested as part of embodied carbon analyses for projects and to inform decisions on material choices. These are independently verified documents which lay out the environmental footprint of products, including Global Warming Potential per unit, measured in kgCO_2e. They are not an indication that a product is low carbon, rather a way of improving transparency around impacts. In our survey, 11 out of 18 relevant organisations stated they currently request EPDs from the supply chain.

In the world of offsite, manufacturers are more significant sources and managers of carbon data than in traditional projects. The factory environment should, in theory, enable easier activity data collection from bills of materials, processes, and logistics. However, some clients report difficulty in sourcing data from manufacturers, mentioning a lack of available EPDs. From our survey and conversations, there were mixed feelings from manufacturers around this issue with some currently developing EPDs and some feeling that other data collection and communication methods were more appropriate for their context. There was also some frustration expressed from the manufacturers' side that clients were not asking for carbon data or EPDs, meaning that those who invested in measurement were not being acknowledged.

There are good reasons why manufacturers may choose not to develop EPDs, especially if the components being fabricated are complex. EPDs give a snapshot of the embodied carbon at a particular moment in time and are costly to renew, meaning they may not capture actions taken to decarbonise processes and the supply chain. Mapping the supply chain and gathering energy use data is challenging and calculation methods and assumptions can vary, making it difficult to be confident in the robustness of EPDs.

We recommend the use of combined approaches, bringing in EPDs where available, but supplementing with activity data and estimates if need be. The forthcoming release of the Built Environment Carbon Database (BECD)[44] will also help to improve accuracy, especially at the design stage where suppliers might not have been selected or been able to provide EPDs. A full list of data sources needed for carbon accounting as well as challenges associated with each data source can be found in Appendix A of ICE's recent report on carbon measurement[45].

When modelling operational carbon, assumptions have to be made around future grid electricity carbon intensity. Setting targets for Energy Use Intensity (kWh/m^2.yr) for building performance avoids this issue, as the metric is not affected by the carbon intensity of the grid. Conversations are ongoing with the best method for converting projected energy use into carbon, and LETI have recently published guidance on proposed two-stage methodology[46].

44 BECD, available here

45 ICE, 2022, Meaningful measurement for whole-life carbon in infrastructure, available here

46 LETI, Operational Carbon in Whole Life Carbon Assessments, available here

Key actions:

- Whether developing EPDs or not, data collection will be required, so make sure energy, fuel and material use is recorded and have conversations with suppliers on sharing of this data as well. Carbon footprints can then be developed for key components or product groupings
- From the client side, mandating EPDs on projects is not advised as innovative materials or suppliers may be excluded. It is better to be flexible and accept multiple forms of carbon data communication. Using combined approaches to understand embodied carbon is valid. For guidance around combined approaches and supplementing data the CWCT's guidance on facades can be applied to other building elements[47].
- The industry needs to move on from using generic data on carbon emissions based on categories of spend to actual carbon in the materials bought.
- If EPDs do exist, it's important that they are used carefully in design models and whole life carbon analyses. Make sure any gaps in EPDs (for example, logistics modules) are filled either by primary data collection or assumptions if need be, and ensure these are communicated.

Knowledge and communication gaps

Everyone involved in a building project has a role to play in enabling a smooth process of carbon data collection. However, there is still a lack of understanding of activity data requirements which complicates embodied carbon and Scope 3 calculations. Training, digitalisation and working groups with suppliers and SMEs can help overcome this barrier.

Key actions:

Encourage supply chain to utilise training sessions and materials provided by industry initiatives like the *Supply Chain Sustainability School* to help widen knowledge of the kinds of data they will need to collect to understand their carbon footprint

Lack of legislative drivers

It's widely agreed that regulation and policy is a necessary driver for the built environment to reduce whole life carbon in projects, but currently, only operational carbon emissions are regulated. There is no legislative requirement for main contractors to report Scope 3 emissions on either an organisational or a project basis. However the adoption of Science Based Targets by many leading organisations has led to investors, clients, contractors and manufacturers taking a much closer interest in their Scope 3 emissions.

The Committee on Climate Change called for mandatory whole-life carbon reporting and standards for the built environment in their 2021 Report to Parliament, and this has also been recommended by the House of Commons Environmental Audit Committee. Cross-industry partnerships are taking up this effort through the Part Z proposals as well as developing voluntary standards such as the UK Net Zero Carbon Buildings Standard initiative.

Key actions:

- Prepare for regulatory change by carrying out whole life carbon assessments, collecting data, and designing to best practice embodied and operational carbon standards

Organisations can find out more about Part Z and pledge support for the initiative through the website.

Examples of best practice:

- Design tools which integrate carbon data are becoming more common amongst manufacturers and architecture practices. Examples include:
- H\B:ERT Emissions reduction tool from Hawkins\Brown[48]
- Moata Carbon Portal from Mott Macdonald[49]
- NG Bailey has developed an internal comparative carbon tool
- Innovare has an internal carbon calculator linked to a REVIT estimating tool, with real time embodied carbon information for design changes

47 CWCT, 2022, How to calculate the embodied carbon of facades: A methodology

48 H\B:ERT Emissions Reduction Tool, available here

49 Mott MacDonald adds Moata Carbon Portal to its digital solutiosn platform, available here

4. Role-specific guidance

Mitigating emissions from the built environment is a huge task and requires every organisation at every project stage to take action. With premanufactured buildings, opportunities to design out carbon arise early in the project, but require collaboration through data and idea sharing between clients, design teams and manufacturers. Depending on the nature of the project and the degree of premanufacture, responsibility for low carbon design and data management may fall more or less on the manufacturer.

The table below provides suggestions for the primary actors in a project on how to optimise the use of offsite and MMC to decarbonise buildings and built assets, covering carbon measurement and reduction actions. More detailed advice for designers can be found in the RIBA Climate Challenge[50], RIBA Embodied and whole life carbon assessment for architects[51], and LETI Climate Emergency Design Guide documents. We also would like to direct readers to the Stakeholder Action Plans within the UKGBC Whole Life Carbon Roadmap, which include support of MMC, and provide specific carbon guidance for organisation types. (Reference: UKGBC, 2021, Net Zero Whole Life Carbon Roadmap Stakeholder Action Plans, available here. The forthcoming PAS 2080 revision will also help to structure adoption of best practice carbon management across the built environment.

Enabler	CLIENTS AND PROCUREMENT TEAMS
Leadership and strategy	• Create and implement a clear strategy to reduce emissions organisationally and on projects in line with or exceeding national targets. • Develop internal capability to inform strategy development, implementation, data collection and reporting. • Show leadership and clear intention, encouraging innovation
Designing and procuring out carbon	• Ensure embodied carbon and operational energy use are include as design objectives within the brief. • Include the social cost of carbon in procurement decisions and utilise this to make the value case for ambitious carbon targets on projects. • Use outcome-based procurement to incentive carbon savings and performance to designed targets. • Involve end users / occupiers in design to understand how low-carbon operation will work in practice, and take advantage of digital tools to do so.
Effective collection and use of data	• Mandate whole life carbon reporting on projects and oversee collection and management of data. • Work with supply chain to understand embodied carbon of products and materials, logistics and fuel use on site. • Ensure hand-overs between facilities management contractors support ongoing monitoring and control of systems (for in use and embodied energy protection).
Encouraging and applying carbon reduction actions	• Encourage standardisation of building types and components across projects, enabling resource efficiency and continual improvement. • Incentivise use of circular economy principles in the supply chain, working with manufacturers on innovative supply models, and setting targets for reuse of materials and recycled content.
Collaboration and knowledge sharing	• Enable long-term collaborative relationships with manufacturers, setting carbon targets for supply chain to work to. For example, utilising a Framework approach, tendering buildings as a group and creating long-term pipelines of work. e.g. the Building Better framework[53]. • Appoint an MMC advisor to make sure you're aware of all the suitable options and weigh up their sustainability impacts.

50 *RIBA, 2030 Climate Challenge, available here*

51 *RIBA, 2019, Whole life carbon assessment for architects, available here*

52 *Bryden Wood, Net Zero Carbon Buildings, available here*

53 *Building Better, available here*

DESIGN TEAMS	MANUFACTURERS	CONTRACTORS AND ASSEMBLY TEAMS
• Create and implement a clear strategy to reduce emissions organisationally on projects in line with or exceeding national targets. • Push back against design changes which unnecessarily increase whole life carbon. Bryden Wood's process, based on UKGBC guidance, can help structure decision making[52].	• Create and implement a clear strategy to reduce emissions organisationally and on projects in line with or exceeding national targets. • Cascade requirements through the supply chain, request embodied carbon data and/or EPDs from materials suppliers. • Explore the potential of providing products as a service.	• Create and implement a clear strategy to reduce emissions organisationally and on projects in line with or exceeding national targets. • Cascade requirements to manufacturers and suppliers, prioritising those which are making interventions to reduce their operational and product emissions.
• Always offer low whole life carbon design choices at the outset regardless of whether the client asks for it. • Design for resilience in a more challenging climate. • Don't specify products and solutions that limit the manufacturers or contractors ability to reduce carbon. • Ensure that designers allow for effective maintenance and end of life re-use. • Involve end users / occupiers in design to understand how low-carbon operation will work in practice, and take advantage of digital tools to do so.	• Understand the actual carbon in the products and materials that you are purchasing. • Understand how to procure components and systems that minimise the energy use of the buildings that you are manufacturing over their lifetime. • Provide the client with options to reduce carbon that include the lifetime energy savings that might accrue.	• Develop a design and procurement process to 'carbon engineer' a project design to enable a reduction to the embodied carbon and operational energy use of the building.
• Understand and balance operation and embodied carbon to make informed decisions about materials and structures. • Assess whole life carbon early in the process, and utilise guides (e.g. RICS, CWCT) to inform appropriate use of assumptions. Rudimentary assessments for embodied carbon can be facilitated through BIM. • Consider benchmarks for building types and work towards best practice. • Obtain feedback on building performance and incorporate learning into future designs.	• Collect activity data and develop accessible, clear and audited carbon footprints. Work towards greater EPD coverage. • Collect upstream and downstream logistics information (e.g. mileage, fuel use) and include in footprints and EPDs. • Create digital twins and/or material passports. • Communicate operational carbon and waste management data and continually improve processes.Obtain feedback on building performance and incorporate learning into future designs.	• Utilise digital twins. • Mandate reporting of and collate activity data for fuel use on site and logistics.
• Follow the carbon hierarchy: build nothing / less in the first instance, utilise low carbon materials, reclaimed and recycled materials, and implement MMC to build more efficiently. • Incorporate materials and systems which have low whole-life carbon impacts into designs. • Be aware that some elements may be over-specified, but that savings may be made from repeatability, through reduced wastage and process time optimisation.	• Optimise materials and systems to achieve low embodied and operational carbon. • Design for replaceability of elements, easy maintenance and deconstruction. • Utilise biogenic materials, recovered materials, enable reuse and recyclability.	• Ensure high quality installation to minimise the performance gap.
• Understand the products, systems and technologies on offer in the supply chain. Manufacturers can share information on this and work with you to integrate products into the design. • Consider engaging with an MMC advisor to understand your options and their sustainability impacts.	• Share long-term maintenance plans and deconstruction plans. • Work with design teams to communicate optimal use of products for low whole life carbon.	• Share data with main contractors, clients and designers where appropriate, and feedback installation information to manufacturers.

Glossary

Design for Manufacture and Assembly (DfMA)	A design approach which focuses on ease of manufacture and efficiency of assembly, inextricably linked to offsite construction
Modern Methods of Construction (MMC)	Ways of working including offsite construction techniques and use of new technologies to improve productivity and efficiency
Offsite manufacture (OSM)	Construction method whereby components or elements of the built asset are completed in a manufacturing facility located away from the installation site
Premanufacture(d)	Processes which reduce the level of on-site labour intensity
Greenhouse Gases (GHG)	Constituents of the atmosphere which have the property of absorbing infrared radiation emitted from Earth's surface and reradiating it back to Earth's surface. In general usage, and in this report, the term is used interchangeably with 'carbon emissions'
Whole life carbon	Total greenhouse gas emission from all phases and modules A-C
Upfront embodied carbon (buildings)	Emissions associated with materials and construction processes up to practical completion (Modules A1-A5)
Embodied carbon (buildings)	The total GHG emissions and removals associated with materials and construction processes throughout the whole life cycle of an asset (Modules A1-A5, B1-B5, C1-C4)
Operational carbon (buildings)	The GHG emissions arising from all energy and water consumed by an asset in-use over its life cycle (Modules B6-B7)
User carbon (UseCarb)	Users' utilisation of infrastructure during the use stage (B8), excluding B6 and B7
Carbon sequestration	The process by which carbon dioxide is removed from the atmosphere and incorporated as 'biogenic carbon' in 'biomass', through photosynthesis and other processes associated with the carbon cycle

Biogenic carbon	The carbon removals associated with carbon sequestration into biomass as well as any emissions associated with this sequestered carbon
Net Zero whole life carbon / Net zero carbon building	Where the sum total of all asset-related GHG emissions, both operational and embodied are minimised following the carbon hierarchy, meet local carbon, energy and water targets, and with any hard to decarbonise carbon removed or offset through robust schemes to amount to zero
Net Zero embodied carbon	The sum total of GHG emissions and removals over an asset's life cycle (Modules A1-A5, B1-B5 and C1-C4) are minimized, meets local carbon targets (e.g.kgCO_2e/m^2), and with additional 'offsets', equals zero
Net Zero upfront carbon	The sum total of GHG emissions excluding carbon sequestration from Modules A1-A5 is minimised, meets local carbon targets, and with additional offsets, equals zero
Net Zero carbon - operational energy	Where no fossil fuels are used, all energy use (Module B6) has been minimized, meets the local energy use target (e.g. kWh/m2/a) and all energy use is generated on- or off- site using renewables that demonstrate additionality. Any residual direct or indirect emissions from energy generation and distribution are offset
Capital carbon (CapCarb)	The scope of 'Capital Carbon' GHG emissions for an infrastructure asset are those that align with the scope of Capital Expenditure as determined by the asset owner's preference. Modules A and C must always be included within the scope with Modules B1-B5 clearly identified as 'capital' or 'operational' within the scope.
Operational carbon (OpCarb)	The scope of 'Operational Carbon' GHG emissions of an infrastructure asset are those that align with the scope of Operational Expenditure as determined by the asset owner's preference. Modules B1-B5 must each be clearly identified as 'Capital Carbon' or 'Operational Carbon' within the scope. Module B8 must be clearly identified as 'Operational Carbon' or 'User Carbon' within the scope. Modules B6 and B7 are always 'Operational Carbon' within the scope.

SUPPLY CHAIN SUSTAINABILITY SCHOOL

Photo Credit: Melius Homes