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Unlocking Resource Efficiency

Phase 1 Construction Report

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Any enquiries regarding this publication should be sent to us at: Resource_efficiency@energysecurity.gov.uk

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Organisation	Type
AECOM	Consultancy
Align JV	Construction
ARUP	Construction
Built Environment Smart Transformation (BEST)	Waste Management
Chartered Institute of Waste Management	Professional body
Constructing Excellence Wales	Trade Association
Edinburgh Napier University	Research
Finishes & Interiors Sector (FIS)	Trade Association
Green Alliance	Research
Herriot Watt University - Geomaterials and Sustainable Building Materials Research Group	Research
Institute for Sustainable Resources	Research
Institute of Materials, Minerals & Mining (IOM3)	Trade Body
Institution of Structural Engineers	Trade Association
Laing O'Rourke	Construction
Loughborough University	Research
Morgan Sindall	Construction
ReLondon	Research
Reusefully	Research
Royal Institute of Chartered Surveyors (RICS)	Professional body
The Environment Agency	Government
UKRI Interdisciplinary Circular Economy Centre for Mineral-based Construction Materials	Research
University College London	Research
University of Leeds	Research
University of Salford	Research
Wood Recyclers Association	Trade Association

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Introduction

The Department for Energy Security and Net Zero commissioned a research project to explore the potential benefits from increasing resource efficiency in the UK. This research was carried out in collaboration with the Department for Environment, Food & Rural Affairs. This report outlines the findings for the construction sector.

For the purposes of this report, resource efficiency is defined as any action that achieves a lower level of resource use for a given level of final consumption. This can occur at any stage of the supply chain including production, consumption, and end-of-life. While material substitution may not always meet the definition of resource efficiency set out above, it is in scope of this research where it reduces whole life carbon.

This research was conducted in the first half of 2023, and reports were written in August 2023. As such, this report does not reflect sector developments beyond that point. The Department for Energy Security and Net Zero has consulted with technical experts as part of research activities for this report. The following report is our understanding of the available evidence and is accurate to the best of our knowledge; however, if any factual errors are encountered, please contact us at Resource_efficiency@energysecurity.gov.uk.

Methodology

This aim of this research was to achieve four key objectives:

- Identify a comprehensive list of resource efficiency measures for each sector;
- Identify current and anticipated drivers and barriers which are affecting improvements in the identified resource efficiency measures in each sector, and their relative importance;
- Build consensus estimates for the current "level of efficiency" and maximum "level of efficiency" in 2035, for each of the identified resource efficiency measures in each sector; and
- Identify the extent to which industry is currently improving resource efficiency and build consensus estimates for the likely "levels of efficiency" in 2035 given current private sector incentives and the existing policy mix (a "business-as-usual" scenario), for each of the identified resource efficiency measures in each sector.

To achieve these research objectives a mixed-methods methodology was developed. A literature review was conducted for each sector to synthesise evidence from the existing literature relevant to these objectives. The findings from this literature review were presented and tested in facilitated workshops with industry and academic experts. The aim of the workshops was to test the findings of the literature and fill any outstanding evidence gaps. This project did not aim to identify policy recommendations but rather understand the potential for resource efficiency in the UK.

This project has attempted to identify three level of efficiency estimates for each resource efficiency measure:

- The **current level of efficiency** which is the best estimate for the current level of efficiency of the measure i.e. what is happening in the UK now (in 2023);
- The **maximum level of efficiency** which is the maximum level of efficiency that is technically possible by 2035 in the UK, without factoring in barriers that could be overcome by 2035 i.e. what is the maximum level that could be achieved; and
- The **business-as-usual (BAU) scenario** which is the level of efficiency that would be expected in the UK by 2035 with the current policy mix and private sector incentives i.e. what would happen if there were no substantial changes in the policy or private sector environment.

These levels of efficiencies have been identified to understand the potential for resource efficiency and do not represent government targets.

To estimate these levels of efficiency an indicator has been developed for each of the identified measures. These indicators have been chosen based on how well they capture the impact of the relevant measure, and how much data there is available on this basis (both in the literature review and from expert stakeholders).

Note, the purpose of the indicators in this research is so estimates on the current, maximum and BAU level of efficiency can be developed on a consistent basis. They are not intended be used as metrics to monitor the progress of these resource efficiency measures over time, or to be used as metrics for resource efficiency policies.

A high-level overview of the research stages is presented below. A more detailed version of this methodology is presented in the Technical Summary which accompanies this publication.

Literature Review

The literature sources were identified through an online search, and through known sources from Defra, the Department for Energy Security and Net Zero, the research team, and expert stakeholders.

Once literature sources had been identified they were reviewed by the research team and given an Indicative Applicability Score (IAS) ranging from 1 to 5 which indicated the applicability of the sources to the research objectives of this study. This score was based on five key criteria: geography, date of publication, sector applicability, methodologies used and level of peer review.

After the five criteria of the IAS had been evaluated, the overall IAS score was calculated, ranging from 1 to 5, according to the number of criteria scoring ‘high’ and ‘low.’

Table 1: Methodology for the calculation of the IAS

Number of 'high' criteria	Number of 'low' criteria	IAS
Indifferent	3 or more	1
<= 1	2	2
>= 2	2	3
<= 2	1	3
>= 3	1	4
<= 1	None	3
2	None	4
>= 3	None	5

A detailed overview of the parameters used to assess high / medium / low scores for each of the five criteria feeding into the IAS calculation can be found in Appendix A.

The research team drafted literature summaries for each sector which synthesised the best available evidence from the literature for each of the four research objectives. When drafting these summaries, literature sources with a higher IAS score were weighted more than those with lower IAS score.

Facilitated workshops

The findings from these literature summaries were then presented at two half-day facilitated workshops per sector. The workshops were attended by a range of sector experts from both academia and industry (covering different aspects of the value chain). The purpose of these workshops was to test the findings of the literature review against stakeholder expertise, and to fill any evidence gaps from the literature.

The stakeholders contributed through sticky notes in a shared virtual Mural board, by participating in the verbal discussions and by voting on pre-defined ranges on the levels of efficiency and the top drivers & barriers.

Finally, the findings of the literature review and the stakeholder engagement were combined to reach final conclusions against each research objective. For the estimates on the level of efficiency for each measure (Objectives 3 and 4), a five-tier evidence RAG rating was assigned to indicate the level of evidence supporting the proposed figures. Only where the datapoints were supported by literature sources with high IAS and a high degree of consensus amongst experts in the workshops, were the datapoints considered to have a "green" evidence RAG rating. The definitions are as follows:

- **Red:** Limited evidence available from literature review or stakeholders
- **Red-amber:** Some evidence available from literature review but it is not relevant/out of date, limited evidence from stakeholders, stakeholders are not experts on this measure

- **Amber:** High quality evidence from either literature or stakeholders
- **Amber-green:** High quality evidence from literature or stakeholders, evidence from stakeholders is supported by some information in the literature (or vice versa)
- **Green:** High quality evidence from literature supported by stakeholder expertise.

It should be noted that the business-as-usual (BAU) level of efficiency was only informed by the stakeholder engagement, so the maximum evidence RAG rating for the BAU is amber.

Sector introduction

The construction sector is an important element of the UK economy, with output accounting for 7% of the UK's GDP.[1] Breaking down the UK construction sector into sub-sectors, the ONS data presents two broad areas of work: new construction and repair and maintenance.[2] Data from 2021 showed that of all work in the UK sector, new construction contributed to 74% of the sector's economic output, with repair and maintenance at 26%.[3] Within the broad areas are various further sub-sectors. These include housing, commercial and infrastructure. Each sub-sector, except for infrastructure, can also be classified as either public or private sector. In 2021, private new housing was the largest new build sub-sector by value, at 22% of overall work.[4]

The statistics provided in the ONS documents cited above are for any activity falling under Category F of the UK SIC code system.[5] This also includes subcontracting of work. The category excludes the manufacturing of construction products, which is classified in Section C. It also excludes the contracting of services for engineering design work, which is classified under Category M. The key difference between contracting and construction projects is the scope of work undertaken. For contracting projects, the contracting body will manage the broad process of designing, acquiring, managing, and executing the building of a structure. Construction by contrast relates to just the managing and executing part of building a structure. Throughout this work there is reference to both construction and contracting activities.

The construction sector has a broad and complex landscape of stakeholders. Each stakeholder will have varying involvement across a construction project lifecycle. This project may be related to any of the sub-sectors outlined previously. The project lifecycle includes stages design, construction process, use and end of life. Stakeholders that may be involved in these stages are architects, planning authorities, engineers, contractors, insurers and material suppliers. Each of these stakeholders are fed into three main skill sectors: contracting, services and products. This complex stakeholder landscape makes construction a high-cost, high-risk and long-term activity.[6]

Given the activities and size of the sector, the environmental impacts of the sector are substantial. Activity within the built environment is responsible for 25% of UK greenhouse gas emissions, excluding surface transport.[7] Engineering and construction is also the world's largest consumer of raw materials, taking in 3bn tonnes of raw materials and 50% of steel

[1] ONS (2023) Construction output in Great Britain: April 2023. Available at: link
[2] ONS (2023) Output in the construction industry: sub-national and sub-sector. Available at: link
[3] Ibid
[4] Ibid
[5] Office for National Statistics (2022) UK SIC 2007. Available at: link
[6] Designing Buildings (2022) UK Construction Industry. Available at: link
[7] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link

production.[8] Examining the downstream impacts, the UK generated 222.2m tonnes of waste in 2018, of which, 137.8m tonnes (62%) was generated by construction, demolition and excavation activities.[9]

Resource efficiency has been identified as an opportunity for the construction sector to reduce its environmental impact. From the supply side, material substitution and efficiency production processes to reduce wastage could reduce total materials required, and the associated emissions, energy use and waste generated. With the demand side, design strategies which include a reduction in overdesign and leaner construction could be deployed to reduce raw material demand, and the associated emissions, energy use and waste generated.

This report will outline measures to achieve resource efficiencies in the UK construction sector and the barriers and drivers in achieving them.

Sector scope

The scope of this report covers the resource efficiency of the construction of projects within the UK. There is consideration of design elements which are concerned with contracting activities undertaken that enable the delivery of actual construction. Within scope also sit the construction sub-sectors of housing, infrastructure and commercial. Each sub-sector is then further categorised by public and private as well as new and repair and maintenance.

The following areas are out of scope of this study:

- Operational emissions – operational emissions are those generated during a building's use phase. These emissions may originate from heating, cooling, ventilation, lighting and water use. Some of the resource efficiency measures found in literature discussed how to minimise operational emissions. This reduction might be achieved by using certain insulation materials for example.
- Specific materials – construction projects across all construction sub-sectors rely on an array of material types. Notable examples of materials used in construction include concrete & cement, steel and glass. Resource efficiencies which relate specifically to these materials can be found in their individual sector reports and are out of scope for this report. What is in scope for the construction sector is the resource efficiency use of these materials in context of the construction industry.

Literature review approach

The sources included in this research were identified via several routes. These included: sources shared by the Department for Energy Security and Net Zero and Defra, sources shared by sector experts, sources shared by workshop participants, or literature identified through an online search. An exhaustive list of the search strings used during the online search is provided in Appendix B, and the list of the literature that was identified and reviewed is provided in Appendix C.

A total of 111 sources were identified, with an average IAS of 4.0. These were split as follows:

[8] ARUP (2016) Circular Economy in the Built Environment. Available at: link
[9] DEFRA (2018) Official Statistics: UK Statistics on waste. Available at: link

- 35 academic papers;
- 17 industry reports;
- 7 policy documents;
- 35 technical studies; and
- 17 website articles.

More detail on the purpose and approach for these literature reviews can be found in the accompanying Technical Summary.

Workshop approach

There were 20 participants in the first workshop. The participants broadly represented the construction value chain: three construction companies, two consultants, one designer/architect, two participants with expertise in EOL/recycling, eight participants from research and academic backgrounds, one government representative and three participants from trade associations or institutions.

There were 15 participants in the second workshop. There were some instances where some stakeholders who had participated in the first workshop were unavailable but were instead replaced with someone from the same organisation in the second workshop. As with the first workshop, the participants broadly represented the construction value chain: one construction company, three participants with expertise in EOL (reuse and recycling), seven participants from research and academic backgrounds, one government representative and two participants from associations or institutions.

List of resource efficiency measures

The construction sector is a large and complex sector which depends on other sectors to produce its raw materials/building components. There are a large number of individual materials used in construction projects. Where possible, discussion has been provided on how individual materials perform in the context of a measure. However, the literature does not always cover every individual material for each measure.

For this research, the construction sector has been defined as starting with building design and ending at building end-of-life/next life. Any resource efficiency measures that occur earlier in the supply chain (e.g., in the manufacture of cement and concrete, steel, glass or plastics sectors) are not included in this report but included in the reports for those specific sectors.

This project has identified six measures which span the construction lifecycle shown in Table 2 below.

Three measures sit in the design stage, and one in each of the manufacture and assembly, use and end of life (EoL) stages.

Table 2: List of resource efficiency measures for the construction sector

#	Lifecycle stage	Strategy	Measure name	Measure indicator
1	Design	Use of secondary raw materials	Use of reused content in buildings	% reused content used in a building by mass
2	Design	Material substitution	Use of material substitution for embodied carbon reduction across the whole lifecycle of a building	% CO_2e reduction in embodied carbon for the entire lifecycle associated with material substitution
3	Design	Light-weighting	Reduction of over-design & delivery in building structures	% reduction in material mass in construction relative to 2023 levels
4	Manufacture and Assembly	Reduction in production wastes	Reduction of construction process wastage	% of total construction materials wasted by mass
5	Use	Lifetime extension	Reducing need for primary material production through repurposing/repair of the existing building stock	% change of new builds avoided by repair/refurbishment of the existing building stock relative to 2023 levels
6	End of Life	Recycling and Reuse	Recovery of building materials for reuse / recycling	% of C&D waste recovered for reuse / recycling

Appendix D contains any measures that were identified but have not been included in this report, alongside the reasons for their exclusion.

Drivers and Barriers

Drivers and barriers were categorised using two separate systems:

1. The PESTLE framework which is focused on the types of changes: political, economic, social, technological, legal and environmental;

2. The COM-B framework which is focused on behaviour change:
    - **Capability**: can this behaviour be accomplished in practice?
        - Physical Capability – e.g., measure may not be compatible for certain processes
        - Psychological Capability – e.g., lack of knowledge
    - **Opportunity**: is there sufficient opportunity for the behaviour to occur?
        - Physical Opportunity: e.g., bad timing, lack of capital
        - Social Opportunity: e.g., not the norm amongst the competition

- **Motivation**: is there sufficient motivation for the behaviour to occur?
    - Reflective motivation: e.g., inability to understand the costs and benefits,
    - Automatic motivation: e.g., lack of interest from customers, greater priorities

1.0 Measure 1 – Use of reused content in buildings

1.1 Construction resource efficiency measure

1.1.1 Description

With the aim of increasing the circularity of materials within the construction sector, there is an increased drive to focus on how material life can be extended. One means of achieving this is to increase the reuse of content in buildings. Specifically, reuse occurs when products and components are used again without applying a transformational process (an example of a transformational process is recycling).[10] This measure discusses the use of reused content, in refurbishment, retrofit and new build.

This measure concentrates on building products and components that have been diverted from becoming waste because of their reuse potential. The reused products and components can come from the deconstruction of an existing built asset, or from excess new building products that were not used in their original construction project.

The reuse potential of a building product/components varies substantially, depending on a range of factors including building type, function in the original building (if applicable), function in the new building, constituent materials and ease of extraction at end-of-life. For example, this measure is considered much more applicable in the commercial and residential sub-sectors than it is in infrastructure, as infrastructure projects tend to be large-scale and unique meaning there is less scope for substantial reuse of materials/components. Across all building types non-structural elements of a building are often easier to reuse than structural elements as they are currently easier to extract at end-of-life and they are not integral to the structure and safety of the new building. However, with new efforts into certification the reuse of structural components is become less challenging. Variations in ease of reuse also exist between materials and within materials, when considering their construction methods. For example, reuse of steel is made challenging when welding is used as a manufacturing method and made easier when bolted joints are used. This measure focuses more on how materials with reuse potential are integrated into a new building. Measure 6 will focus on materials are extracted from the first stage of their lifecycle.

It is important to distinguish reuse from recycling as they have unique barriers and drivers. Steel beams are a good example to illustrate the difference. If a steel beam is recycled, the raw material will be placed into a furnace and processed into its constituent materials before being re-manufactured through for example rolling. By contrast, a steel beam destined for reuse will not be broken down into constituent materials and its existing form will be maintained, with limited or no extra reprocessing required. Discussion of the recycled content of specific materials, namely glass and steel, is included in their respective sector reports (note glass is included in Phase 2 of this research).

[10] Designing Buildings Wiki (2021) Reuse of building products and materials – barriers and opportunities. Available at: link

1.1.2 Examples in practice

Four example materials that offer reuse potential in the construction sector are described below. Note, these materials are not a comprehensive list, but are the materials for which relevant information and data was found in the literature review.

Quantitative data supporting the actual reuse rates was not found for all materials. As such, just because materials such as bricks and woodwork do not have current levels of efficiency disclosed, does not imply they cannot be reused, rather there was no data found supporting the rate at which they were reused.

Structural steel

- The construction sector is the biggest user of steel produced in Europe.[11] Finished products the construction sector uses include heavy structural sections, rebar and light structural sections.[12] Not all of these products are as amenable to reuse as others. For example, where heavy steel sections use welded connections, facilitating their reuse will be challenging. As designers are still learning and implementing the practice of design for reuse, it may be some time before the majority of joins become bolted instead of welded. Products which are most suited to reuse include steel piles, structural steel members and light gauge sections such as railings. [13]
- When reusing steel, it is inspected in its primary lifecycle application, with its dimensions and mechanical properties tested. The section is then sand blasted to remove coatings before being modified to the properties required for the second lifecycle stage. The Steel Construction Institute has set out a process of how to characterise and design with reused steel through various protocol releases.[14] Steel can be used for structural applications in its second lifecycle, accounting for a potential reduction in mechanical performance relative to its first lifecycle.
- The PROGRESS project, a recent and on-going joint UK-EU collaboration, is investigating the re-use of structural steel, specifically in single storey buildings (e.g., distribution warehouses).[15] This building type accounts for 60% of structural steel used in the UK, representing a significant mass of primary material and thus an opportunity to improve resource efficiency by avoiding the need for primary production.[16]

Woodwork, flooring and off-cuts

- In its reuse guide, Zero Waste Scotland identified wood products such as beams and joists, railway sleepers, floorboards, staircases, doors, windows as well as wood off-cuts generated during construction to all have the potential for reuse either for the original application[17] (e.g., beams as beams) or for new applications (e.g., railways sleepers in landscape applications).

[11] EUROFER (2021) European steel in figures 2022. Available at: link
[12] SteelConstruction (2022) Recycling and reuse [Online], Available at: link
[13] Ibid
[14] Steel Construction Institute (2018) Protocols [Online], Available at: link
[15] Reuse of steel framed buildings (2020) SCI Steel [Online], Available at: link
[16] Ibid
[17] Zero Waste Scotland (2023) Maximising re-use of materials on-site. Available at: link

Bricks, concrete and masonry

- These products are durable and potentially long-lasting. Reclaimed bricks and masonry may be selected for aesthetic reasons, but they must be technically appropriate for new work. Before reuse, they typically require testing to confirm that they are suitable for the purpose intended.[18,19]

Modular raised access flooring

- These systems are often used in commercial premises (e.g., offices) to allow the passage of mechanical and electrical services under the floor. The UKGBC cites a provider offering raised access flooring, which has been refurbished for re-use.[20] The company, RMF Services, runs a take-back scheme.[21] This involves tacking back used flooring products, testing them and providing a new warranty for the products.

1.1.3 Measure indicator

The indicator selected was the **% of reused content used in a building by mass.**

A formal reused content calculation method (e.g., as part of an ISO standard) was not identified during the study. In standard ISO 14021,[22] the definition of **recycled content** is 'the proportion, by mass, of recycled material in a product', and so a similar approach was proposed for reused content.

The other indicators that were identified in the literature and by stakeholders are outlined below:

- **Material circularity index -** An academic report by Gonzelez et al. discussed the material circularity index (MCI) as an indicator for the combined recycled and reused content.[23] Due to this indicator comprising recycled and reused content, it was disregarded for the purposes of this study.

- **Material specific indicators -** Several stakeholders flagged that the reuse rate will vary substantially between materials (e.g., steel and timber are more likely to be reused than concrete), and so it might be more meaningful to have an indicator for each key material type, rather than a combined indicator across all materials. A similar point was made by stakeholders about Measure 6. However, whilst data on materials, such as structural steel, is available, there is no data available on woodwork, bricks, masonry and modular raised flooring. As such, this indicator was discarded.

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[18] RMF Services (2019) RMF Eco Range Testing [Online]. Available at: link
[19] Brick Development Association (2023) Reuse of clay brickwork. Available at: link
[20] UKGBC (2021) Raised Modular Flooring. Available at: link
[21] RMF Services (2019) RMF Eco Range Testing [Online]. Available at: link
[22] WRAP Cymru (2022) Low Carbon & Resource Efficiency Construction Procurement. Available at: link
[23] Gonzalez, A and Sendra, C and Herena, A and Rosquillas, M and Vaz, D (2021) Methodology to assess the circularity in building construction and refurbishment activities. Available at: link

1.2 Available sources

1.2.1 Literature review

The full list of sources covering this topic either qualitatively, quantitatively, or both were:

- One peer reviewed journal published by Gonzalez et al.[24] (IAS 5);
- Three technical studies by The International Energy Agency (IEA)[25] (IAS 4), the UK Green Building Council (UKGBC) (IAS 5)[26] and Zero Waste Scotland (ZWS)[27] (IAS 5);
- One policy document published by the House of Commons Environmental Audit Committee (IAS 3);[28]
- Two industry reports by the United States Environmental Protection Agency (EPA) (IAS 2)[29] and London Energy Transformation Initiative (LETI) (IAS 4);[30] and
- One website article published by SteelConstruction (IAS 2).[31]

Whilst the sources were classified as mid-to-high quality, and clearly identified the role for reused content in a more resource efficient construction sector, they contained limited quantitative data on reused content by mass at a building level. The highest IAS was 5 and the lowest was 2, with an average IAS of 3.7 across the sources. Five of the sources were based in the UK and three were based at a global level. Whilst the concept of reusing components/material in the construction sector was discussed qualitatively in eight publications, there were only two sources that provided quantitative data points.

Of the literature discussing reused content, they were mainly case studies and sources discussing steel reuse as a specific material. The majority of sources were looking at the environmental benefits of reuse, namely avoiding waste being sent to landfill, and the reduction of carbon emissions relating to reaching the national net zero carbon by 2050 target. Four of the studies were representative of the UK market. However, of the other four sources, three were generic and applicable to the UK. The final source was published in the US context, which again was deemed applicable to the UK market.

Based on the literature that has been found during this project, there is limited evidence covering reuse rates across the construction sector for many materials.

1.2.2 Workshops

There was less discussion on this measure's levels of efficiency relative to other measures; this was possibly due to the nature of the organisations represented at the workshop. Less than 10% of attendees were from construction companies, who are likely to give the most up to date information on incorporating reused content into designs. The barriers and drivers

[24] Ibid
[25] International Energy Agency (2020) Iron and Steel Technology Roadmap. Available at: link
[26] UKGBC (2019) Circular economy guidance for construction clients. Available at: link
[27] Zero Waste Scotland (2023) Maximising reuse of materials on site. Available at: link
[28] House of Commons Environmental Audit Committee (2022) Building to net zero: costing carbon in construction. Available at: link
[29] US Environmental Protection Agency (2010) FY2004 OSWER Innovation Pilot Results Fact Sheet – Deconstruction and Design for Reuse. Available at: link
[30] LETI (2020) LETI Climate Emergency Design Guide. Available at: link
[31] SteelConstruction (2012) The recycling and reuse survey [Online]. Available at: link

received more engagement in discussion than levels of efficiency, providing insights into how levels of reused content can be improved. The measure received a high number of votes from attendees on both the levels of efficiency and the barriers and drivers.

The pre-workshop surveys completed by participants identified that the literature reviewed for this measure covered the measure well, and no further sources were identified by stakeholders.

1.3 Drivers & Barriers

A range of drivers and barriers influence the extent to which this measure can be achieved. An initial list of drivers and barriers were identified in the literature, then refined by stakeholders in the workshops. The most notable drivers and barriers, including their PESTLE and COM-B categorisation, are described in the following sub-sections.

The most significant drivers and barriers, as voted for by workshop participants, are highlighted in bold.

1.3.1 Drivers

Five drivers were identified for Measure 1. Two were social (specification guidance, reuse networks), one was on environmental benefits, one on economic opportunities and the other on regulatory changes. The complete list of drivers for using reused content in building design and construction is shown in the table below, with the top drivers marked in bold.

Table 3: Drivers for construction Measure 1

Description	PESTLE	COM-B
Opportunity to develop a market around reused products	**Economic**	**Motivation – reflective**
Environmental benefits: reduction of raw material requirements and reduction of embodied carbon.	**Environmental**	**Opportunity – social**
Guidance on the specification of reused content.	Social	Opportunity – social
UK reuse networks	Social	Opportunity – social
Requirement of circular economy statements	Legal	Motivation – reflective

Opportunity to develop a market around reused products

Stakeholders concluded that the most significant driver for this measure was stimulation of the reused material market amongst product manufacturers. By increasing the reused content within buildings, the market for reused content will grow. This will in turn lead to a greater availability of reused products for designers, engineers and architects to select for construction projects. However, stakeholders highlighted that this potential driver was also a barrier, as there needs to be a first mover between the supplier and the user of reused material. Section 2.3.2 discusses the barriers that are preventing the uptake in reused content. As will be discussed in Section 2.3.2, one of the barriers to further uptake is the significant length of time that may elapse between the specification of reused material required and its subsequent use in a construction project. There is a possibility that this long period of time would enable the market to respond to the new demand for reused material, ensuring the specifiers needs can be met.

Environmental benefits: reduction of raw material requirements and reduction of embodied carbon.

Stakeholders also highlighted that if the market can be stimulated, there are significant environmental benefits of reusing products by reducing environmental impacts through reduced raw material requirements and significant carbon savings.[32] These carbon savings originate from the removal of energy intensive processing steps that come from, for example, the furnace used in the steel and glass manufacturing process. As whole life carbon assessments (WLCAs) become more prevalent within the construction industry, sufficing that the functional and economic requirements are still met, the use of reused materials may increase as they are the carbon savings from reuse become more visible.

UK reuse networks

On the supply side, suppliers may hesitate to offer more reused content as there is insufficient demand. Driving supply forward is the fledgling presence of UK reuse networks, such as the 'Excess Materials Exchange'.[33] This online platform lists materials that are ready for reuse, along with the option for users to disclose the products history. The UKGBC provides a more comprehensive list of reuse networks in its Circular Economy Guidance report.[34]

Whilst these networks are driving action on this measure, they are currently small and few in number. The immature nature of these networks currently also acts as a barrier to achieving resource efficiency through this measure on a larger scale.

Guidance on the specification of reused content.

Increasing guidance on the specification of reused content by clients is slowly stimulating the market of reused materials amongst product manufacturers. For example, WRAP procurement guidance covers how to specify recycled and reused content.[35] The document provides specific percentages of reused and recycled content in a specification and correlates them to standards. Standard practice is less than 15% reused/recycled content, good practice 15-20% and best practice 20%+. The guidance also provides valuable commentary on what different standards should be applied to construction specifications. It is plausible that engineers and architects can specify for reused content in a confident and informed manner by using the guidance. With the confidence provided by the guidance, it is more likely that the specification request will be made in the first instance.

Requirement of circular economy statements

One stakeholder expressed that the Circular Economy statements introduced by the Greater London Authority[36] should drive positive change with reused content due to the focus on maximising residual value and value over the lifetime. Furthermore, the pre-demolition audits

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[32] WRAP (2022) Low carbon and resource efficient construction procurement. Available at: link
[33] Excess Material Exchange (2023). Available at link
[34] UKGBC (2019) Circular Economy guidance for construction clients. Available at: link
[35] Ibid
[36] Greater London Authority (2022) London Plan Guidance. Circular Economy Statements. Available at: link

that are recommended in the Circular Economy statements will identify materials suitable for reuse, increasing the supply of reused content and driving this measure forward.

Other insights

While cost savings were cited as a driver of reuse by workshop stakeholders, within the literature, there does not appear to be consensus on the commercial benefits. Whilst one source stated that there are no commercial drivers for reuse[37], this source was relatively outdated (published in 2012). A more recent report (from 2023) provided multiple reasons why there are commercial benefits of reuse.[38] Benefits of reuse include reduced waste disposal costs, avoidance of primary material use and positive publicity.

1.3.2 Barriers

Five barriers were identified for Measure 1. Two were technological (lack of supply, limited data), two were legal (certification and liability) and one was social for best practices. The complete list of barriers to using reused content in building design are shown in the table below.

Table 4: Barriers for construction Measure 1

Description	PESTLE	COM-B
Lack of consistent supply of reused products or components.	**Technological**	**Capability – physical**
Limited data availability on the location, quality and quantity of reusable components in the existing building stock.	**Technological**	**Capability – physical**
Lack of certification instruments.	**Legal**	**Capability – psychological**
Issues with liability, insurance and warranties.	Legal	Opportunity – social
Lack of best practices on reuse & social perception.	Social	Opportunity – social

Lack of consistent supply of reused products or components.

The most significant barrier, according to stakeholders, was the lack of a consistent supply of reused products, compared to virgin materials. Virgin materials are considered to be more predictable in their availability.[39] Stakeholders mentioned that this was a particular challenge for SME's.

This is a current limiting factor rather than a systematic issue that will prevent further reused content being used in the future. As reuse becomes more common the quantity of materials available for reuse will increase, reducing the impact of this barrier.

[37] SteelConstruction (2012) The recycling and reuse survey [Online]. Available at: link
[38] Zero Waste Scotland (2023) Maximising reuse of materials on site. Available at: link
[39] Kozminska, U (2019) Circular design: reused materials and the future reuse of building elements in architecture. Process, challenges and case studies, IOP Conf Series. 225. Available at: link

Limited data availability on the location, quality and quantity of reusable components in the existing building stock.

Linked to the lack of availability, stakeholders also discussed the lack of information about reused products – this applies both to data on availability/location and to the previous in-use history:

- Search costs: There is typically limited data available on the location, quality, and quantity of reusable products in the existing building stock. This translates into additional cost and time to try and identify what building components can be re-used.[40] Currently there is limited information covering the UK reuse networks. One example is the previously mentioned 'Excess Materials Exchange'.[41] The lack of data availability is also compounded by the dynamic nature of supply. One stakeholder raised the point that the time between design – with reused content – and production of the building may be 1 to 2 years. With such significant time elapsing and the possible associated uncertainty may lead to materials no longer being available. Examples of uncertainties would stem from where the material is stored and who would bear the financial burden of the storage.
- Information failures: The lack of knowledge surrounding material's in-use history, including aspects such as loading conditions and historic maintenance and servicing, prevents and limits reuse. Fatigue of steel due to loading, for example, can be important when considering the re-use of structural steel.[42]

Material passports have been proposed as an enabling technology to overcome these barriers.[43] Additionally, inventories or networks such as those included in the UKGBC report, are believed to have the potential to increase the uptake of reused materials.[44] An example of a company, based in the Netherlands, looking to enable such inventories is attempting to capture information on the materials which already exist in our building stock. [45]

Lack of certification instruments.

According to stakeholders, the lack of proper certification was another important barrier, a fact also corroborated in a literature report.[46] It was discussed that there is a need to develop a more rigorous standardisation of materials that have been reused. This lack of standardisation is observed in the literature also, with only protocols for the reuse of structural steel produced by the Steel Construction Institute found in the literature.[47] Stakeholders noted that developing methods to assess material quality, or grading, would generate greater confidence in reused materials – this will stimulate further growth of reused products. From an economic perspective, it is likely there will be additional costs of the certification process. Coupled with the cost of refurbishing, transportation and potentially storage – and depending on which stakeholder bears the cost – the cost of reused content may be greater than virgin material.

Issues with liability, insurance, and warranties.

[40] BAMB, (2016) Synthesis of the state of the art – D1. Available at: link
[41] Excess Materials Exchange (2022) Vision [Online]. Available at: link
[42] SteelConstruction (2022) Recycling and reuse [Online], Available at: link (Accessed 2nd March 2023)
[43] Green Alliance (2023) Circular Construction. Available at: link
[44] UKGBC (2020) How to guide for reuse. Available at: link
[45] MADASTER (2023) Our purpose – Main website. Available at: link
[46] Brick Development Association (2023) Reuse of clay brickwork. Available at: link
[47] Steel Construction Institute (2019) Protocol for reusing structural steel. Available at: link

Linked to the previous point about certification, liability has also been identified as a key barrier. Reused products may not be covered under warranty and insurances. For example, reused bricks are not covered under any British Standards. In instances where planning permission states exclusive use of reclaimed bricks in planning consents, specifiers must have insurances which covers this use. The obligation of increased quality assurance and certification would probably hamper the existing market for reusable construction products due to the additional costs and time required.[48]

Lack of best practices on reuse & social perception.

Finally, it has been highlighted that there are not enough examples of best reuse practices to provide evidence for wider industry adoption.[49] Examples of successful case studies could help overcome perception issues from the user's point of view.

1.4 Levels of efficiency

Table 5: Levels of efficiency for construction Measure 1

Indicator: % reused content used in a building by mass			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	< 5%	11-20%	5-15%
Confidence level	Red – Amber	Red – Amber	Red

1.4.1 Current level of efficiency

While data on the use of recycled content[50], and combined recycled and reused content[51] at a building level are reported in the literature, data on just the reused content alone was very limited.

As there was such limited data for the building as a whole, the literature search investigated reuse rates of specific materials. Steel was the only material found to have studies conducted on reuse rates. The reuse rate of structural steel is given as 'currently low' in a high-quality literature source with an indicative applicability score (IAS) of 4.[52] One web source, discussing reuse rates for steel such as heavy structural sections and light structural steel, takes data from the 2010/12 Eurofer survey on steel use. The maximum reuse rate was for steel piles (15% reuse) and the lowest reuse rate was for rebar and internal light sheeting (0% reuse)[53]. It was not disclosed whether the material would be reused on new build construction projects or retrofit projects.

In the qualitative discussion, stakeholders expressed that the current levels of reused content are likely to be very low. Stakeholders proposed the very low reuse rates was due to the very

[48] BAMB, (2016) Synthesis of the state of the art – D1. Available at: link
[49] Hale, S.E et al. (2021) The reuse of excavated soils from construction and demolition projects: limitations and possibilities. Available at: link
[50] WRAP Cymru (2022) Low Carbon & Resource Efficiency Construction Procurement. Available at: link
[51] WRAP Cymru (2022) Low Carbon & Resource Efficiency Construction Procurement. Available at: link
[52] International Energy Agency (2020) Iron and Steel Technology Roadmap. Available at: link
[53] SteelConstruction (2022) Recycling and reuse [Online], Available at: link (Accessed 2nd March 2023)

limited number of reused materials/components that are available to the market currently. It's possible and likely there are other barriers preventing the uptake of reused content, such as lack of certification instruments or supply uncertainty as discussed in Table 3. One stakeholder provided feedback that one of the most successful construction products to be reused is raised access flooring.

Only three workshop attendees voted on the numerical ranges, and all agreed on the range 0% to 5%. Despite the low number of votes, a sector expert is included in those who voted. One stakeholder also provided an estimate verbally, that 1-2% of timber used in a construction project is reused content.

Overall, the sources of quantitative data for the current level of efficiency were poor and the stakeholders did not reach a consensus. Therefore, the current level of efficiency of <5% will be stated for this measure. A red/amber evidence RAG rating was given to this measure. Whilst there are high quality sources, they only disclose levels of efficiency that are relevant to one material, rather than the construction sector as a whole. Furthermore, some stakeholders could not provide estimates on the levels of efficiency.

1.4.2 Maximum level of efficiency in 2035

One 2010 case study published in the United States found that 20% by mass of a single-family residence was reused in the construction of a newly-built larger, commercial space.[54] This was the only level of efficiency at a building level identified in the literature review. This is a case study demonstrating what could be achieved technically rather than what is currently being achieved across the sector with current construction practices and uses a different indicator from the one proposed here (% of a building which is reused vs. % of a building which is reused components). Within the case study, there was no breakdown of what building components were reused, for example, super-structure, finishings or individual components.

One further source published by the Green Alliance, discusses how specific instances of reuse could affect the resource efficiency of the construction sector.[55] The instances modelled include reuse of structural steel, timber and bricks, repurposing of foundations and increasing reuse of glass, stone, aluminium and plastic by 5%. These packages give a 3% reduction in raw material usage for the construction sector. This study covers the majority of the materials that are suitable for reuse and is a source with high credibility. However, it is important to note that this study's indicators do not align with the indicator used in this study.

The workshops received 6 votes out of 15 participants. Half of the votes were in the 11-15% range and the other half >20%, giving no consensus on the levels of efficiency. One stakeholder mentioned that there is much unlocked potential in making structural products from recovered timber. Two of the experts in this topic area cast votes, with one casting their vote as >20% and the other as 11-15%. Three stakeholders stated that they did not know what levels of efficiency were achievable, including two sector experts.

One stakeholder alluded to the fact that technically, there is scope to increase the reused content in buildings, with the market situation being the limiting factor. For example, at an individual project level, a stakeholder stated that timber could be sourced from 100% reused content. There was no further quantitative data on other reused materials provided. However, the qualitative trend garnered from stakeholder discussions and literature confirms that the

[54] US Environmental Protection Agency (2010) FY2004 OSWER Innovation Pilot Results Fact Sheet – Deconstruction and Design for Reuse. Available at: link
[55] Green Alliance (2023) Circular construction: Building for a greener UK economy. Available at: link

maximum level of efficiency can technically be higher than the current level of efficiency. How quickly this maximum level of efficiency is reached, will depend on how rapidly and effectively barriers such as lack of information and logistical support are removed.

Due to there being no industry wide study and lack of consensus from the workshops, the widest range has been taken at 11-20%. The range has been curtailed at 20% given the balance of votes between the 11-15% and >20% range. A red-amber evidence RAG rating was assigned to this measure. This reflects that there was little literature covering this topic and limited consensus from workshops.

1.4.3 Business-as-usual in 2035

One stakeholder explained that structural materials on new build projects generally do not have any reused proportion, but this will likely change in the next few years. It is expected that this will mostly be due to improved certainty over the quality of reused content through increasing awareness and certification, and the corresponding effects on insurance and liability. Such uncertainty would be particularly pronounced for structural components, which are particularly important for a building's safety.

This suggests that the business-as-usual scenario should have higher reused content than the current level of efficiency. Stakeholders shared that the extent to which there is an increase will likely depend on the market health of reused content, with the market situation improving only if or when the supply or demand side situation improves first and breaks the current 'first mover' situation.

Only three votes were cast for quantitative ranges: one for the range 0-5%, the other two for the range 6-10%. In the discussion, stakeholders expressed different viewpoints:

- one stakeholder specialised in reuse mentioned that 5% would be the maximum BAU level under the current mix of drivers and barriers;
- another stakeholder from academia estimated a range of 10% to 15%;
- another stakeholder from academia estimated a range of 15% to 20% in a best-case scenario. Arguably, this level of efficiency is more pertinent to the maximum level of efficiency, given its reference to 'best case'. As it was discussed in the context of BAU, it is still reported in this section.

There was consensus that the key barrier affecting this measure is the market situation and lack of supply. It is not clear from stakeholders or literature when this barrier, as well as others, will be removed. One topic expert, part of an organisation specialising in the circular economy, cast their vote in the 0-5% range. As the 15-20% range was declared as a best case scenario, something not likely to be included in the business as usual setting, it is not included in the reported range.

Given the uncertainty associated with realising the range of levels of efficiency, the full range of relevant votes will be reported: 5-15%. The lower end of the range is reported as 5% to align with the current level of efficiency. A red rating is given for this level of efficiency due to the limited number of votes cast.

2.0 Measure 2 – Use of material substitution for embodied carbon reduction across the whole lifecycle of a building

2.1 Construction resource efficiency measure

2.1.1 Description

This measure refers to the substitution of materials with materials that would bring about a reduction in whole building embodied carbon, while providing the same level of performance (e.g. function, safety).

The literature search for this portion of the study sought out materials used in construction which on an otherwise equivalent basis (accounting for factors such as functional, safety and financial performance) would bring about a reduction in whole building embodied carbon.

When discussing the products lifecycle, we deferred to British Standard BS 15978 which provided a definition of raw materials production, construction, and end of life.[56] This purposefully excludes the use/operational phase of the lifecycle which has also been deemed out of scope for this study.

The sub-sectors this measure applies to are commercial, residential and infrastructure.

There was discussion in the literature of low carbon versions of specific materials, where relevant these are covered in the sector-specific reports. Low carbon cement for example, is covered under Measure 1 in the Unlocking Resource Efficiency: Phase 1 Cement and Concrete Report, with recycled steel covered in the Unlocking Resource Efficiency: Phase 1 Steel Report, Measures 3 and 4.

2.1.2 Examples in practice

This section provides examples of materials that have been discussed in the literature as having the potential to reduce whole life carbon emissions in the construction sector. It is not an exhaustive list of materials, but a list of the materials that were found in the literature review. The inclusion of a material in this report does not imply it is low carbon in every scenario.

Given the complexities of buildings and infrastructure, reducing the embodied carbon of the material may not always result in reduction across the whole lifecycle (e.g., end of life emissions might vary between materials). Therefore, there may not always be a 'one size fits all' approach to low-carbon materials in construction.[57]

To define a low carbon construction material, a whole life carbon assessment (WLCA) is needed which takes into account not only the carbon emissions associated with different materials, but also the impact of different materials on functionality, lifespan and safety. This is coined as the phrase, lifecycle thinking. If for example, a material substitution is suggested

[56] European Standards (2011) Sustainability of construction works. Assessment of environmental performance of buildings. Calculation method. Available at: link
[57] The Institution of Structural Engineers (2021) Making low-carbon material choices. Available at: link

which would produce a lower carbon impact in the production lifecycle stage, but the replacement material will need to have twice the mass of material going into the building, there may not be a net carbon emissions reduction over the whole lifecycle.

This is reflected in relevant industry guidance, for example when considering timber, Royal Institution of Chartered Surveyors advice states:

> *'[the] approach is also proposed to encourage more holistic thinking about the use of timber formwork based on what the potential is in the long run, rather than simply within the very limited boundary of the project under study'.*[58]

This measure was scoped to be intentionally broad. It attempted to fully characterise what material substitution could be made, at what rate these substitutions were happening and the substitutions potential carbon benefits.

The following materials are those which have been shown, on a functionally equivalent basis, to reduce embodied carbon emissions compared to using another material:

Timber framing instead of masonry

- Timber framing can be used to replace masonry, which is currently the common choice for UK framing. Masonry frames are made up of bricks and blocks. Timber frames can fulfil the same function as masonry, being used as open and closed panel framing systems.[59] On a functionally equivalent basis, substituting timber for masonry has been shown to reduce embodied carbon of a house by 1.7-3.2 tonnes of CO_2e per house, with results fully discussed in Section 3.4.1.[60] It was also disclosed by stakeholders that in Scotland, approximately 80% of new build homes already use timber framing.

Cross laminated timber instead of concrete framing

- Cross-laminated timber (CLT) is an engineered product, comprising multiple layers of sawn wood that is glued together. Each layer alternates in its orientation, rotating 90 degrees between layers. It has been demonstrated as an alternative for concrete floor, roof and wall elements. The results of the study are expanded in Section 4.4.1, but substituting concrete frames for CLT, on a functionally equivalent basis, can reduce the embodied carbon by 12.8-18 tonnes of CO_2e per flat. [61] Recarbonation of concrete was not included in the scope of the study calculating this figure.

High-strength steel instead of standard steel

- High-strength steel enables resource efficiency by what are known as 'specific' strength properties. Specific strength is a measure of a materials strength, scaled to its density which can also be referred to interchangeably with mass if the same volume is considered. Therefore, high strength steel has a higher specific strength than standard steel, meaning it can perform the same functional role as standard steel, at a lower total mass. A case study showcasing the design of a stadium roof, showed that a high

[58] RICS (2017) Whole life carbon assessment for the built environment. Available at: link
[59] Structural Timber Association (2023) Timber frames [Online]. Available at: link
[60] The BioComposites Centre (2019) Wood in Construction in the UK: An analysis of carbon abatement potential. Available at: link
[61] The BioComposites Centre (2019) Wood in Construction in the UK: An analysis of carbon abatement potential. Available at: link

strength steel design will require less material than standard steel. [62] The carbon saving which resulted was 900,000 kg of CO_2e over the building's lifecycle. However, it is not a given that high-strength steel will reduce the carbon emissions of every project, as the reported carbon saving is for a very specific infrastructure case study, unlike the more generic scenarios considered for the timber and CLT substitutions discussed prior. Transport distances and recycling capacity are factors are examples of factors that should also be considered through conducting a whole lifecycle carbon assessment.[63]

2.1.3 Measure indicator

The indicator selected for this measure was the **% CO_2e reduction in embodied carbon for the entire lifecycle associated with material substitution.**

This measure focuses specifically on embodied carbon – over the lifecycle. This covers the production, construction process, use and end of life impacts. The impacts do not relate to operational carbon, such as energy use, as these impacts are out of this project's scope.

In line with the rest of this report, it was initially attempted to find levels of efficiency set at an economy wide/all materials level. However, as will be discussed in Section 2.4, there was minimal literature found giving quantified levels of efficiency for this measure. As such, data fully aligned to the scope of this measure was not found. Instead, the quantitative information found for this measure generally reflected what could be achieved if construction systems are changed in construction of residential new builds, rather than the national economy as a whole.

Discarded indicators include:

- **% CO_2 reduction in whole life carbon associated with material substitution.** Whilst this indicator was discussed, the whole life carbon definition raised issues with scope. Any considerations associated with the use phase or operational emissions were considered out of scope for this study. As the definition of whole life carbon includes operational emissions, this indicator was discarded.
- **% new build homes using timber frames** – this indicator was discarded when accounting for stakeholder feedback. The feedback stated that the measure was misleading and implied that timber was the only material substitution which could be made; and
- **Number of buildings built using engineered wood products instead of steel** – this indicator was also discarded as it is limited to a single material and not representative of the whole sector; and
- **% use of timber in design by building mass** – this was again discarded as it was limited to a single material and not representative of the whole sector.

[62] University of Sheffield (2021) High strength steel offers the potential to lower CO_2 emissions in the automotive industry. [Online]. Available at: link
[63] International Molybdenum Association (2013) High-strength steel – sustainable and money saving. Available at: link

2.2 Available sources

2.2.1 Literature Review

Five literature sources discuss the topic of material substitution in the construction sector, from the standpoint of carbon emissions reduction of specific materials:

- Two policy documents by the then-named Department for Business, Energy & Industrial Strategy (IAS 4) [64] and the House of Commons Environmental Audit Committee (IAS 3);[65]
- One academic report by The BioComposites Centre (IAS 5);[66]
- One industry report by the Green Alliance (IAS 5);[67] and
- One technical report by the International Molybdenum Association (IAS 4).[68]

The lowest IAS score of the sources was 3, and the highest 5, with an average IAS of 4.2. One quantitative data source was identified on the potential emissions reductions at a national level from substituting timber for existing materials (no specific materials were given). [69] Other sources focussed on the impact of individual material substitutions, namely timber for masonry and cross-laminated timber for concrete.[70] [71] Three of the reports were published specifically considering the UK context. Importantly, the reports by The BioComposites Centre and the Green Alliance – both keys report for this section, were set at the UK level. One report was set at an international level and deemed applicable to the UK market also.

From the literature sources, there were no discussions identified covering how many material substitutions are currently being made. Instead, the literature reports on the carbon savings that could be made if certain material substitutions were used. This is reflected in the structuring of the measures levels of efficiency discussed in Section 3.4. Further research investigating the rate at which material substitutions are currently made would add value to further resource efficiency research.

There were also no sources identified in the literature that had quantified data for the overall sectoral impact of making multiple material substitutions. There was one literature source which did discuss embodied carbon savings at an economy level, but only for timber.[72]

The complexity of the sector could explain this lack of literature.

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[64] BEIS (2017) Future capacities and capabilities of the UK steel industry. Available at: link

[65] House of Commons Environmental Audit Committee (2022) Building to net zero: costing carbon in construction. Available at: link

[66] The BioComposites Centre (2019) Wood in Construction in the UK: An analysis of carbon abatement potential. Available at: link

[67] Green Alliance (2023) Circular construction: Building for a greener UK economy. Available at: link

[68] International Molybdenum Association (2013) High-strength steel – sustainable and money saving. Available at: link

[69] The BioComposites Centre (2019) Wood in Construction in the UK: An analysis of carbon abatement potential. Available at: link

[70] Ibid

[71] House of Commons Environmental Audit Committee (2022) Building to net zero: costing carbon in construction. Available at: link

[72] The BioComposites Centre (2019) Wood in Construction in the UK: An analysis of carbon abatement potential. Available at: link

2.2.2 Workshops

This measure received good engagement from the stakeholders, with lots of discussion in both workshops one and two. Workshop one revealed a need to re-scope the measure and indicator. Taking into account stakeholder feedback, the measure was changed from ‘Material substitution for low carbon materials’ to ‘Use of materials substitution for embodied carbon reduction across the whole lifecycle’. The indicator was changed from ‘New build homes using timber frames’ to ‘% CO_2 reduction in embodied carbon for the entire lifecycle associated with material substitution’. Changing this measure was instigated by a need to address the whole lifecycle before deeming something to be low or lower carbon than another material. Furthermore, the indicator was changed to provide an industry average approach as opposed to a specific material.

Voting in workshop two was undertaken by a small number of stakeholders, with limited engagement. Stakeholders commented that the level of efficiency is challenging to comment on given the significant number of variables which affect any estimates.

2.3 Drivers & Barriers

2.3.1 Drivers

Three drivers were found for Measure 2. All three were technological. The drivers for measure 2 are shown in Table 6. The most significant drivers, as voted for by workshop participants, are highlighted in bold.

Table 6: Drivers for construction Measure 2

Description	PESTLE	COM-B
Increased uptake of WLCA for construction projects	**Technological**	**Capability – psychological**
Reducing emissions	**Technological**	**Capability – physical**
Development of domestic supply chain of UK wood products.	Technological	Capability – physical
Industry initiatives	Environmental	Opportunity - social

Increased uptake of WLCA for construction projects

The only driver which received notable votes in the workshop was the increased uptake of WLCA in the construction sector. This increased uptake of WLCA is corroborated in the literature by the recent publication of guidance covering how to conduct a WLCA for construction by bodies such as LETI and the Greater London Authority. [73] [74] The need for assessing embodied carbon performance of construction projects is stemming from demand for low carbon construction. This is driven at least in part by the UK’s commitment to net zero by 2050, and construction specific drivers such as through the Carbon Net Zero Guidance

[73] Greater London Authority (2022) Whole Life-Cycle Carbon Assessments. Available at: link
[74] LETI (2020) Embodied Carbon Target Alignment. Available at: link

document for the construction industry.[75] This increased uptake is expected to lead to a greater understanding within the construction industry of which materials will deliver embodied carbon reduction.

Reducing emissions

The motivations which may lead to the undertaking of a WLCA include a perceived need to undertake a WLCA and thus make material substitutions, to meet internal or external pressures to reduce emissions. These pressures may be originating from consumers wishing to be associated more with low carbon or 'green' building projects.[76] Furthermore, organisations looking to secure finance may need to submit a carbon emissions statement as part of the submission. Finally, targets/regulations may drive the need to carry out a WLCA. An example of a target, set by RIBA in the climate challenge, is a $750\ kg\ CO_2\ eq.m^{-2}$ limit by 2030 for new build offices and $625\ kg\ CO_2\ eq.m^{-2}$ by 2030 for domestic/residential. Stakeholders suggested that regulation to mandate whole life carbon assessments or set targets/limits on building whole life carbon could further drive material substitutions.

Development of domestic supply chain of UK wood products.

The latest figures show that UK wood production is increasing, up by over 7% comparing 2012 to 2021.[77] This suggests that the UK wood market may be responding to an increased demand for locally, sustainably sourced timber, from the construction sector. With a greater supply of wood material on the market, there is greater opportunity to use it in construction projects where its use will enable lower embodied carbon. However, it is worth noting that the UK remains a significant importer of wood as of 2021, and there is uncertainty over future supply networks. [78]

Industry Initiatives

Industry wide initiatives to support the reduction of embodied and operational carbon in the construction sector can support the industry to increase the use of lower carbon materials. For example, The Future Homes Hub has published a report exploring embodies and whole life carbon which explores (among other things) possible material substitutions to achieve a lower embodied carbon. This report finds that substituting aerated concrete block & mortar with a timber frame can achieve carbon savings of up to 16%.[79] The Net Zero Building Standard is an industry initiative that is due to publish later this year that will aim to bring together Net-Zero Carbon requirements for all major building types. This standard will aim to robustly define what 'net zero' means for buildings and hopes to enable the construction industry to measure built assets to ensure they are in line with climate targets and net zero ambitions.[80]

2.3.2 Barriers

Six barriers were identified for Measure 2. Three were economic-related issues (volatile demand, alternative material costs and future supply predictability), two were technical

[75] Government Commercial Function (2022) Promoting net zero carbon and sustainability in construction. Available at: link
[76] Akomea-Frimpong, I et al. (2022) Green finance for green buildings: A systematic review and conceptual foundation. Available at: link
[77] The Forestry Agency of the Forestry Commission (2022) Forestry Statistics 2022 – Chapter 3: Trade. Available at: link
[78] Ibid
[79] Future Homes Hub (2023), Embodied and Whole Life Carbon: 2023-2025 Implementation plan for the homebuilding industry. Available at link.
[80] UK Net Zero Cabron Buildings Standard (2023). Available at link

(functional equivalence and data) and one was related to upskilling requirements. The barriers for Measure 2 discussed in this section are presented in Table 7. The most significant barriers, as voted for by workshop participants, are highlighted in bold.

Table 7: Barriers for construction Measure 2

Description	PESTLE	COM-B
Volatile demand economics for alternative materials.	**Economic**	**Opportunity – social**
Higher cost of alternative materials.	**Economic**	**Opportunity – social**
Need for upskilling.	Social	Capability – psychological
Parts using biomaterials, and alternative materials, can require more material to meet the same functional requirements.	Technological	Motivation – reflective
Future supply (and predictability) of alternative materials affected by climate change.	Economic	Motivation – reflective
Lack of data covering full range of alternative materials which can be used in construction	Technological	Motivation - reflective

Higher cost of alternative materials

One barrier which was voted as significant by stakeholders was the higher cost of alternative materials, though stakeholders provided no specific examples. One report on high-strength steel stated that it is more costly than standard steel, however overall cost savings are achieved due to less total steel being required.[81] For materials such as timber, in the same case study which gave the embodied carbon reductions, financial costs were also given for switching masonry to timber framed structures.[82] The increase in cost of switching from masonry to timber-frame in detached and semi-detached houses was 0.59% and 0.46%, respectively. A study cited in the BioComposites Centre report also stated that Cross Laminated Timber (CLT) is more expensive than concrete, by 0.12%.[83]

Whilst not related to the direct cost of purchasing materials, the cost of undertaking a WLCA can prohibit their implementation.[84] WLCAs are also technically complex and whilst there is guidance now being published, the skills to undertake them are not always present in the workforce.

Volatile demand for alternative materials

Another barrier which was voted as significant by stakeholders, was the volatile demand for alternative materials used in construction. A key concern was how this volatility would impact the cost of alternative materials. For example, IBIS World identified that within the United

[81] International Molybdenum Association (2013) High-strength steel – sustainable and money saving. Available at: link
[82] The BioComposites Centre (2019) Wood in Construction in the UK: An analysis of carbon abatement potential. Available at: link
[83]Ibid
[84] Kaswan, M and Rathi, R (2021) Investigation of life cycle assessment barriers for sustainable development in manufacturing using grey relational analysis and best worst method. Available at: link

Kingdom, the timber price index increased by over 30% in 2022 before decreasing by 16.2% in 2023[85], a significant fluctuation within a two-year period.

Need for upskilling

As with any material used in the construction sector, there is a need to deliver rigorous training to ensure the correct delivery of projects. This barrier was voted as significant by stakeholders in the workshops. This would likely be for specific materials, such as timber which requires coatings to lend fire resistance.

Other barriers

When new materials – such as biomaterials - are considered for replacement of existing materials, each will have a unique level of functional performance. If the replacement material has a lower functional performance for equivalent weights, then more material will need to be used to have the same functional performance. Depending on the emissions associated with producing a unit level of this material, this may lead to greater overall emissions as a result of using more material. As such, the functional performance of potential materials for substitution may be a barrier for material substitution to occur.

Another factor to consider is climate change. As the planet warms, as evidenced by the latest IPCC Synthesis Report, there will be effects on the supply chains.[86] For bio products, such as flax, crop yields may reduce significantly due to the warmer and drier climate. Assuming everything else stays constant, this will lead to an increase of the fibres cost as supply falls and the market would likely reduce its use of the fibre. Whilst flax is an example, it is by no means the only material that will likely be affected by climate change. These economic challenges will likely limit the uptake of alternative materials and thus prevent material substitution.

Finally, with more novel biomaterials it is likely that there will be a limit to the data that is available to construction professionals such as designers. This will likely limit their uptake in the short term, as understanding on how to use these materials will be limited, also restricting material substitutions from taking place.

2.4 Levels of efficiency

Table 8: Levels of efficiency for construction Measure 2

Indicator: Percentage CO_2e reduction in embodied carbon for the entire lifecycle associated with material substitution			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	20 – 36%	0 – 20%
Confidence level	N/A	Red	Red

[85] IBIS World (2023) Timber price index. [Online] Available at: link
[86] IPCC (2023) Climate Change 2023: Synthesis Report. Available at: link

2.4.1 Current level of efficiency

This measure was baselined on the current year. This is because currently there is limited information existing as to what material substitutions are actually being made. The data that is present in the studies focuses on quantifying the potential embodied carbon reductions that could result from making theoretical substitutions, but the rates at which the substitutions are made have not been disclosed. As such, the data points that have been given are theoretical maximum levels of efficiency and are discussed in that section.

2.4.2 Maximum level of efficiency in 2035

When searching for literature covering material substitution, care was taken to focus on materials that were shown to offer an embodied carbon reduction whilst maintaining functional equivalence. The two materials that were found in the literature as meeting these criteria were wood and steel, with wood heavily discussed and steel discussed in only one literature source. Alternative materials for insulation were also identified in the literature as a potential material for reducing embodied building emissions. On a per kg basis, alternative insulation materials may reduce the embodied emissions of a building through reducing production and end of life associated emissions. However, there have been no studies found which consider the functional equivalence of insulation materials, something which could be addressed by future research.

The scope of this measure was intended to be at commercial, infrastructure and residential level. However, upon reviewing the literature it became clear that only quantitative data covering the residential sub-sector was available.

Limited literature values gave quantitative data points for embodied carbon emissions savings. One study investigated the replacement of timber and cross laminated timber (CLT) for masonry and concrete frames, respectively.[87] The study had two levels of analysis, one more rigorous analysis which focussed on the emissions savings from material substitution at the individual housing level. The second section took a higher-level approach and estimated economy wide savings.

The subsequent section is structured with literature findings first, starting at a building level then increasing in scope to economy wide level. Literature findings are summarised, before reviewing workshop levels of efficiency and then combining the overall literature findings with those of the workshop, to bring a final level of efficiency.

Building-level scale

Emissions savings were disclosed for switching structural timber for masonry and CLT for concrete for a detached house, end terrace house, mid terrace house, bungalow, low rise flat (3 storeys) and mid-rise flat (6 storeys). For brevity, the embodied emissions savings are not reported here but available at the source. [88]

Taking the arithmetic mean of the values reported in the literature source, the average embodied carbon reductions achieved by substituting timber for masonry building systems for the building types, which were majority residential, shown is 20%.[89] The minimum saving was

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[87] The BioComposites Centre (2019) Wood in Construction in the UK: An analysis of carbon abatement potential. Available at: link

[88] Ibid

[89] Ibid

12% and the maximum was 28%.[90] The embodied carbon savings come from two factors, first the fact that masonry is a higher carbon material in production than timber. Secondly, it is associated with the sequestration of biogenic carbon during the timber's growth, which only occurs if the source is sustainably managed.

Substituting CLT for concrete gives a much higher average emissions reduction of 90%.[91] This is attributed to the higher displacement of concrete materials, achieved through its high performing functional properties, bringing about a much higher reduction in embodied emissions. Whilst the carbon emissions savings from substituting CLT for concrete is significantly higher than substituting timber for masonry, this was only demonstrated for a small number of case studies. By contrast, substituting timber for masonry was demonstrated for multiple case studies.

Data provided in the report published by the House of Commons Environmental Audit Committee provided embodied carbon values, over a 60-year assessment period, baselined against m2;[92]

- Cross-laminated timber – 409 kg CO_2e eq. per square metre;
- Steel frame – 759 kg CO_2e eq. per square metre;
- Concrete frame – 517 kg eq. CO_2e per square metre; and
- Timber frame – 423 kg eq. CO_2e per square metre.

Data was also provided in the written evidence document of the same report, covering the total embodied carbon for a super structure, for different materials: [93]

- Cross laminated timber (excluding sequestration) – 333,499 kg CO_2 eq.
- Steel – 685,965 kg CO_2 eq.; and
- Concrete – 418,341 kg CO_2e eq.

These data points show a smaller reduction of emissions when substituting CLT for concrete, at 23%. It is unclear from the sources, why there are such significant differences. The size of the structure being assessed is potentially a factor, with the structure assessed in the House of Commons report larger than the case studies reported in the BioComposites report.

When discussing timber, information was also provided on current uptake of timber frames in Scottish housing. One stakeholder gave 86% as a percentage of new builds using timber frames, another gave 75-80% of new builds using timber frames and one gave >85%. This gives a ball-park figure on wood use in Scottish construction. It is not representative of the situation in the rest of the United Kingdom, which stakeholders implied had a lower usage of timber in frames.

The data reviewed shows that steel is a high emissions option. However, when substituting high strength steel for standard steel, emissions savings can be achieved. A study assessing a sporting stadium roof structure in Sweden, assessed that 900,000 kg of CO_2e could be saved

[90] Ibid
[91] Ibid
[92] House of Commons Environmental Audit Committee (2022) Building to net zero: costing carbon in construction.. Available at: link
[93] House of Commons Environmental Audit Committee (2022) Written Evidence from Mesh Energy. Available at: link

in the switch.[94] This included the benefit of the steel recycling process at end of life, making it technically whole life carbon. However, it is anticipated that a significant portion of the total emissions savings are derived from the reduced material mass needed from the higher strength of high strength steel.

This is also supported by a report from the House of Commons Audit Committee, which cited a European-level meta-analysis which studied the embodied carbon emissions of 80 building case studies. Timber, glued laminated timber, concrete and steel beams were considered, with the embodied emissions per kg of material being lowest for timber and highest for steel beam.[95]

It therefore appears that there are significant embodied emissions savings that could be achieved by substituting timber in place of current building materials.

Economy-wide scale

Emissions savings, in absolute terms, were also found at an economy wide level in one study. The study modelled the carbon savings that would be expected if 28% of new residential builds were constructed with timber or CLT instead of masonry or concrete, compared to a baseline where 0% of new residential builds were built with timber or CLT. This modelling estimated that this level of timber/CLT use would reduce the embodied carbon emissions from the construction of these buildings by 5%.

This scenario was modelled because data suggested that 28% of UK housing was constructed with timber frames in 2016. This means that this 5% emission reduction does not represent the maximum emissions savings that could be achieved from this measure, but an estimate of the emissions savings that are already being achieved from the current implementation of this measure.

However, combining this modelling with the information from stakeholders on the use of timber frames in Scottish housing (which is thought to be much higher at ~80%), this modelling does suggest that substantial additional carbon savings could be delivered through this measure if the proportion of residential building constructed with timber frames was increased.

Workshop

3 participants, out of 15, voted on this level of efficiency, all casting their votes in the >50% range. This supports the upper range of the levels of efficiency that are documented in the literature. Of the few stakeholders who cast their votes, none were experts in this specific topic. It is possible that when voting, stakeholders thought they were voting for specific lower carbon materials as well, such as cement materials.

Overall summary

Creating a final range to report for this measure is challenging. This is because the literature reviewed mainly focused on the carbon savings achieved at the building level from specific material substitutions, rather than estimates of the emissions savings that could be achieved

[94] International Molybdenum Association (2013) High-strength steel – sustainable and money saving. Available at: link

[95] International Energy Agency (2016) Evaluation of embodied energy and CO_2e. for building construction (Annex 57). Available at: link

by the construction sector as a whole. Stakeholders also struggled to quantify the carbon savings from this measure, with the vast majority choosing not to vote.

Given all of this, the average value for the building level substitutions (36%) from the literature was used as the upper bound for this measure. This was used as the upper bound to reflect the fact that not all buildings will be suitable for these substitutions, and there is limited evidence that these substitutions are applicable in the commercial, and particularly the infrastructure, sub-sectors. The lower bound for this measure is set at 20%. This is the upper bound of the BAU level of efficiency (described below) to reflect the fact that stakeholders agreed that the maximum level of efficiency was unlikely to be achieved in a BAU scenario.

It is important to note that the wide range of different material substitutions, their varying suitability for different applications and the gaps in the literature reviewed means that there is substantial uncertainty surrounding this estimate. This was echoed by stakeholders in the workshops and is reflected in some of their votes which suggested maximum savings of >50% could be achieved.

To reflect this uncertainty a red RAG rating has been given to this measure. This rating is selected given the wide range of values reported as well as a lack of literature found at the correct scope for this study. This is an extremely wide ranging and complex measure that would benefit from further research.

2.4.3 Business-as-usual in 2035

In the workshop there was agreement from stakeholders that substituting materials, on a functionally equivalent basis, would yield reductions of embodied carbon. This will be driven in a BAU scenario by embodied emissions targets set by bodies such as the Royal Institute of British Architects (RIBA), with their recommended targets.[96] However, it was also agreed by stakeholders that there are a significant number of barriers that are preventing this measure from being fully realised in a BAU scenario. For example, stakeholders raised concerns about the negative effects that material substitution may have from an overall circularity perspective. These adverse effects could drive the business-as-usual uptake to be lower than the maximum level of efficiency. Furthermore, there are significant technical challenges associated with undertaking WLCAs and the lack of current regulation enforcing their completion.

Translating the discussion on drivers and barriers into votes proved challenging as the majority of stakeholders declined to vote on this measure. A total of 3 out of 15 participants voted on this level of efficiency. 2 votes were cast in the 11-20% category and 1 was cast in the 21-30% category. One stakeholder casting their vote in this topic did have significant expertise in the area, with their vote being cast in the 11-20% range.

One stakeholder stated that projects they've worked on investigating material substitution, yielded 20% reduction in embodied carbon emissions. However, this carbon saving originated from the use of reused material (Measure 1), without disclosing which specific material types were included. The stakeholder data point fell inside the 11-20% category, essentially increasing the number of votes in the category to three.

Overall, the majority of votes were cast in the 11-20% vote, with an expert voting in this category. However, there is significant complexity associated with this measure and very few stakeholders voted. There were several comments by stakeholders in the workshop that little

[96] Royal Institute of British Architects (2021) RIBA 2030 Climate Challenge. Available at: link

change would be expected in a BAU scenario, so the range has been changed to 0 – 20% to reflect this.

To account for the complexity of the measure and the uncertainty from stakeholders, the RAG rating is to red.

3.0 Measure 3 – Reduction of over-design & delivery in building structures

3.1 Construction resource efficiency measure

3.1.1 Description

Over-design of a building or component often results from the cumulative addition of various design margins beyond those required by the design's functional requirements and relevant standards and regulations. Design-efficiency is also used interchangeably in the literature to describe over-design as a process.[97]

Over-design can be due to a desire to err on the side of caution, and place a conservative margin for additional strength, durability, capacity, reliability, future proofing, or anticipated wear and tear. However, it also increases the volume of materials required, the asset's mass and complexity. Over-design can occur in any building element where it is structural or secondary and related to the aesthetic appearance of the building.

The Factor of Safety (FoS) is a measure that can be used to understand the potential level of over-design of a given building component. The FoS is the ratio of the maximum functional loading which can be sustained by a component, such as a timber beam, to the typical (or working) loading it will experience. An optimised FoS represents a perfectly efficient component which will not fail against expected service loads, whilst having no unnecessary loading capacity.

Over-delivery on a construction project can be defined as where there is a mass of material used on a construction project above and beyond what was originally set out in the specification. For example, if 10kg of insulation is required to fill a new build home, but 11kg is delivered and used, this would count as over-delivery against the specification.

The sub-sectors this measure applies to are commercial, residential and infrastructure. This measure shares similarities with Measure 4, lean design of concrete structures, in the Unlocking Resource Efficiency: Phase 1 Cement and Concrete report. This measure has a broader focus, taking a holistic approach to construction projects (and therefore covers a range of materials), whereas Measure 4 in the cement report looks at cement and concrete products specifically.

3.1.2 Examples in practice

There are a number of methods which were found to achieve resource efficiencies through the reduction of over-design and delivery. Whilst all of the below examples have different descriptions and names, they are all means to achieve the same ends of reducing a structures mass and thus achieving resource efficiency.

Shape optimisation of structures

[97] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link

One example is building re-shaping. Structures with long lengths that are flat, such as roofs, are often trapped in negative reinforcement loops. As they are flat, they are subjected to high bending forces. This requires a greater mass of concrete to reinforce the structure, increasing the bending forces and the feedback loop continues. By looking to use structures which are acting in pure tension or compression, these structures are not subjected to such high bending forces and thus can be more economical with their weight and thus the mass of construction materials required. An example of a linear pure tension structure is a suspension bridge. Utilising manufacturing methods such as steel cable-nets and high-performance tensile fabrics can make rigid structures more efficient.

One stakeholder from a construction company mentioned that a super-structure could be delivered with 60% less material (assumed to be compared to the average specification), thanks to material savings due to the shape of the structure. It was also noted by another stakeholder in a workshop that switching from a flat slab to a rib could provide a 40% reduction in material usage.

More generally, shape optimisation can now be applied to many structural elements used in the construction sector. This can be carried out by specialised finite-element software, which considers the load an element, or combination of elements, and then a trained engineer will assess which areas of the element can reduce their weight. There is still consideration of the elements factor of safety (FoS) so that is fulfils its function within the specific safety related boundaries. A newer method is generative design, which is where the optimisation is carried out by a software program rather than a trained engineer.

Structural Optimisation

Structural steel is a leading example of where design efficiencies can be made through structural optimisation. A study by Durant et al. showed that in a typical steel-framed building, the mass of the frame could be reduced by 15-30%.[98] These savings can be made by reducing the utilisation ratio of the structural element, such that the actual load it receives is much closer in value to the what the structural element can bear as specified in building codes.[99] It was further reported that in the US, the average utilisation ratio used by structural engineers is 0.5.[100] Moreover, in the work of Hawkins et al., the report showed that a 30-45% weight saving of steel was possible by removing unnecessary material.[101] Whilst this example of structural optimisation has been made for steel, the principle of structural optimisation can be applied wherever a component within a building is subjected to load.

3.1.3 Measure indicator

The selected indicator was **% reduction in material mass in construction relative to 2023 levels**.

The scope of this indicator is set at an industry level and is not focussing on specific materials. The indicator has been selected based on the current level of data granularity reported in the literature. Current data granularity levels are insufficient to break down the level of efficiency further by built asset type, even though this will vary[102]. It is noted that the reference to 2023

[98] Moynihan, M.C and Allwood, J.M (2014) Utilisation of structural steel in buildings. Available at: link
[99] Dunant, C.F and Drewniok, M.P and Orr, J.J et al. (2021) Good early stage design decisions can halve embodied CO_2 and lower structural frames' cost. Available at: link
[100] Poole, I (2020) Rationalisation versus optimisation – getting the balance right in changing times. Available at: link
[101] Hawkins et al. (2022) Construction sector innovation within absolute zero. Available at: link
[102] Workshop stakeholders identified infrastructure projects as being a particular area where over-design occurs.

levels will not be reflected in the literature. It is included to acknowledge that this measure is benchmarked with a current level of efficiency of 0% in the year of this report (2023).

This indicator applies to any material used to complete a construction project, either in residential, commercial or infrastructure sectors. Where some materials are not discussed hereafter, it is not due to them being out of scope, rather, they are not discussed in the literature from an over-design perspective.

Indicators that were considered but ultimately discarded were:

- **% of material by mass not functionally used** – this was discarded as this indicator discusses only design efficiencies of functional parts. Over-delivery would thus be excluded if only this indicator was used.
- **% of structure mass in membrane action by volume** – this indicator was very niche and relates only to steel structural members. It would have therefore excluded over-delivery and over-design of other materials. As a result, it was discarded as an indicator.

3.2 Available sources

3.2.1 Literature Review

There were different aspects of over-design and over-delivery efficiencies which were reported in the literature. It was found that over-design was more reported on that over-delivery. This included a discussion of general design efficiency, over-design in specific materials, over-design against codified requirements, and shape optimisation. There were ten reports identified for this study:

- Three industry reports, by UKGBC [103] (IAS 5), CNCA [104] (IAS 2) and The Green Alliance[105] (IAS 5);
- Four academic journals by Schmitz et al.[106] (IAS 5), Orr et al.[107] (IAS 4), Hawkins et al.[108] (IAS 5) and Moynihan and Allwood [109] (IAS 4); and
- Two technical studies by Cartwright et al.[110] (IAS 5) and The Institution of Structural Engineers[111] (IAS 5).

[103] UK Green Building Council (2021) Net Zero Whole Life Carbon Roadmap – Technical report. A Pathway to Net Zero for the UK Built Environment. Available at: link
[104] CNCA (2020) City policy framework for dramatically reducing embodied carbon. Available at: link
[105] Green Alliance (2023) Circular construction: Building for a greener UK economy. Available at: link
[106] Schmitz, R.P (2006), 'Fabric-formed concrete Panel Design', Architectural Engineering Conference 2006. Available at: link
[107] Orr, J.J et al. (2011), ' Concrete structures using Fabric Formwork', The Structural Engineer, 89 (9). Available at: link
[108] Hawkins, W and Drewniok, M and Dunant, C.F and Horton, P and Romain, P and Stephenson, S and Sergen, F and Allwood, J (2022) Construction sector innovation within absolute zero. Available at: link
[109] Moynihan, M.C and Allwood, J.M (2014) Utilisation of structural steel in buildings. Available at: link
[110] Cartwright, B and Lowres, F and Turner, E and Hobbs G (2021) CIRCUIT – Recommendation on circularity indicators
[111] The Institution of Structural Engineers (2022) How to achieve a SCORS A rating using current materials and technology. Available at: link

The lowest IAS score was 2 and the highest 5, with an average of 4.4. Only the UKGBC publication reported quantitative data on the level of efficiency for the selected indicator at the required level of scope. All the reports included discussion on resource efficiency, even if the discussion was set in the context of other topics. Two reports were focussed on construction from a net zero perspective with one other report discussing resource efficiency from an embodied carbon perspective. Two reports discussed resource efficiency from the perspective of the circular economy and how it can improve resource efficiency. The final reports were set at the specific material level, considering structural steel and concrete. Four of the documents were set at the UK market level. The CNCA is an organisation which is set at city level and represents many cities. One of these cities is the UK, hence deeming the report applicable to the UK. The four academic journals are not applicable to any specific country but refer to materials known to be used in the UK market, so deemed applicable.

Stakeholders identified no missing sources for the literature review in the pre-workshop surveys.

3.2.2 Workshops

Stakeholders provided a good level of commentary on this measure, providing valuable insights into the barriers and drivers affecting the realisation of design and delivery efficiency. Voting was less valuable, with stakeholders unable to provide quantitative data on the measure. It appears that this is due to the lack of industry/national level data, with most studies stakeholders were aware of being case studies, with a local geographical focus. Furthermore, stakeholders commented that design efficiencies are often discussed in the context of carbon reductions, something which is corroborated in the literature.[112] There was no comment made by stakeholders about the link between delivery efficiencies and carbon reductions, though it is logical this would occur.

3.3 Drivers & Barriers

3.3.1 Drivers

Three drivers were identified for Measure 3. The drivers are shown in Table 9 with the most significant drivers, as voted for by workshop participants, are highlighted in bold.

Table 9: Drivers for construction Measure 3

Description	PESTLE	COM-B
Reduction in use of virgin and / or recycled materials and/or decarbonisation trend.	**Environmental**	**Motivation – reflective**
Increased uptake of Building Information Modelling (BIM) and design code changes	**Technological**	**Motivation – reflective**
Promotion of the waste hierarchy	**Social**	**Motivation – reflective**

[112] Hawkins, W and Drewniok, M and Dunant, C.F and Horton, P and Romain, P and Stephenson, S and Sergen, F and Allwood, J (2022) Construction sector innovation within absolute zero. Available at: link

Reduction in use of virgin and/or recycled materials and/or decarbonisation trend.

Only one driver was identified in the literature: reduction in use of virgin and/or recycled material which leads to reduced environmental impacts.[113] Three stakeholders supported this, mentioning that the trend towards decarbonisation could help in reducing over-design and delivery, in particular by driving a performance-based design approach. At a high-level, this could be driven by the same pressure to deliver greater evidence on embodied carbon performance across the building stock, through the completion of WLCA studies.[114] This was verified by stakeholders, with two stating that decarbonisation targets are currently driving material use reduction through a reduction in over-design and over-delivery.

Increased uptake of Building Information Modelling (BIM) and design code changes

BIM can enable a reduction on overdesign/delivery by enabling greater visibility on the flow of materials related to construction projects. Furthermore, it enables integration with design tools such as finite element modelling, which will allow real-time updates of designs as they iterate, increasing the likelihood of maintaining design efficiency.

For a more detailed description of BIM, please see Section 8, covering enablers supporting all measures where BIM is outlined.

A further driver that was discussed was the updating of codified requirements. Stakeholders proposed that standards, such as Eurocode standards covering structural steel design in buildings, could be updated.[115] The update could include a maximum mass requirement, to complement the existing minimum mass requirement already defined.

Promotion of waste hierarchy

The waste hierarchy, as set out by Defra, states that prevention is the most preferable solution when considering products reaching their end of life phase.[116] In descending order of preference, the other solutions following prevention are preparing for re-use, recycling, other recovery, and disposal. With prevention being the most preferable option at end of life, this represents a direct driver for a reduction of over-design and delivery.

Other insights

Reduced materials costs would be an obvious driver, but the economics of over-design are not working in favour of this measure as the reduced material costs are generally outweighed by greater labour costs from design. Thus, this has been classified as a barrier (see Section 4.3.2).

3.3.2 Barriers

Seven barriers were found for Measure 3. Three were social (lack of education, risk aversion and design choices), two were technological (confidence in materials and conflicts between competing factors) one was an economic factor of additional design time, and one was legal, relating to design code reviews. Table 10 shows the barriers discussed for Measure 3, with the most significant barriers, as voted for by workshop participants, highlighted in bold.

[113] Metabolic (2021) The circular design of buildings. Available at: link
[114] LETI (2020) Embodied Carbon Target Alignment. Available at: link
[115] Moynihan , M and Allwood, J (2014) Utilisation of structural steel in buildings. Available at: link
[116] DEFRA (2011) Guidance on applying the Waste Hierarchy. Available at: link

Table 10: Barriers for construction Measure 3

Description	PESTLE	COM-B
Additional design & testing work is more expensive than material savings.	**Economic**	**Motivation – reflective**
Need for benchmarks for designers and review of the construction codes to eliminate prescriptive requirements that drive over-design (for example live load).	**Legal**	**Motivation – automatic**
Technological confidence required to reduce factors of efficiency (applies to manufacturing processes and certification schemes).	**Technological**	**Capability – psychological**
Lack of education and communication within the value chain.	Social	Capability – psychological Opportunity – social
Risk averse actors of the value chain.	Social	Motivation – automatic
Conflicts with other resource efficiency measures, such as building life extension or recyclability. Also conflicts with operational carbon.	Technological	Capability – physical
Aesthetic choices by designers may lead to superfluous structures, such as large canopies made of steel and glass.	Social	Opportunity – social

Additional design & testing work is more expensive than material savings.

The barrier ranked the highest by stakeholders was an economic barrier: reducing over-design requires additional design work which tends to be more costly than the material savings achieved (due to the relatively low price of materials compared to labour). On top of the design work, more rigorous structural analysis (along with mechanical testing) might also be needed to generate the required confidence levels in materials and or structures.[117] These activities also result in increased labour costs. One stakeholder mentioned this is not a priority for designers and engineers, and there are no incentives in place for conducting the additional work.

The next three barriers were all ranked with similar levels of importance, and all are inter-related.

Designers need benchmarks

Designers need benchmarks to understand when over-design may be happening and understand where changes could be made. Stakeholders suggested that changes to requirements for building information modelling and design codes would help mitigate this barrier.

[117] Hawkins, W et al. (2022) Construction Sector Innovation within Absolute Zero. Available at: link

An example of a codified requirement that could be altered is the UK National Annex for Eurocode – Basis of Structural Design.[118] The factors of safety within this study could be reviewed with a view to reducing them where feasible against safety requirements. Stakeholders did confirm that this was practically achievable. Literature also confirmed that it has been achieved already, with the first standard in the 1880s giving a safety factor of 4, with 1.3-1.45 achieved in Eurocode 3 with the most recent update of this standard being in 2014.[119] This reduction was cited mainly due to confidence that has been gained in the production of steel, but highlights the scope to reduce it further.[120] Such an activity would likely require engagement of construction sector stakeholders such as insurance bodies, builders and architects.

Technological confidence

In order to reduce over-design, it is required to have full confidence in the manufacturing process; this would allow reducing the need for factors of efficiency and reducing redundancies.[121] Where recycled or reused materials may be used, full confidence in certification schemes is also required to avoid overdesign (see Measure 1 which discusses certification challenges for reused materials).[122]

Risk averse actors of the value chain

The insurance sector was described by stakeholders in the workshop as being risk-averse, and this cascades down to the rest of the actors of the value chain. Over-design and over-delivery are often a response to the perception of risk.

Lack of education and communication

Another barrier raised by stakeholders is the lack of education and communication within the different actors of the supply chain. Stakeholders highlighted that the actors may not be aware that over-design is happening, nor of the impacts of over-design and over-delivery on resource efficiency.

An example would be offices that are designed to cope with more staff than needed in terms of the number of lifts, toilets, lighting or heating and ventilation requirements. Stakeholders suggested possible mitigations for this barrier, such as education and training for the different actors of the construction value chain (designers, architects and engineers); this could help change the culture of practice. Additionally, it would be helpful having these conversations earlier in the construction project.

Conflicts between the resource efficiency measures,

Finally, stakeholders also mentioned the need to consider the whole lifecycle of the building and the interaction with other resource efficiency measures as a barrier for this measure:

- This measure could result in a reduction of recyclability, reusability or incorporation of reused content, depending on the choice of materials and construction techniques. This is because a reduction in overdesign may lead to a preference for construction methods that have high confidence, e.g., using virgin materials and components, or methods that are well-established. This may prevent the use of reused or recycled

[118] BSI (2015) Eurocode: Basis of structural design. Available at: link
[119] BSI (2015) Eurocode: Basis of structural design. Available at: link
[120] Moynihan , M and Allwood, J (2014) Utilisation of structural steel in buildings. Available at: link
[121] Metabolic (2021) The circular design of buildings. Available at: link
[122] Ibid

content/components. As was discussed in Measure 1, confidence in the properties of reused content is currently low, so there is a trade-off to be had if trying to achieve both resource efficiencies.

- To future-proof buildings, some level of over-design may be needed to ensure adaptability. Climate change could require different specifications; some examples of increased specifications provided by a stakeholder include higher summer temps, snow load, rain levels and wind speeds. Furthermore, it could be theorised that increasing over-design will lead to longer durability of buildings and thus avoiding construction in the future. Moreover, by increasing over-design there could also be a reduction in future demolitions as vertical extensions may be possible given the additional structural performance the building holds.
- This measure could result in increased operational carbon during the building lifetime, and it could result in a trade-off with the energy performance targets. For example, a 'lighter' building would have less embodied carbon, but it could be less insulated and lead to higher energy requirements for heating and cooling. Thus, the discussion can ultimately end up being a carbon discussion, in terms of upfront savings of the embodied carbon vs later savings of the operational carbon.

Stakeholders mentioned some actions that could help mitigate some of the barriers:

- The ability and/or requirement of measuring material intensity; and
- Transitioning to a performance-based design approach.

3.4 Levels of efficiency

Table 11: Levels of efficiency for construction Measure 3

Indicator: % reduction in material mass in construction relative to 2023 levels			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	10 – 21%	0 – 10%
Confidence level	N/A	Amber	Red – Amber

3.4.1 Current level of efficiency

This measure has been baselined in the report year (2023). Thus, the current level of efficiency is 0%.

3.4.2 Maximum level of efficiency in 2035

A report by Green Alliance showed that optimising material usage at the design stage substantially impacted the materials needed in construction.[123] The use of the following strategies to achieve this were modelled to show that compared to current business as usual

[123] Green Alliance (2023) Circular construction: Building for a greener UK economy. Available at: link

practices they could achieve a reduction of 21% in material mass used by 2035 (over an unknown boundary of construction sub-sector);

- Optimising design of buildings using digital tools;
- Reducing overspecification of materials in infrastructure;
- Optimising concrete reinforcement;
- Optimising structural steel use;
- Flexible formwork technology to create more complex concrete structures that minimise waste;
- Post-tensioning concrete floor slabs, to reinforce them while requiring less material; and
- Increasing the use of precast concrete elements

Of the seven strategies that were modelled, there are four that directly relate to the cement and concrete sector, presenting an area of overlap with the discussion of measures in the Unlocking Resource Efficiency: Phase 1 Cement and Concrete Report.

Interrogating whether all the strategies modelled by the Green Alliance study are applicable to this measure, the first four listed strategies clearly are within scope as well as post tensioning concrete floor slabs. The flexible formwork strategy implies that its key intention is to minimise waste through moulding concrete close, ideally exactly, to its intended final net shape even when this is complex. The use of formwork will also simultaneously prevent over-design by providing greater confidence that the concrete geometry selected by the designer is matched when the concrete is poured. The final modelled strategy to consider is the use of precast concrete elements. Precast concrete elements also reduce over-design by the same ilk as flexible formwork, by increasing confidence through consistent quality of production. The specifics of the concrete technologies that have been shown to reduce construction process wastage, are covered in more detail in the Unlocking Resource Efficiency: Phase 1 Cement and Concrete Report. Thus, all of these strategies can be considered to relate to this measure.

Another relevant study is a UKGBC study which combined the potential material savings through design efficiencies from 5 studies, each reporting on different materials.[124] Using these studies, they linearly extrapolated the potential material savings into a forecast. The maximum level of efficiency, interpreted from a graph in 2035 was estimated to be 10%. The source did not provide details on which construction sub-sectors these savings applied to, so it was assumed to be across infrastructure, commercial and residential sectors. The IAS of the data source itself was rated the highest possible score of 5. Whilst the materials that were optimised for over-design were not disclosed, the source is still used given its high IAS and is assumed to be based on the full breadth of materials used in the construction sector.

Neither of the two sources discussed or assessed over design or over delivery for retrofit, repair or renovation, appearing only to discuss efficiencies applied to the new build process.

The results of these studies were presented at the workshops, where stakeholders were asked to vote on the maximum level of efficiency they thought could be achieved by 2035. The was a widespread of votes cast (from 20 – 24% to >30%), with a majority of participants choosing to

[124] UK Green Building Council (2021) Net Zero Whole Life Carbon Roadmap – Technical report. A Pathway to Net Zero for the UK Built Environment. Available at: link

vote “don’t know”. One of the stakeholders did state 100% utilisation to code could be achieved by reviewing the codes and removing the over-design built into them.

Exploring what prevented stakeholders from making an estimate, it appears their knowledge was focused on concrete design efficiency rather than the broad construction sector values required for this measure. Furthermore, the maximum levels of efficiency that can be reached for this measure are highly dependent on the material type, something raised by stakeholders. As such, it is likely this disagreement with the indicator also contributed to the lack of contributions for this measure.

Because of the lack of consensus from stakeholders the level of efficiency chosen is primarily based on the literature. The maximum level of efficiency in 2035 will thus combine both reports, giving a range of 10-21%. The range was given by sources both having the highest possible IAS. However, limited stakeholder consensus was built on the levels of efficiency through voting. As such, an amber evidence RAG rating was given for this measure.

3.4.2 Business-as-usual in 2035

A total of 6 participants out of 15 voted to estimate the business-as-usual level of efficiency in 2035. Three categories received 2 votes each, namely 8-10%, >20% and ‘don’t know’. One stakeholder mentioned that overspecification is likely to be a common practice in infrastructure projects, but without being able to quantify it. Another topic expert, who has experience in the design element of construction projects, voted in the >20% range.

There are a significant number of barriers that outweigh the number of drivers for this measure. As such, it is likely there will be a significant gap between the business-as-usual and maximum levels of efficiency. The existence of a significant gap between BAU and the maximum technical level of efficiency is further evidenced by the need to develop technological confidence and also benchmarks for designers. Generating both technological confidence and official benchmarks are time consuming activities. Furthermore, generating technological confidence would likely be undertaken through testing campaigns, which require both time and money. A culture of risk aversion, backed by insurance and liability requirements, was also agreed on by stakeholders as being a prevalent culture in the industry.

Contrasting the significance of the barriers with the limited number of drivers, there is a non-zero risk that there will be no improvement against this measure’s indicator by 2035. Stakeholders were very positive during the workshop discussion about the potential for material savings that are technically possible through reduction of over-design. However, there were limited suggestions by stakeholders that a substantial shift is expected in the current environment.

Taking the votes casts and assessing the drivers and barriers for this measure and the stakeholder discussion, a BAU range of 0 – 10% has been chosen. The >20% vote has been discarded as it’s an outlier with the rest of the votes and to align with the maximum technical literature values. Furthermore, the narrative of the stakeholder discussions heavily suggests there will be limited progress in overcoming the barriers facing this measure. The range has therefore been extended to include 0% to reflect the substantial barriers that exist to improvements to this measure, and the stakeholder view that these will be difficult to overcome in the current environment. A red/amber RAG rating was assigned to this measure.

4.0 Measure 4 – Reduction of construction process wastage

4.1 Construction resource efficiency measure

4.1.1 Description

This measure concentrates on the reduction of waste arising from any process associated with construction. This includes waste from on-site and off-site construction activities such as wasteful design, overordering, offcuts or damaged material, material expiring, or material not being used.

This measure applies to all construction sub-sectors, although the literature found tended to refer to the residential and commercial sub-sectors.

4.1.2 Examples in practice

There are a range of approaches that can be adopted to reduce construction waste generation, some examples include:

- At the preliminary design stage, investigating options that are simple to construct and minimise waste;
- During detailed design, developing work sequences and material logistics plans that will minimise waste (e.g. design to minimise off-cuts of materials).
- As work programmes are developed ensuring work is undertaken efficiently, avoiding unnecessary waste caused by excessive rework and poor coordination between trades;
- Avoiding damage to materials during delivery and storage through handling errors and inadequate storage;
- Returning packaging and surplus materials (e.g., plasterboard off-cuts) to the original manufacturer for reuse or recycling; and
- Reusing temporary works materials (e.g., formworks, hoarding, etc).

Site Waste Management Plans (SWMPs) offer a mechanism by which these options can be assessed and recorded. These help construction companies understand which construction and demolition activities will generate waste, the steps that can be taken to reduce waste, and how unavoidable waste can be effectively managed. SWMPs were a legal requirement from 2008-2013 in England, and whilst no longer legally required, they are still considered to be good practice.[125]

4.1.3 Enablers

Enablers are activities which, while not delivering resource efficiency savings themselves, support the delivery of these savings. Section 8 discusses the enablers common to multiple

[125] CIRCUIT Circular Economy Wiki (2022) Site Waste Management plan SWMP. Available at: link

measures at greater length. This section discusses enablers which are related to this measure only.

Industrialised Housing Construction (IHC) methods are a type of offsite prefabrication and include a variety of technologies such as prefabrication and 3D printing of building modules, where they are applied to the housing sector. IHC methods have been reported to reduce construction process waste from 54.6 tonnes per 100m2 when using traditional 'wet' construction methods to 1.5 tonnes per 100m2.[126] These improvements were achieved by closing the loop of material flows, feeding waste back into industrialised processes and optimising mass flows. Improved precision of machinery and controlled environments are another driver for waste reduction, whereby the risk of incorrect manufacturing methods is significantly reduced. IHC can also deliver costs savings and it has been estimated that by 2035 there could between 385 to 515 million £ per annum of savings, if IHC is realised to its fullest potential.[127]

Pre-fabricated housing is an exemplar technology of IHC. It refers to the process of constructing parts of a construction project off-site. Parts are then transported to the construction site and assembled. The resource efficiency opportunities lie in the ability for manufacturers to repeatedly manufacture the same part, thereby allowing for material use optimisation. From a programming perspective, time-scales are more clearly defined given the controlled factory environment. With more clearly defined time-scales, there theoretically should be more opportunity to reduce over-ordering. This reduction would be due to programme managers having less uncertainty with regards to their ordering schedules.

There will inevitably always be an element of on-site manufacturing which must take place. For example, assembling pre-fabricated units on site would count as a manufacturing operation. Waste may still arise from these processes, albeit with the potential to be far smaller in magnitude than traditional construction methods. This highlights the need for recognising the unavoidable nature of waste in certain areas of the construction sector.

Asides from the resource efficiency benefits, some other advantages of this technology are:

- Reduction of on-site accidents due to less material assembly being done on-site.[128] As fewer components are assembled on-site, this requires fewer on-site assembly operations to take place such as welding or bolting joints. Fewer operations reduce the opportunity for accidents to occur. This, in turn, links to a better working environment for operators.
- Because elements are taken offsite and produced in factories, bad weather (which would usually impact on-site production) does not interrupt production which continues as scheduled.[129]
- Workflows in factories are well-defined, leaving an opportunity to optimise workers' safety and create well-defined practices.[130]

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[126] Miller, D et al. (2013) Resource efficiency in industrialized housing construction: A systematic review of current performance and future opportunities. Available at: link
[127] Ellen MaCarthur Foundation (2015) Delivering the circular economy: a toolkit for policymakers. Available at: link
[128] Zero Waste Scotland (Date unknown) Best practice guide to improving waste management on construction sites. Available at: link
[129] Kedir, F et al. (2018) A sustainable transition to industrialised housing construction in developing economies. Available at: link
[130] Ibid

- Higher cost predictability because of the repeatability of the processes used.[131]

The major disadvantage is the high initial investment cost;[132] this is due to the uncertainty in several areas, for example:

- Demand for IHC, as it is not a mainstream practice;
- Construction perception as a low-tech industry. It is believed that precision foundations cannot be built to accept pre-fabricated superstructures, a statement disclosed by a stakeholder;
- transportation and logistics of the modules, as there can be project constraints; and
- lack of codes and standards.

Additionally, one stakeholder highlighted a risk of adverse impact – standardisation can drive waste reduction but also lead to material inefficiency e.g., if the same structure/materials are used in multiple use cases, although some use cases could be achieved with fewer materials.

Another potential reason is that if standardisation is undertaken with a process that generates large volumes of process wastage, then this may lead to material inefficiency in the long run.

4.1.4 Measure indicator

The selected indicator for this measure was **% of total construction materials wasted by mass**. Waste is defined in this report as material purchased to complete a construction project that is not used for this purpose. The destination of the material not used to complete a construction project can include reuse, recycling, energy recovery, or disposal. As noted in the measure description, the focus is on construction process wastage, whether that be generated on or offsite.

Indicators identified during the literature review and workshops that have been discarded were:

- **Waste generated per unit gross internal floor area (GIFA)** – There were concerns that the Gross Internal Floor Area part of the indicator would have been too specific to enable engagement and consensus building from the workshops;
- **Total weight of waste generated per dwelling (tonnes)** – this was excluded as a relative (not absolute) indicator is needed to estimate the different levels of efficiency;
- **Total cost savings per year per company** – this was excluded as it did not represent a material saving; and
- **Carbon intensity of the waste produced** – this indicator is well aligned with the decarbonisation efforts of the sector and would help prioritise the waste streams with highest embodied carbon. However, it was not selected as this project is focused on resource efficiency from the standpoint of reducing material demand.

[131] Ibid
[132] Agha, A et al (2021) Modular Construction in the United Kingdom Housing Sector: Barriers and Implications, Journal of Architectural Engineering Technology, 10(2). Available at: link

4.2 Available sources

4.2.1 Literature Review

The literature review identified six publications that discussed reducing construction waste.

- Five technical publications by Building Research Establishment/Environment Agency (IAS 4),[133] Ellen MacArthur Foundation (IAS 4),[134] Defra (IAS 5),[135] Construction Leadership Council/Green Construction Board[136] and Building Intellect (IAS 5)[137] ; and
- A peer-reviewed journal publication by Kedir and Hall (IAS 5).[138]

The highest IAS was 5 and the lowest 4, with an average of 4.5. All sources were published in the last decade, except for the BRE/EA paper. Geographically, all publications found applied to the UK, apart from the peer-reviewed journal publication. As the peer-reviewed journal publication did not focus on a particular country and had technologies that are relevant to the UK construction sector, it was applicable for this study.

Each of the publications discussed, in various contexts, waste generated during the construction process. Contextually, the papers had 'Resource Efficiency' in the title in three of the four publications, highlighting the high level of relevance. The studies discussed wastage in construction processes at a sector wide level. The concept of construction process wastage (the combination of onsite and offsite construction waste) and its corresponding indicator is not directly mentioned in any sources. However, construction site wastage is discussed in the six sources found in the literature review. As the levels of efficiency for construction site wastage were known and from valid sources, the workshops were used to expand these to include both onsite and offsite estimates.

When reviewing the literature sources, none differentiated between the type of construction site where waste would be generated. Specifically, there was no differentiation between new build or retrofit, renovation and repair activities for either onsite or offsite activities.

4.2.2 Workshops

Attendees at both workshops were well-placed to discuss this measure. The scientific expertise brought by academics was complemented by two construction companies with practical experience. One area not represented was an offsite construction manufacturing company, such as one that would manufacture pre-fabricated housing units.

This measure received average levels of stakeholder engagement in the workshop, with more engagement in the voting compared to the broader discussion of the measure. The feedback received in the first workshop was very valuable and led to the inclusion of offsite processes

133 Building Research Establishment & Environment Agency (2008) The economic and environmental benefits of resource efficiency in construction. Available at: link

134 Ellen MacArthur Foundation (2015) Delivering the circular economy: a toolkit for policymakers. Available at: link

135 DEFRA (2021) Waste prevention programme for England 2021. Available at: link

136 Construction Leadership Council and The Green Construction Board (2020) Zero avoidable waste in construction. Available at: link

137 Building Intellect (2013) Offsite construction – sustainability characteristics. Available at: link

138 Kedir, F and Hall, D (2021) Resource efficiency in industrialised housing. Available at: link

being included in the scope of the measure. The inclusion of offsite processes in the scope was well received in the second workshop, with good stakeholder engagement.

Stakeholders showed agreement that this measure has resource efficiency potential and higher levels of efficiency can be achieved; one stakeholder mentioned that certain waste types are easily avoidable.

4.3 Drivers & Barriers

This section describes the drivers and barriers to the reduction of construction process wastage.

4.3.1 Drivers

Four drivers have been identified for this measure; three relate to different aspects of waste (economic savings, waste measurement, and digital technologies) and one related to offsite construction. It is worth noting that some of the drivers in Measure 6 (related to reuse / recycling of waste) also apply to this measure.

Table 12: Drivers for construction Measure 4

Description	PESTLE	COM-B
Measurement of process waste (e.g., corporate reporting requirements)	**Technological**	**Motivation – reflective**
Higher cost and workflow predictability of IHC methods	**Economic**	**Motivation – reflective**
Uptake of digital technologies to predict, monitor and characterise of waste	**Technological**	**Capability – physical**
Reduction of waste management costs	Economic	Motivation – reflective

Measurement of process waste

Some stakeholders mentioned that the act of measuring waste in itself is a driver, as it influences behaviour to reduce it (i.e. Hawthorne effects). Site waste management plans, when they were a legal requirement in England under the Site Waste Management Plan Regulations (2008), did mandate contractors to quantify, plan and record how waste was handled during the project, but since the regulations were repealed in 2013, there has not been a legal requirement to measure and report on construction waste quantities and their handling. One stakeholder mentioned that corporate reporting requirements was a driver. The GCB report[139] presents waste analysis and reporting as one of the actions of the route map.

One example provided by a stakeholder saw a 5% waste reduction after implementing detailed waste measurement. However, another stakeholder cautioned that measurement can lead to adverse behaviours, such as incorporating unnecessary material into the building (against

[139] Construction Leadership Council and The Green Construction Board (2020) Zero avoidable waste in construction. Available at: link

Measure 3) to avoid it being classed as “waste”. Another stakeholder mentioned that digital technologies would help measure and monitor onsite waste.

Higher cost and workflow predictability of IHC methods

Another driver identified by stakeholders was the higher cost predictability of IHC methods. The processes used in pre-fabricated housing modules often use automated methods, such as Computer Numerically Controlled machinery. With increased automation, repeatability increases and costs can be accurately predicted through interfacing with computer software.[140] As a result, construction sector project managers may favour this predictability of costs when delivering budgets for their projects. As a general note, this driver assumes that off-site manufacturing methods and IHC will reduce construction process wastage.

Digital technologies

Stakeholders also discussed the uptake of digital technologies, making it easier to track and therefore minimise wastage. Specific technologies include those enabling tracking and measuring waste flows on a construction site. Exemplar technologies identified in the literature include using digital algorithms to accurately predict the value of waste generated on a construction site.[141] By analysing over 2,000 records of building demolition projects, the algorithm could predict what waste would be generated and its residual value.

Reduction of waste management costs

The final driver identified was the reduction of waste management costs.[142] Waste management and disposal costs are stated as being 30% of a construction firm’s pre-tax profit.[143] Stakeholders mentioned that any potential increase in waste management costs would result in lower levels of waste.

4.3.2 Barriers

Barriers to this measure focus mainly on the relationships between stakeholders and how responsibility is apportioned between them regarding waste. One technical barrier was also raised covering how waste is quantified. The barriers discussed are shown in Table 13.

Table 13: Barriers for construction Measure 4

Description	PESTLE	COM-B
Lack of collaboration within the supply chain	**Social**	**Motivation – automatic**
Need for higher levels of skills and education about waste minimisation	**Social**	**Capability – psychological**
Waste measurement: Difficulty in calculating waste rates and getting accurate information	**Technological**	**Capability – physical**

140 Galvez-Martos, J-L and Styles, D and Schoenberger, H and Zeschmar-Lahl, B (2023) Construction and Demolition Waste Best Management Practice in Europe. Available at: link

141 GeoSpatial World (2021) The applications of digital technology to construction waste management. Available at: link

142 Zero Waste Scotland (Date unknown) Best practice guide to improving waste management on construction sites. Available at: link

143 ARUP (2016) The Circular Economy in the Built Environment. Available at: link

Description	PESTLE	COM-B
Waste measurement: Behaviour changes revert back as soon as observation stops (Hawthorne effect)	Social	Motivation – automatic
High impact of the design phase on waste generation	Social	Opportunity – social

Lack of collaboration within the supply chain

Stakeholders mentioned that the current value chain in the construction industry is fragmented, with several levels of subcontracting and a lack of vertical integration, making innovation challenging. Greater collaboration within the value chain would help drive this measure, but it is not currently happening. Some examples were provided:

- If suppliers had (more) take-back policies for surplus materials, it would help avoid construction waste because a large amount of what is currently wasted is unused and reusable.
- One stakeholder mentioned a lack of willingness from architects to engage in waste reduction activities. In some cases (for example, plasterboard), waste is produced due to the design of the structure, which may not match standardised product sizes. This represents an opportunity to reduce waste by designing it out.
- Another stakeholder explained that the majority of the construction workforce on a project are subcontractors, so there is no incentive to reduce waste. There was no further elaboration of this issue, however, literature pointed to the fact that some subcontractors are incentivised financially for the quantity of work installed per day, which can incentivise waste production.[144]

The above complex relationship between stakeholders was summarised in literature as the 'circle of blame'.[145] The circle of blame is summarised as an unwillingness of the contractor, client and designer to take responsibility for correct waste management on a construction site. Better communication between the stakeholders and outlining of responsibilities was stated as a means of overcoming this barrier.

Need for higher level of skills and education about waste minimisation

Training and education uptake regarding minimisation of construction process waste also received significant votes as a key barrier from stakeholders. For contractors or sub-contractors working on a site, training is required, for example, on how to separate waste streams correctly. [146] The literature only discussed how waste should be handled from a training perspective. However, it could also be reasonably expected that training in methods such as Industrialised Housing Construction (IHC) which are relatively new, is required. Training on IHC would be targeted at both those assembling the units at the construction site and those designing with IHC structures, such as engineers or architects. Training on concepts such as the waste hierarchy and what constitutes best practices on waste itself could also be required.

[144] Environment Agency (2008) The economic and environmental benefits of resource efficiency in construction. Available at: link
[145] Ibid
[146] Zero Waste Scotland (2020) Maximising re-use of materials on-site. Available at: link

Waste measurement

There are several barriers related to waste measurement.

- Stakeholders discussed the Hawthorne effect, a human behaviour which causes behaviour modification when the human is aware of being observed. This can be a barrier because when the observation on waste generation is no longer observed, workers are likely to revert to their original behaviour of not correctly handling waste on a construction site. It should be noted that the Hawthorne effect was also discussed as a driver.
- While measuring waste has been described as a driver, stakeholders also identified the difficulty of measuring waste accurately. One stakeholder noted that material flows could not be quantified within 5% accuracy.
- One stakeholder recommended that weight measurement be made more nuanced with differentiated classifications; this would highlight variations in the value of materials instead of measuring waste by mass which often leads to less dense materials being masked by higher density or more voluminous wastage. If there is a greater classification of waste by either carbon emissions or by economic value, efforts to identify which waste streams are having the most impact and thus require most attention can be improved.
- Another stakeholder explained the difficulties in calculating the wastage rate. The stakeholder discussed using SmartWaste which is a type of software used by construction sites for monitoring and reporting flows including waste. While softwares like SmartWaste are valuable tools, they can only provide the quantities of waste. The wastage rate requires knowledge of the material being delivered and product-level information. The lack of robust information in the Environmental Product Declarations (EPD) makes them unsuitable for calculating the current wastage rate. Site studies are generally the only ones that provide robust, detailed information.
- Another stakeholder mentioned that, even if the waste data was accurate, what is most important to identify is the cause of the waste. As a result, the root causes of the waste are often not sufficiently well understood.

High impact of the design phase

Finally, the literature also stated that the majority of the decisions which will affect how and when waste is generated are made during the design phase. This is when materials are selected and key decisions are made. As such, the design phase has a disproportionately high impact on the waste that is generated. As the design phase is generally undertaken by different people than the construction phase this limits the efforts that can be made to reduce waste at construction.

Stakeholders proposed as a possible mitigation for this barrier that Extended Producer Responsibility (EPR) is applied to more products. EPR is an environmental policy whereby a producer takes responsibility for the performance of the product at the post-consumer stage of the products lifecycle. In the context of this measure, this would likely imply that a stakeholder involved in the design of a project would take responsibility for ensuring minimal waste during completion.

4.4 Levels of efficiency

Table 14: Levels of efficiency for construction Measure 4

Indicator: % of total construction materials wasted by mass			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	10 – 15%	1 – 5%	5 –15%
Confidence level	Green	Amber	Red – Amber

4.4.1 Current level of efficiency

Onsite waste

Several literature sources discussed onsite wastage rates, these included:

- The Circular Economy report by Ellen MacArthur Foundation (IAS 4) stated that 10-15% of materials were wasted onsite due to over-ordering, inadequate storage, and poor coordination between construction site stakeholders.[147]
- The report on Waste Prevention Programme England (IAS 5) identified that up to 15% of materials were wasted during the construction process.[148]
- A report on offsite construction (IAS 5) stated that 10% was a 'reasonable average figure across all building types' for onsite waste generation.[149]

The consensus for onsite levels of efficiency from the literature, therefore, lies in the range 10-15% of total construction materials wasted by mass.

Participants were asked to vote for the current onsite waste rates in the first workshop. Participants voted for ranges including 10-14% and 20-24%. Three votes were cast in the 10-14% category, the most for any category. There was no discussion on these votes in the workshop, with the focus of the conversation being on the need to define avoidable waste alongside the aforementioned barriers and drivers.

Offsite waste

Manufacturing processes, such as those employed in offsite manufacturing, generate approximately 1-3% waste, according to one literature source.[150] However, one stakeholder raised concerns that this estimate was too low and provided an estimate of 15% for actual offsite manufacturing waste figures.

Further concerns were raised by stakeholders about the offsite production location. If the offsite production occurs in a factory based outside the United Kingdom, any waste reporting

[147] Ellen MacArthur Foundation (2015) Delivering the circular economy: a toolkit for policymakers. Available at: link
[148] DEFRA (2021) Waste prevention programme for England 2021. Available at: link
[149] Building Intellect (2013) Offsite construction – sustainability characteristics. Available at: link
[150] Building Intellect (2013) Offsite construction – sustainability characteristics. Available at: link

framework for levels of efficiency would need to ensure waste figures were disclosed from that process.

Overall process waste

Voting in the second workshop (for overall process waste) showed a majority by one vote for the current level of efficiency in the range of 11-15%, with four votes overall. Three other votes cast were in the 16-20% category. One sector expert, working in an engineering and construction delivery company, cast their vote in the 11-15% vote range.

A significant number of attendees cast their vote for this measure, with seven attendees – out of 14 total - casting their vote in the three categories available. One stakeholder mentioned that the chosen data points are acceptable estimates as industry averages, and that there is a wider diversity of efficiency levels depending on specific materials and/or approaches to construction. Stakeholders reinforced the point that offsite waste generation does not currently guarantee lower waste rates compared to onsite, or ‘wet’, manufacturing methods, but did not quantify the difference.

The lower bound of the voting level at 11% was adjusted down to 10% to reflect the values found in the literature review. There is therefore consensus from workshops and literature that the current level of efficiency is 10-15%. As a result, a green evidence RAG rating was assigned to this measure.

4.4.2 Maximum level of efficiency in 2035

There was no literature identified providing evidence of the maximum potential level of efficiency.

At the second workshops attendees voted on the maximum level of efficiency for overall process waste generation (onsite and offsite). Voting in the workshops showed consensus that the maximum level of efficiency in 2035 would be in the range 0-5% as voted by two-thirds of the attendees; the remaining third opted for the range of 6% to 10%. One stakeholder mentioned currently a well-managed site with specific waste management resources can achieve a level of efficiency under 5%. The topic expert cast their vote in the 0-5% range.

Many stakeholders pointed out that zero waste is unachievable. There was discussion from stakeholders around the need to differentiate between zero avoidable waste and zero absolute waste. One stakeholder stated that regardless of the manufacturing method, even if assembling pre-fabricated units on-site, waste would be generated. Packaging waste was mentioned as a significant part of unavoidable waste. The material and volume of packaging used for construction site materials is decided well before the packaging arrives on the construction site. As such, the construction site cannot directly influence the choice or mass of packaging used and it is classified as unavoidable waste.

Another stakeholder also discussed that the maximum level of efficiency reached would depend on the market share and whether off-site manufacturing gains in the market over conventional manufacturing methods.

Given that stakeholders expressed views that 0% waste is likely unattainable, the selected range for this measure is 1-5%. As this view had consensus from the majority of stakeholders, including one topic expert, an amber evidence RAG rating was assigned.

4.4.3 Business-as-usual in 2035

During the workshops, stakeholders explained the challenges facing the industry in overcoming the barriers of this measure. One factor currently limiting improvements in waste generation on construction sites is the variation between standards of site employees. Whilst some may be well versed in minimising waste generation and handling, others may not be. A potential area for improvement was suggested by one stakeholder. They pointed out that if there is a specific individual nominated to handle the management of waste on a construction site, waste generation rates fall significantly, as evidenced by a confidential project. Also discussed were challenges in generating accurate waste data that can be linked from materials being classified at the waste stage to the products arriving at the construction site. Without being able to link the waste generated to the product it arrived with or is part of, the waste data cannot be generated. The means to overcome this requires significant improvements in data collection which implies both time and financial investment. Finally, stakeholders addressed the sheer complexity of understanding of what is causing waste generation on construction sites as well as the need to understand it. These substantial barriers suggest that limited improvements in waste generation are expected in a BAU scenario.

Reflecting this the majority of stakeholders in the workshop voted that the business-as-usual level of efficiency in 2035 would be in the range of 11-15%. Votes were also cast for the 0-5% and 6-10% ranges, but with fewer votes than the 11-15% range. One topic expert placed their vote in the 6-10%. Another stakeholder who voted for the range of 6-10% mentioned that this level of efficiency would depend on the evolution of the offsite manufacturing market, which could drive improvements.

Given the spread of votes, the selected range was 5% to 15% with a red-amber evidence RAG rating.

The proximity of the business-as-usual case in 2035 to the current efficiency level is likely attributed to significant barriers limiting production waste reduction. Changes are required to remove these barriers, such as better relationships between stakeholders regarding the management of waste generated on a construction site. Embracing new relationship dynamics and areas of responsibility is not likely to be a quick challenge to overcome.

5.0 Measure 5 – Reducing need for primary material production through repurposing/repair of the existing building stock

5.1 Construction resource efficiency measure

5.1.1 Description

Extending the lifetime of the existing building stock by avoiding premature demolition and replacement has the potential to reduce raw material demand through reducing the demand for new construction. For example, a commercial building designed for 75+ years may be demolished prematurely at 30 to 40 years,[151] and a new building constructed in its place.

Many motivations may lead to the premature demolition of a building and redevelopment, some financial and others including the changing aesthetic tastes of consumers. Increasing renovation, retrofit and refurbishment will have a key role to play in upgrading existing building stock, and avoiding the loss of value in the current embodied building materials.[152] One stakeholder mentioned that RIBA estimates 50,000 buildings are demolished annually; while not all may be avoidable, some could benefit from renovation, retrofit and refurbishment to prevent demolition.

This measure applies to the residential, commercial and industrial sub-sectors. However, studies identified in the literature review primarily focused on examples in the residential and commercial sub-sectors. This suggests that these sub-sectors are currently using/considering this measure more than the infrastructure sub-sectors. This makes sense when you consider that infrastructure projects tend to be purpose built, large-scale, and carry out essential functions. This decreases the opportunity for them to be repurposed.

There are several lifetime extension methods described for this measure. It was acknowledged in the literature that the construction industry is still developing clear definitions for these terms and that they are often used interchangeably.[153] The Designing Buildings Wiki provides a clear definition of each of the below.[154] The definitions are added to with information from other sources where pertinent:

- Retrofit – providing something with a component or feature not fitted during manufacturing or adding something it did not have when constructed. A study by Shahi et al. proposed that retrofit does not include structural improvements;[155]

[151] IEA (2019) Iron and Steel Technology Roadmap. Available at: link
[152] Cities of making (2020) Foundries of the future. Available at: link
[153] Shahi, S et al. (2020) A definition framework for building adaption projects. Available at: link
[154] Designing Buildings Wiki (2022) Renovation v refurbishment v retrofit. Available at: link
[155] Shahi, S et al. (2020) A definition framework for building adaption projects. Available at: link

- Refurbishment – the process of improvement which may include elements of the retrofitting process. There are blurred boundaries between refurbishment and retrofitting;
- Renovation – Taking something and returning it to a good state of repair. Renovation is most often carried out on buildings that are to some extent derelict, broken or in significant need of repair. Activities may include changing the layout of a structure.[156] and;
- Repair – the process of returning a building or components to its original state or service provision, after a failure, or to improve the product's/building's overall performance.

5.1.2 Examples in practice

Retrofitting of existing buildings is an opportunity to reduce the need to build new homes. It has gathered attention as a way of meeting changing needs of society whilst allowing the retention of existing building materials and thus improving resource efficiency. For example, instead of demolishing commercial buildings, they could be repurposed into flats.[157]

A notable example of retrofitting is the Architects Journal retrofit of the year for 2023, Sheffield's Park Hill building.[158] The former derelict estate, originally built in the 1960s, has seen a two-phase upgrade, retrofitting the space to offer 260 flats for residential buyers. This project has avoided demolishing an otherwise derelict building, which would have undoubtedly led to the generation of significant volumes of demolition waste, and demand for raw materials on a future construction project.

An example of refurbishment is the 1 Triton Square project.[159] Instead of moving into a newly built office space, the 1 Triton Square premises was instead refurbished to meet the evolving needs of British Land. As part of the scheme, the refurbishment of a 3,500 square meter façade was undertaken, making it one of the largest scale examples of refurbishment to date.

The Architects Journal also provided an example of the renovation of two flats in North London into a single-family home. This new home made better use of the space based on the family's requirements.[160] It could be assumed that renovating this flat prevented the new build of a two-bed house.

In terms of the refurbishment of civil infrastructure, United Utilities provides an example through its refurbishment of the Vyrnwy Aqueduct as part of its modernisation programme.[161] Another example is the recent repurposing of Battersea Power Station into a mix of commercial and residential spaces.[162]

5.1.3 Measure indicator

The selected indicator for this measure was **the % change of new builds avoided by repair/retrofit/refurbishment of the existing building stock relative to 2023 levels**. The scope of this indicator sits at a national level, rather than on a building-by-building basis.

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[156] Ibid
[157] ECA (2022) Converting commercial offices to residential accommodation [Online] Available at: link
[158] Architects Journal (2023) AJ Retrofit Awards 2023 [Online] Available at: link
[159] ARUP (2022) 1 Triton Square: How can existing buildings combat climate change. Available at: link
[160] Architects Journal (2011) Calabria Road Renovation [Online] Available at: link
[161] United Utilities (2022) Vyrnwy Aqueduct Modernisation Programme press release [Online] Available at: link
[162] CIBSE Journal (2022): Case Study: Battersea Power Station [Online] Available at: link

Furthermore, this measure's scope will specifically cover new builds of residential, commercial and infrastructure projects.

It is noted that the reference to 2023 levels will not be reflected in the studies referenced. It is included to acknowledge that this measure is benchmarked with a current level of efficiency of 0%, in the year of this report (2023).

The resource efficiency savings from this measure come from reducing the volume of materials required to give a building its new required characteristics, as retrofit/refurbishment/renovation and repair generally require a lesser volume of new materials than the equivalent new construction.

Other measure indicators identified during the literature review and workshops that were not selected include:

- **Cumulative raw material demand reduction** – While this indicator would provide the most straightforward connection to resource efficiency, the main reason for not selecting it is that it is not a common indicator in the construction industry. The literature sources did not yield any useful datapoints using this indicator and it was decided not to present it to stakeholders to avoid participants being unable to engage. Additionally, it presented measurement issues as it could be conflated with raw material reductions under Measure 3 (e.g., lean design).
- **% of existing buildings saved from demolition due to lifetime extension** –This was discarded due to the lack of available data and due to challenges of identifying the buildings – if a building is refurbished / retrofitted / renovated, it would be difficult to know whether the building was effectively saved from demolition or demolition was never considered in the first place.
- **% of lifetime extension of the buildings due to repair and refurbishment** –This metric was presented to stakeholders in the first workshops, but there was a general disagreement with its effectiveness due to the difficulty of separating actual lifetime vs service life and the lack of correlation with material savings.

5.2 Available sources

5.2.1 Literature Review

The concepts of repair, retrofit, renovation and refurbishment are covered to an extent within the literature. [163] [164] However, there was very little discussion of the potential resource efficiencies that can be achieved through this measure.

The primary data source in the literature was a technical report by the Green Alliance (IAS 5).[165] The report was highly relevant and discussed the potential material savings from a raft of measures, including an increase in retrofit in the residential and commercial sector. In addition, the roadmap to the sustainability of iron and steel (IAS 4) discusses how the cumulative production of raw materials may be reduced by avoiding premature demolition, although this is

163 Designing Buildings Wiki (2022) Renovation v refurbishment v retrofit. Available at: link
164 Shahi, S et al. (2020) A definition framework for building adaption projects. Available at: link
165 IEA (2019) Iron and Steel Technology Roadmap. Available at: link

specifically applied to the steel industry.[166] Finally, a US report conducted a lifetime carbon assessment analysis of several case study scenarios. The report has an IAS of 5 due to the applicability of the findings.[167] The study focussed on quantifying the environmental impacts of building reuse and renovation versus new construction, over a 75-year timespan. The study found that from an environmental impact perspective, reuse almost always had a lower environmental impact compared to new construction when comparing buildings of similar size and functionality.

5.2.2 Workshops

During the workshops, meaningful discussion was had on this measure, but there was less discussion relative to the other measures. Stakeholders were well placed to speak on this, with those engaging being from academic institutions with particular expertise on the topic and/or being part of projects leading on the topic area.

Stakeholders agreed on the overall principle that repair, retrofit, refurbishment and renovation should be prioritised over demolition and discussed inter-dependencies with Measure 1 – use of reused content in buildings. Stakeholders also discussed that refurbishment is not always an option, since there are cases where buildings are no longer fit for use, damaged beyond repair, or the space for low-rise buildings could be used for high-rise buildings (where policy and land value supports high-rise to maximise the gross internal floor area per unit area of land). Thus, stakeholders recommended considering whole lifecycle carbon alongside resource efficiency as these decisions can depend on the project and the context.

5.3 Drivers & Barriers

5.3.1 Drivers

There were seven drivers discussed overall. Two economic related (cost savings, job creation), two legal or regulation related (pre-demolition audits and changes to permitted development rights), two technical (vertical savings and material savings) and finally one social relating to shifting citizen attitudes. The drivers are shown in Table 15.

Table 15: Drivers for construction Measure 5

Description	PESTLE	COM-B
Savings associated with undertaking retrofit, renovation or repair, relative to the costs of demolishing and subsequent new builds.	**Economic**	**Motivation – reflective**
Shifts in citizen attitudes away from the perception that new is better	**Social**	**Motivation – social**
Job creation	Economic	Opportunity – social
Material and environmental savings.	Environmental	Motivation – reflective

[166] Ibid

[167] Preservation Green Lab (2022) The Greenest Building: Quantifying the Environmental Value of Building Reuse Available at: link

Description	PESTLE	COM-B
Vertical extensions in the over-designed existing building stock.	Technological	Capability – physical
Pre-demolition audits.	Legal	Motivation – reflective
Potential changes to permitted development rights easing refurbishment.	Legal	Opportunity – psychological

Reduction of capital savings

Stakeholders voted the lower cost of refurbishment compared to demolition and new build as the most significant driver for this measure. Some information in the literature supported this, with one study citing that retrofitting British Land's London headquarters was 15-18.5% lower in cost relative to a new build.[168]

However, there is disagreement on the relative cost of refurbishment over demolition and new build, and it will depend on the specifics of the project. For example, one academic stakeholder reported that demolishing and rebuilding was generally cheaper and easier (and so would be a barrier to this measure). The current exemption of VAT on new builds is likely a contributing factor to the relative cost of demolishing and generating new builds, as opposed to using the existing building stocks.

Job creation

Another point of discussion was the potential to create new jobs in new highly skilled areas. For example, extending the building lifetime can be enabled by digital monitoring equipment. This monitoring equipment will require training to handle and incorporate into a workflow. Regarding job creation from a wider economic perspective, an anticipated 500,000 new highly skilled jobs could result from a coordinated national retrofit programme.[169]

Shift in citizen attitudes

With the general public showing increased consideration of the environment, there may be more appetite for retrofit.[170] As retrofit has been shown to reduce carbon, this could be associated with being a more sustainable choice. Therefore, the increased concern for the environment amongst the public may drive a reduction in new builds and an increase in retrofit, repair or renovation undertaken.

Material and environmental savings

Another important driver is the raw material savings/carbon savings that can be achieved from this measure. Refurbishment instead of demolition and new build generally results in a reduction in the use of virgin and or recycled materials, thus improving the resource efficiency of the construction sector. One stakeholder highlighted this measure as the most efficient way of reducing virgin material consumption. This, in turn, drives a reduction of embodied carbon,

[168] Green Alliance (2023) Circular construction: Building for a greener UK economy. Available at: link
[169] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link
[170] ONS (2021) Three-quarters of adults in Greater Britain worry about climate change. Available at: link

which is a key metric for the industry. A report by Preservation Green Lab shows that reuse and retrofit can deliver significant carbon savings.[171]

Vertical extensions

Workshop stakeholders have stated that the existing building stock is currently over-designed. This allows vertical extensions to be undertaken without requiring additional strengthening. Thus, this is an opportunity to reduce the need for new builds and extend vertically in cities.[172]

Pre-demolition audits

Circular economy statements are now required for certain planning applications in regions of London. As part of these statements, a pre-demolition audit is undertaken, assessing how all waste generated during any demolition will be recycled or reused. The guidance has also been recommended for any stakeholders such as designers or architects, who do not require a circular economy statement but wish to improve their schemes sustainability metrics.[173] Stakeholders corroborated their importance in extending the lifetime of buildings through planning for and carrying out repairs where possible. However, other stakeholders have discussed the risk of ease of circumvention, and that they could be considered a 'tick-boxing' exercise.

Potential changes to permitted development rights easing refurbishment

Finally, stakeholders also mentioned that there are proposed changes to the permitted development rights as part of the Levelling-up and Regeneration Bill.[174] This will mean that changing the use of buildings does not require changes in planning permission, thus benefiting refurbishment projects.

5.3.2 Barriers

There were eight barriers in total discussed for this measure. Three barriers related to economic factors (VAT on retrofit, cost of retrofit design and demolition having higher economic value), three were social related (lack of skills, dull retrofit perception, lack of user requirement consideration), two were technical (uncertainty in refurbishment and lack of current building stocks), and one was legal (lack of regulation). The barriers discussed are shown in Table 16.

[171] Preservation Green Lab (2022) the Greenest building: Quantifying the environmental Value of building reuse. Available at: link
[172] Hawkins, W et al. (2022) Construction Sector Innovation within Absolute Zero
[173] Greater London Authority (2022) London Plan Guidance. Circular Economy Statements. Available at: link
[174] HMG (2023) HL Bill 84. Levelling-Up and Regeneration Bill. Available at: link

Table 16: Barriers for construction Measure 5

Description	PESTLE	COM-B
20% VAT on retrofit, refurbishment and renovation but new build has 0%.	**Economic**	**Motivation – reflective**
Cost of design of future retrofit.	**Economic**	**Motivation – reflective**
Demolition and new build having higher economic value and profitability.	Economic	Motivation – reflective
Lack of skills in refurbishment.	Social	Capability – psychological
Public perception that retrofit is dull and not exciting, and that 'new is better'.	Social	Motivation – automatic
Lack of regulation supporting refurbishment.	Legal	Motivation – reflective
Lack of consideration of user requirements and future planning can result in premature housing demolitions.	Social	Motivation – automatic
There is more uncertainty in refurbishment compared to demolition and new build.	Technological Economic	Motivation – automatic
Lack of understanding of current building stock	Technological	Motivation - automatic

The top two barriers identified by workshop participants were financially related (marked in bold). This corroborates the views expressed in the literature that a significant challenge in driving retrofit uptake is incentivising it financially.[175]

Financial barriers

- New build homes have a 0% VAT rate placed on labour and building materials. Retrofit, refurbishment and renovation activities are subject to 20% VAT.[176] This shifts financial incentives towards new construction.
- Cost of design for future retrofit. A higher initial investment is potentially associated with designing buildings to enable future refurbishment and retrofit. As building ownership changes regularly the original client may be different from the client for the retrofit, and so they may not benefit from their higher initial investment.
- Finally, while cost savings has been mentioned as a key driver, one stakeholder highlighted that demolition and rebuilding are perceived as having higher economic value and higher profitability. This is also mentioned in a Green Alliance report[177] which explains that early demolition of buildings is widespread due to demolition and new build being more economically viable. One stakeholder pointed out that there are currently no restrictions on demolition.

To counter these barriers, stakeholders have suggested that tax and economic incentives discouraging demolition of buildings could drive this measure. The UKGBC predicted that based on a positively changing fiscal landscape (e.g., removal of VAT for retrofitting activities),

[175] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link
[176] Green Alliance (2023) Circular Construction – Building for a greener UK economy. Available at: link
[177] Green Alliance (2023) Circular Construction – Building for a greener UK economy. Available at: link

there would be a significant increase in retrofitted homes in the UK. Specifically, 1.4 million homes would be retrofitted between 2018-2025. 7.6 million would be retrofitted between 2025-2030, and 9.3 million between 2030-2035[178].

Public perception

Public perception is another identified barrier, as stakeholders agreed that retrofit is considered dull and unexciting and that 'new is better'. One stakeholder mentioned that this also applies to the architects and designers, who can perceive refurbishment and/or modular design as low status and/or creatively restrictive. Another stakeholder mentioned "The Tyranny of the Ribbon" to exemplify the higher publicity and attention from inaugurating a new building compared to a refurbishment.

Lack of regulation supporting refurbishment

Stakeholders agreed that the current policy environment is not supporting refurbishment to its maximum potential. While pre-demolition audits were listed in the previous section as a driver, stakeholders mentioned the need for increased regulation to counter the current barriers, making a case for demolition harder and providing incentives to maintain the existing fabric of a building/retrofit. Stakeholders mentioned two positive examples:

- The Greater London Authority requires Circular Economy Statements for planning applications,[179] which require an assessment of circularity at the onset of a construction project. The pre-demolition audit must assess if the building materials in the buildings are suitable for reclamation; this will drive only the most necessary demolition cases.[180]
- The French environmental regulation RE2020,[181] which considers whole lifecycle carbon, including refurbishment and demolition.

One stakeholder from academia mentioned that recognising the value of existing buildings is key to avoiding premature demolition. This requires consideration of all the future requirements, not just of the users, but urban planning requirements (e.g., evolution of the neighbourhood and city).

Higher levels of uncertainty associated with building refurbishment

Stakeholders also mentioned higher levels of uncertainty associated with building refurbishment, compared to new build. This can be a technical risk, due to the lack of information on the state of the building, which also translates into economic risk. As a mitigation, stakeholders suggested the creation of building insurance mechanisms suited to reuse/refurbishment. This was also discussed in one literature source.[182]

Lack of understanding of the current building stock

A further barrier related to refurbishment and retrofit is the lack of understanding of current building stock in the UK. Without a full understanding of the building stock, it will likely restrict

[178] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link
[179] Greater London Authority (2022) London Plan Guidance. Circular Economy Statements. Available at: link
[180] This is in line with Commitment 1.1 of the GLA Circular Economy ambitions, which is to reduce demand for building materials by prioritising refurbishment over demolition.
[181] Ministère de la Transition Écologique et de la Cohésion des Territoires (2020). Guide RE 2020. Available at: link
[182] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link

retrofit and refurbishment activities. This is because the size of the opportunity to carry out such activities will not be understood correctly.

Lack of skills in refurbishment

Finally, while job creation was identified as a driver, its related barrier is the current lack of skills in refurbishment, which could prevent reaching the maximum level of efficiency.

Stakeholders also discussed potential mitigations for these barriers:

- The use of technology can remove some barriers and facilitate refurbishment. Examples mentioned by stakeholders include technology for scanning buildings, digital twins, access to LCAs, human-robot collaboration, service-life prediction models, etc.
- If smaller companies are able to enter the market, there will likely be a raft of innovative new concepts supporting retrofit, renovation or refurbishment. For example, Stonewood Builders, a company appearing to employ <100 persons, recently delivered an award-winning renovation of a traditional brick building in Dorest.[183] This will stimulate the market and overcome the concept that retrofit is 'against the grain'.
- In new builds, requirements to design for reversibility or adaptability would help extend their lifetime.

5.4 Levels of efficiency

Table 17: Levels of efficiency for construction Measure 5

Indicator: the % change of new builds avoided by repair/retrofit/refurbishment of the existing building stock relative to 2023 levels			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Value	0%	>25%	4 – 14%
Confidence level	N/A	Red–Amber	Red

5.4.1 Current level of efficiency

As there was no data identified on the current percentage of new builds that was avoided by refurbishment, retrofit and renovation of the existing building stock, this measure is baselined at current levels. Therefore, the current level of efficiency is defined as 0%.

Thus, the indicator being selected at 0% does not mean this measure is not happening – as already discussed in earlier sections, refurbishment in the UK is taking place and currently realising resource efficiency benefits. One source identified that in 2018, of the approximately 250,000 new domestic properties delivered, 42,000 of them were properties converted for domestic purposes.[184]

[183] Architects Journal (2023) AJ Retrofit Awards 2023 [Online] Available at: link
[184] Drewniok, M.P (2022) Mapping material use and Embodied carbon in UK construction. Available at: link

5.4.2 Maximum level of efficiency in 2035

The Green Alliance modelled the potential reductions in raw material use through five circular economy best practices.[185] One best practice was demand reduction, which considered two factors. The first was tripling the number of flats created through retrofitting commercial buildings. The second was reducing projected spending on roads to cover only maintenance instead of new road construction. The resulting reduction in raw material demand (for all 5 scenarios), relative to a business-as-usual scenario by 2035, was 8%. This is illustrative of the reduction possibly achieved through the circular economy strategies that have been modelled. However, as the GA modelling uses a different indicator than this report, and only looked at some examples of this measure, the figure cannot directly inform our maximum level of efficiency for this measure.

Workshop stakeholders also agreed that retrofitting commercial buildings could deliver resource efficiency benefits, with one stakeholder providing a data point that 42,000 homes were recently delivered as converted flats having been changed from commercial space (the value originates in the study provided by the stakeholder).[186]

In the workshop voting session few stakeholders voted for this measure, providing corroboration that there is substantial uncertainty around the resource efficiency potential for this measure. However, the votes that were cast were unanimous in the > 25% range. This is in line with the qualitative discussions held, where stakeholders have cited this measure as having a high resource efficiency potential. However, there was uncertainty about quantifying the link between the construction industry's retrofit, refurb or repair activities and the indicator selected for this measure. Of those votes cast, two stakeholders had expertise in the circular economy, specifically applied to the construction sector.

The voting will therefore guide the maximum level of efficiency for this measure and be placed at >25%. Despite the lack of corroborating literature, there was consensus for this voting range along with one vote cast by a topic expert. However, with no guide on where in the >25% range the level of efficiency sites, this measure will be given a red RAG rating. This measure requires significant further research efforts to understand the potential resource efficiency improvements it may yield.

5.4.3 Business-as-usual in 2035

In workshop stakeholder voting, the majority of votes were in the 'don't know' category. There were, however, two stakeholders who voted for the range 10% to 14%. The topic experts voted in the 'don't know' category and the 10-14% category.

The discussion on this measure was relatively limited compared to other measures. When the discussion stared on the barriers and drivers, no comments were made. As such, besides from the number of barriers significantly outweighing the drivers, there is no further evidence to support the differences between BAU and current/maximum level of efficiency. In text contributions, one stakeholder mentioned that current renovation rates are not likely to increase substantially without considerable economic support. Another stakeholder suggested that the BAU is likely to be 0% due to Jevons paradox.[187] Stakeholders also discussed that a combination of economic and psychological barriers restrict the uptake of this measure.

[185] Green Alliance (2023) Circular Construction – Building for a greener UK economy. Available at: link
[186] Drewniok, M.P (2022) Mapping material use and Embodied carbon in UK construction. Available at: link
[187] According to this paradox, when the efficiency of a resource is increased, the costs are lowered and the demand increases; thus, the resulting consumption can be higher despite the efficiencies.

Specifically, the psychological barrier of changing perceptions on retrofit, for example, has the potential to take significant time to overcome. However, shifting perceptions towards the environment may provide the stimulus necessary to drive this measure forward and effect positive change.

Given the stakeholders comments that there is already refurbishment and retrofit underway in the UK, the level of efficiency is not set at 0% for BAU. However, there is little in the way of academic literature to support what its possible values are. As such, the lower value of the band is set at 4%, or one voting range up from 0%. The upper band of the range is then set at 14%, in line with the stakeholder voting. Given the fact that there was minimal discussion and voting, a red RAG rating was given.

5.5 Other insights

One of the stakeholders warned against the negative impacts of certain land-use changes and converting industrial and commercial space into residential buildings. While these changes may be driven by economic incentives (with residential providing higher value), it could lead to the relocation of industry and commercial activities. This, in turn, could potentially lead to lower overall efficiency.[188] Specifically, relocation of industrial activities may require reallocation of key infrastructure supporting, for example, heavy industry. This new requirement to construct infrastructure would, in turn, require further resources.

[188] Cities of making (2020) Foundries of the Future. A Guide for 21st Century Cities of Making. Available at: link

6.0 Measure 6 – Recovery of building materials for reuse/recycling

6.1 Construction resource efficiency measure

6.1.1 Description

This measure concentrates on the treatment of construction and demolition (C&D) waste once it has been generated at end of life, i.e. the proportion of waste generated that is diverted from landfill or energy recovery, through recycling or reuse, thus reducing the primary raw material demand through new construction products. This includes all waste generated on building (residential and commercial) and infrastructure sites during construction and demolition activities.

It is important to distinguish Measure 6 from Measure 1 for the reuse element of this measure. Measure 1 focuses on how materials that have been prepared for reuse are incorporated into a construction project. Measure 6 by contrast, focuses on extracting materials/structures from a lifecycle and preparing them for use in a subsequent lifecycle.

When considering C&D waste, it should be noted there will likely always be some waste that is not suitable for reuse or recycling. These are waste flows which are considered hazardous and are not suitable for further use or processing, such as materials that contains asbestos.

Excavation waste has been excluded from this measure because it is not classified as a construction material.

6.1.2 Examples in practice

- Reuse of materials – Reuse of components entails that they are removed from one lifecycle and, with minimal processing steps carried out, are placed in the next lifecycle. Reuse of materials in this way is enabled by design factors such as design for disassembly. Examples include disassembling a structural steel beam that has been used in a building frame. This would be achieved by removing connecting bolts at steel joins. Once this activity has been carried out, the component would be classified as prepared for reuse. Timber beams are also discussed as construction materials which could be prepared for reuse.

- High-value recycling of C&D waste (no or negligible change to the material value of the material that is recycled) – Recycling processes for glass and steel are high-value as the materials can be recycled without significant material losses. Plastics do exhibit more material losses in the recycling process than glass and steel but still maintain a significant portion of the first lifecycle properties.

- Low-value recycling/downcycling (a process where the material value of the recycled material is significantly lower than the level of the material before recycling) – On a general level, plastics often lose value during the recycling process through a loss in the quality of the material. This may take place due to chemical limitations in the process, efficiency losses or contamination of the waste stream. Low-value recycling also occurs when construction products are a composite of multiple individual materials. These materials cannot be fully separated due to the bonding of multiple materials. An example of downcycling is the production of recycled aggregates, such as recycled concrete aggregate. This is covered in more detail in the Unlocking Resource Efficiency: Phase 1 Cement and Concrete Report.

6.1.3 Measure indicator

This measure has two indicators:

- **Percentage of C&D waste recovered and prepared for reuse, by mass**; and
- **Percentage of C&D waste recovered for recycling, by mass**. It is important to distinguish between Measure 1 and Measure 6 when discussing reuse. Measure 1 focuses on the incorporation of reused content into a construction project. By contrast, this measure discusses how materials are recovered for reuse and then prepared for reuse in another lifecycle.

This indicator covers only waste that is non-hazardous. It is likely that for hazardous waste, there will be limited scope for its recycling or reuse, so it is not discussed further for this measure.

The measure indicators identified during the literature review and workshops that were not selected were:

- **Percentage recycling and reuse rate by building weight** – It was identified by stakeholders and in the literature [189], that separating out reuse and recycling reporting would help to stimulate more progress in the area. As such, this indicator was discarded.

6.2 Available sources

6.2.1 Literature Review

This measure was the most documented within the literature. A total of 14 sources discussing recycling and/or reusing C&D waste and its destination at the end of life were identified:

- Four academic reports by Gonzalez et al. (IAS 5)[190], Cooper et al. (IAS 5);[191] Durmisevic et al. (IAS 5)[192] and Arm, M et al. (IAS 5).[193]

[189] Green Alliance (2023) Circular Construction: Building for a greener Economy. Available at: link
[190] Gonzalez, A et al. (2021) Methodology to assess the circularity in building construction and refurbishment activities. Available at: link
[191] Cooper, S (2016) A multi-method approach for analysing the potential employment impacts of material efficiency. Available at: link
[192] Durmisevic, E et al. (2021) Development of a conceptual digital deconstruction platform with integrated Reversible BIM to aid decision making and facilitate a circular economy. Available at: link
[193] Arm, M et al. (2017) How Does the European Recovery Target for Construction & Demolition Waste Affect Resource Management? Available at: link

- Seven technical reports by Cartwright et al. (IAS 4) [194], Ellen MacArthur Foundation (IAS 4) [195], Building Research Establishment (IAS 3) [196], Greater London Authority (IAS 3) [197], UKGBC (IAS 4) [198], Zero Waste Scotland (IAS 4) [199] and ARUP (IAS 4).[200]
- Two policy documents by the House of Commons Environmental Audit Committee (IAS 3) [201] and Zero Waste Scotland (IAS 4). [202];
- One website article by INTERREG (IAS 4).[203]

The maximum IAS was 5, the minimum 3 and the average 4.28. This high IAS average indicated the strength of the literature covering this measure.

The level of the discussion of this measure in literature was varied, with some sources focusing on individual construction site levels, whilst others focused at a national level.[204] [205] The themes of the papers within the literature included discussion on resource efficiency as well as decarbonisation, net zero pathways and the circular economy.

A common discussion within the literature was the recycling and reuse rate of C&D waste, from the perspective of avoiding landfill. Examples included a technical report by the Greater London Authority (IAS 4),[206] an academic journal publication (IAS 5),[207] and technical studies by the UK Green Building Council (IAS 4)[208] and Zero Waste Scotland (IAS 4).[209] Technical reports by the Ellen MacArthur Foundation (IAS 4)[210] and ARUP (IAS 4)[211] also discussed the mass of waste that would avoid landfill. There were many qualitative discussions on this topic within the literature, but quantitative data points were relatively limited.

Literature was sought on the material-specific influences on the overall construction sector recycling and reuse rates. Some discussion was identified on both glass and steel and their respective recycling and reuse rates, but this did not cover all materials, with a gap identified for material-specific breakdowns. The papers which covered steel are included as references, but readers are referred to the Unlocking Resource Efficiency: Phase 1 Steel Report for a full

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194 Cartwright, B et al. (2021) CIRCUIT - Recommendations on circularity indicators. Available at: link
195 Ellen MacArthur Foundation (2015) Delivering the circular economy: a toolkit for policymakers. Available at: link
196 Building Research Establishment (2008) The economic and environmental benefits of resource efficiency in construction. Available at: link
197 London Mayors Office (2017) Design for a circular economy. Available at: link
198 UKGBC (2021) Net Zero Whole Life Carbon Roadmap. A Pathway to Net Zero for the UK Built Environment - Technical Report. Available at: link
199 Zero Waste Scotland (2017) Procuring Resource Efficient Construction Projects. Available at: link
200 ARUP (2016) The Circular Economy in the Built Environment. Available at: link
201 House of Commons Environmental Audit Committee (2022) Building to net zero: costing carbon in construction. Available at: link
202 Zero Waste Scotland (Unknown) Best practice guide to improving waste management on construction sites. Available at: link
203 INTERREG (2018) FCRBE - Facilitating the circulation of reclaimed building elements in Northwestern Europe. [Online] Available at: link
204 Zero Waste Scotland (Unknown) Best practice guide to improving waste management on construction sites. Available at: link
205 UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link
206 Greater London Authority (2017) Design for a circular economy. Available at: link
207 Durmisevic, et al. (2021) Development of a conceptual digital deconstruction platform with integrated Reversible BIM to aid decision making and facilitate a circular economy. Available at: link
208 UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link
209 Zero Waste Scotland (2017) Procuring resource efficient construction. Available at: link
210 Ellen MacArthur Foundation (2015) Delivering the circular economy: a toolkit for policymakers. Available at: link
211 The Circular Economy in the Built Environment (2016) ARUP. Available at: link

discussion.[212] [213] Recycling rates for a large number of materials were discussed in a technical study by the Building Research Establishment, which is not scored at the highest IAS level due to it being published in 2008 (IAS 4).[214]

6.2.2 Workshops

This measure received the highest level of stakeholder engagement out of all the measures in both workshops and correlated with the high number of literature sources also discussing the measure. Engagement on this measure was from a range of stakeholders, including academics and construction trade associations. Discussion in the workshops was in depth for this measure, with stakeholders providing insights into both the levels of efficiency and the drivers and barriers related to this measure.

6.3 Drivers & Barriers

Due to the strong connection between Measure 1, use of reused content, and the reuse element of Measure 6, it should be considered that all drivers and barriers identified under Measure 1 are also relevant for Measure 6. Measure 1 represents the demand side of the equation, (i.e., willingness to incorporate reused content in buildings) and Measure 6 represents the supply side of the equation (i.e., ability to provide reused components).

6.3.1 Drivers

Four drivers were identified for this measure. Two were related to legal or regulatory aspects (planning requirement and reduction of liability), one was economic (economic benefits) and one was environmental (carbon benefits). All drivers are shown in Table 18.

Table 18: Drivers for construction Measure 6

Description	PESTLE	COM-B
Economic benefits from the reuse and recycling.	**Economic**	**Motivation – reflective**
Carbon benefits of reuse / recycling	Environmental	Motivation – reflective
Planning requirements (e.g., circular economy statements or pre-demolition audits)	Legal	Motivation – reflective
Reduction of potential future liability on local community	Legal	Motivation – reflective

212 Cooper et al. (2016) A multi-method approach for analysing the potential employment impacts of material efficiency. Available at: link
213 House of Commons, Environmental Audit Committee (2022) Building to net zero: costing carbon in construction. Available at: link
214 Building Research Establishment (2008) The economic and environmental benefits of resource efficiency in construction. Available at: link

Economic benefits from reuse and recycling

The top identified driver (marked in bold in the table above) was the economic benefits from this measure,[215] in terms of avoided waste management costs. However, there was some discussion around whether this was a driver or a barrier.

- Two stakeholders from the waste management sector and academia believed that it was a driver of this measure due to the economic savings from the avoided landfill tax. One stakeholder mentioned that construction and waste management companies operated sophisticated financial models which consider, not only the landfill taxes but also the costs of transporting waste to the disposal sites.
- However, two stakeholders (one from a think tank and academia) disagreed with the Landfill Tax being a driver. There is a standard landfill tax rate of £102.10/ tonne for active materials as of April 2023, and a much lower rate of £3.25/ tonne for inactive/inert waste in England. Due to the predominance of inert material generated by construction and demolition activity, it was considered by the stakeholders that the lower rate of Landfill Tax was too low to drive change.

Carbon benefits of reuse/recycling

Stakeholders agreed on the carbon benefits of reuse and recycling, which can drive reuse and recycling rates. Stakeholders also agreed on prioritising reuse (where possible) over recycling. Some stakeholders mentioned steel and the superstructures (made of steel) should be prioritised for reuse due to the carbon potential. The carbon of potential of steel is high due to the energy intensive furnace process used in steel production.

A key motivation for emission reduction is a need to meet internal or external pressures. Internal pressures could be set by the leadership, with a company putting in place a decarbonisation plan, through for example, Science Based Target Initiatives.

External pressures could arise from a client setting an emissions-related target. These external pressures were raised as being a significant motivation for reducing carbon in the construction sector.

Planning requirements

Similar to what has been seen for other measures, planning requirements such as the Greater London Authority Circular Economy statements[216] or pre-demolition audits can help drive this measure. These requirements force an evaluation of the waste generated and a justification of the selected end-of-life mechanisms, thus highlighting opportunities for reuse and recycling.

Reduction of potential future liability

A final driver that was only identified through the literature was the benefit of design for disassembly in terms of facilitating reuse and recycling at the end of first life.[217] This has the potential to reduce future liability and waste disposal costs and burden on the community where the building was located of finding waste disposal solutions.

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[215] BRE Group (n.d.) Design for Deconstruction - helping construction unlock the benefits of the Circular Economy
[216] Greater London Authority (2022) London Plan Guidance. Circular Economy Statements. Available at: link
[217] Hamer Center for Community Design (2008) DfD – Design for Disassembly in the Built Environment

6.3.2 Barriers

There were eight barriers identified for this measure. Five were technical (sorting facilities, unable to reuse materials, lack of product data, segregation space), two were regulatory (regulatory framework and reporting methods) and the lack of skills was identified as the only social barrier. The barriers are shown in Table 19.

Table 19: Barriers for construction Measure 6

Description	PESTLE	COM-B
Lack of sorting, testing and storing facilities for materials.	**Technological**	**Capability – physical**
Current waste reporting methods and requirements.	**Legal**	**Capability – psychological**
Market conditions.	**Economic** **Social**	**Motivation – reflective**
Regulatory framework.	**Legal**	**Motivation – automatic**
Lack of data on the product properties and specifications entering the waste stream.	**Technological**	**Capability – physical**
Materials not being able to be reused or recycled.	Technological	Capability – physical
Lack of space for onsite segregation.	Technological	Capability – physical
Lack of relevant skills in the workforce.	Social	Capability – psychological

Lack of sorting, testing and storing facilities

One of the key barriers identified was the lack of sorting, testing and storing facilities for recovered materials. This is most relevant for reused materials which may require storage for lengthy periods of time after end-of-life processing before being reused.

Material flows destined for recycling, by contrast, are not necessarily held for such a lengthy period of time and can be processed into recyclate relatively quickly, subject to recycling site capacity. Furthermore, the destination of recyclate can be multi-sector, as opposed to reuse where the subsequent application is often niche, increasing time for storage requirements. The discussions around testing and certifications echoed the discussions held under Measure 1.

Current waste reporting methods and requirements

Another barrier identified as significant and widely discussed by stakeholders is related to waste reporting requirements, where the following issues were identified:

- The level of granularity of current reporting is seen as insufficient. Of all waste in the UK in 2016, 63% was due to construction, demolition and excavation waste. Of this, 50% was construction and demolition waste and 43% was excavation waste.[218] Reporting on

[218] Adams, K (2020) Zero Avoidable Waste in Construction

construction, demolition and excavation waste streams is not generally done separately which prevents having a more accurate image of what wastes are fully avoidable.

- Some stakeholders questioned the current recycling figures due to the lack of traceability of the final destinations, being described as ‘obscure’. Additionally, it was reported that the misdescription of waste was not uncommon, thus reducing the reliability of the report figures.
- Waste is typically measured in tonnes at the point of treatment and disposal. As such, heavier materials will skew the results in their ‘favour’. Most of this heavy waste is inert material which could have a lower environmental impact relative to the other wastes which may degrade in landfill resulting in carbon emissions. Every potential classification measure of waste will have an impact on what materials are classified as best/worst in field. Some proposed alternatives are:
    - Defra has recommended moving to impact-based targets to assess performance.[219]
    - One stakeholder recommended setting material-specific reuse/recycling targets to counter the effect of the heavy materials.
    - Another stakeholder recommended calculating the reuse rate based on the embodied carbon of the building and its elements; this would give greater weighting to reusing the higher carbon elements.
- Stakeholders discussed the differences within recycling that can’t generally be seen in the data, such as the prevalence of low-quality recycling or ‘downcycling’. Stakeholders suggested a stronger focus is needed on high-quality recycling or closed-loop recycling.

One stakeholder mentioned that mandatory electronic waste tracking would improve data and identify material streams that can be better reused and recovered. However, if a product or component is reused before it becomes waste, it will not be captured in this system.

Market conditions

Another key barrier related to the market situation for reuse and recycling. Even though it has been also identified as a driver, stakeholders generally agreed that the current market forces are preventing higher uptakes of reuse and recycling, and that it is not profitable for some materials to recycle or reuse them.

- As discussed in the drivers section, some stakeholders believe that landfill taxes are not sufficiently preventing the disposal of recyclable or reusable materials. A point not discussed by stakeholders, but which could remove the market conditions barrier, would be the removal of VAT on recycled materials.
- Similar to the discussion under Measure 1, there is a current lack of demand for reused and or recycled materials.
- There is a difference in the scales of the industries. Currently, reuse is happening at low levels, almost on a case-by-case basis, so it is difficult to match this activity with large-scale new build developments which require larger, standardised quantities for incorporating reused components.

[219] Adams, K (2020) Zero Avoidable Waste in Construction

- Stakeholders also mentioned the lack of cross-industry coordination on the reuse of materials, and the inability to match supply with demand. A stakeholder proposed an example of an instrument that could help overcome these barriers: a national-level database outlining what materials become available for reuse, where they are and when they will become available.
- Some stakeholders mentioned economic competition from the waste-to-energy industry; this could mean it is more advantageous to incinerate certain materials than reuse or recycle them. There are many variables that would affect the economic implications of waste treatment, so translating the stakeholders comments into conclusions for this report is challenging. It is likely that the stakeholder is implying the costs associated with prep for reuse activities, mainly transport and storage and testing/certification, may be greater than the cost of incineration. For context, the 2020 WRAP gate fees report states that the median gate fee of incineration is £93/tonne, relative to the median gate fee for landfill of non-hazardous material which is £116/tonne.[220] Economic costs were not observed in the literature review for reuse so cannot be compared.
- The economic benefits of selling materials and components for reuse and recycling are currently a barrier. A stakeholder explained that most ordinary materials, even when recovered intact, have little resale value and it is more profitable to focus on demolition speed.
- Current industry business models do not favour the design for reuse or recyclability as the actors involved in the building design are not necessarily the ones who will bear the cost of waste management. This relates to the 'circle of blame' in the construction sector, where actors across the sector are unwilling to collaborate and accept responsibility.

Lack of data on the product properties and specifications entering the waste stream.

As also discussed under Measure 1 barriers, the lack of data on the product properties and specifications entering the waste stream hinders recycling and reuse. Stakeholders proposed that better data could be enabled through material passports.

Lack of space for onsite segregation.

Stakeholders reported that there is often a lack of space on a construction site to segregate material streams fully. This presents a lack of opportunity to recover waste correctly on a construction site.

Lack of relevant skills in the workforce.

Skillset within the construction workforce was also identified as a barrier; there is an opportunity to increase training and awareness, as well as overall availability, in two areas:

- Waste management: waste disposal routes, correct sorting and waste management plan implementation processes, waste data reporting (as discussed earlier).
- Circularity: deconstruction, disassembly, material certification and storage.

Regulatory framework

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220 WRAP (2020) Comparing the costs of alternative waste treatment options. Available at: link

Finally, there were several comments about the regulatory framework not driving enough change for this measure. Some stakeholders expressed that the lack of (mandatory) targets was a barrier. Several stakeholders suggested that additional tax benefits for recycled and reusable materials would promote more reuse and recycling, to overcome the market barrier.

Other insights

There are also technical challenges preventing higher reuse and/or recycling. If the products are not designed to be reused or recycled in the first place (e.g., composite materials), it will be very challenging to avoid disposal. This is due to the technical challenge/impossibility of separating out materials that may be, for instance, bonded together using wet adhesives. Given the buildings' long lifespan, this will likely continue being a barrier for a long time. Once the products reach their end of life, not all of them are in a condition that is suitable for reuse, for example, some timber beams. Stakeholders discussed two potential mitigations:

- a ban on non-recyclable materials in the construction industry, and
- design for reusability and recyclability.

6.4 Levels of efficiency

Table 20: Levels of efficiency for construction Measure 6

Indicator: % of C&D waste recovered for reuse / recycling			
Level of efficiency	Current	Maximum in 2035	Business-as-usual in 2035
Reuse – Value	2 – 7%	15 – 20%	5%
Reuse – Confidence level	Amber	Amber	Red
Recycling – Value	67 – 73%	75 –80%	>85%
Recycling – Confidence level	Amber	Amber	Red

The complexities of this measure warrant an introduction on the reported levels of efficiency. Possible destinations of this waste are landfill, incineration, recycling and reuse. The sum of these destinations must be 100%. As such, when the data for levels of efficiency does not sum to 100%, there is a proportion of waste going to landfill or incineration.

Note, this approach has been taken for this measure because it aligns with information from the literature and from stakeholders. Other sector reports in this project with similar measure may take a different approach, due to different data availability.

6.4.1 Current level of efficiency

There were several literature sources which discussed recycling rates. Data on recycling rates were split between specific materials or case studies and national rates, with the latter being most pertinent to this study. As such, the remainder of this section is split between national and material specific levels of reporting.

It should be noted that with the reuse data that is reported, there is no distinction made in the literature of whether the material/structure sent for reuse will be ultimately reused. Whether material is reused in a construction project, is covered in Measure 1. The rates reported hereafter covering reuse are assumed to be classifying a given proportion of waste generated as being suitable for reuse.

National Level

Defra report an overall recovery rate (92.3% at a national level) of non-hazardous construction and demolition waste, and this was quoted by several stakeholders. [221] However, this includes a range of operations other than recycling and reuse (e.g., energy from waste), and excavation waste (which is considered reused when backfilled), which are out of the scope of this study. Because of this, this figure cannot directly inform the current level of efficiency for this study.

A UKGBC report identified in the literature review, projects using best case assumptions, destinations of C&D waste, over a time period from 2018 to 2050, split between reuse, recycle, incineration and landfill.[222] The rates for reuse and recycling for 2018 and 2023, respectively, are provided below:

- Reuse – 2% and 4%; and
- Recycle – 67% and 69%,

These data points should be treated with a tolerance of +/-2.5%, as they were interpreted from a graphical source. The 2023 values best reflect the current level of efficiency for the purposes of this study.

In terms of reuse, an additional Interreg Project focused on the UK, the northern half of France, Belgium and to a lesser intensity, the Netherlands, Ireland, the rest of France and Luxembourg.[223] It identified that only 1% of building elements were reused following their first application. This, along with the UKGBC data, demonstrates that the rates of recycling are significantly higher than those for reuse.

In terms of recycling rates, Durmisevic et al.[224] provided a geographical European recycling average of C&D waste of 50% (assumed to be in 2021, the year of the source publication), this was lower than the UK specific UKGBC studies recycling rate in 2023 of 69%.[225] As neither source provided a link to the primary data used, it was not possible to understand the discrepancies in these two recycling rates, but could reflect different practices across European states and the UK.

Specific data

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[221] Defra (2022) UK Statistics on waste. Table 7: Recovery rate from non-hazardous construction and demolition waste, UK, 2010–2018 Available at: link

[222] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link

[223] INTERREG (2018) FCRBE - Facilitating the circulation of reclaimed building elements in Northwestern Europe. Available at: link

[224] Durmisevic, et al. (2021) Development of a conceptual digital deconstruction platform with integrated Reversible BIM to aid decision making and facilitate a circular economy. Available at: link

[225] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link

To help validate the national level data, sources of project level data are also reported where they were available. ARUP, for example, reported that 62% of the waste on the London 2012 Olympic Park development was reused, recycled or composted.[226]

One stakeholder provided different data points for current reuse rates by materials:

- glass, aluminium, plastic, concrete at 0%;
- different types of steel 1-12.5%; and
- timber 2.5%.

Another stakeholder explained that there is very little reuse on timber, only in one-off projects; between 1% and 2% of all wood waste are reused. Further comments were made by stakeholders, stating that most timber is currently incinerated.

A further stakeholder mentioned that current recycling rates, such as those reported in this section, are not taking into account losses, which would reduce current recycling rates down to 40% - 50%. This was not universally agreed however, with another stakeholder reporting that a 70% recycling target has already been comfortably exceeded. Another stakeholder provided an overall recycling and reuse rate for construction and demolition waste of 90% but did not segregate these rates into those required for the indicator chosen for this measure. However, these rates do all support there currently being a non-zero percentage of avoidable C&D waste going to landfill and incineration, in-line with statistics in the UKGBC report. [227]

Tying all this data together, the data from the UKGBC report (IAS 5) [228] is validated by the other data points cited by Zero Waste Scotland [229] and ARUP[230] which were for single projects, and the peer-reviewed paper, which covers the EU.[231] As this literature source has a high IAS and multiple other literature sources and case studies were found that broadly aligned with the UKGBC values, we have chosen to rely on the UKGBC values for the current level of efficiency (reuse 2 – 7%, recycling 67 – 73%). An amber RAG rating has been used as there was some disagreement between stakeholders and the literature values.

6.4.2 Maximum level of efficiency in 2035

National level

The source by UKGBC (with IAS of 5) also provided maximum levels of efficiency for 2035: 15% to 22% for the reuse rate and 75% for the recycling rate (± 5% for recycling rate only due to graphical interpretation). These values are assumed to be maximum efficiency levels rather than business-as-usual due to the supporting statement attached to the data that ‘ambitious estimates’ were made when deriving the data. These values were presented to the stakeholders in the workshops and the majority vote was that the levels should be higher. One stakeholder explained that around 25% of wood waste is “clean” solid timber – if recovered carefully, all could be reused.

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[226] ARUP (2016) The circular economy in the built environment. Available at: link
[227] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link
[228] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link
[229] Zero Waste Scotland (2023) Best practice guide to improving waste management on construction sites. Available at: link
[230] ARUP (2016) The circular economy in the built environment. Available at: link
[231] Durmisevic, et al. (2021) Development of a conceptual digital deconstruction platform with integrated Reversible BIM to aid decision making and facilitate a circular economy. Available at: link

A limiting factor for maximum level of efficiencies for recycling was identified by stakeholders as being highly materials specific. By declaring an industry average level of efficiency for this material, the better or worse levels of efficiency for certain materials will be masked in the average.

Specific data

On an individual construction site case study, a report by Zero Waste Scotland stated that 96% of construction waste was removed.[232] Including excavation waste, 100% of waste was recycled. This level of efficiency is perhaps so high given the demonstrator nature of the house, which was a 2-storey residential new-build. This demonstrates what can be achieved on a small-scale but might not be representative of what could be achieved by the whole sector.

Thus, the maximum levels of efficiency have been selected as the ranges of the UKGBC source, with the potential of reaching 100% between reuse and recycling: 15% to 20% for reuse and 75% to 80% for recycling. This range reflects, at the lower bounds, the scenario where a degree of avoidable C&D waste still enters into landfill or incineration. At the upper range, there is the potential for 0% C&D waste entering into landfill or incineration. The evidence RAG rating of amber has been allocated due to the disagreement between the literature and the stakeholders.

6.4.3 Business-as-usual in 2035

When stakeholders were asked to provide the best estimates for the business-as-usual scenario in 2035, the votes were as follows:

- For reuse, the votes ranged from 0% to 25%, with the preferred option being between 5% and 9%.
    - A stakeholder explained that reuse rates vary considerably by material and, as an example, structural steel reuse is increasing.
    - Three stakeholders estimated 10% or less.
    - One stakeholder estimated 4% due to the high number of barriers and even suggesting the trend has been downwards.
    - Two stakeholders estimated 10-14%, one of who works at a centre which specialises in topics connected to this measure.
- For recycling, the votes ranged from below 65% to above 85%, with the latter being the preferred option. There were comments about what was being counted under recycling. It was assumed that the stakeholder was referring to the difference between sent for recycling and the actual recycling rate of materials. The stakeholder who held expertise in this topic area also voted for above 85%, lending confidence to the voting range >85%.

Therefore, the selected ranges for the BAU are 5% to 9% for reuse and >85% for recycling. This implies that in a BAU scenario it is expected that a non-zero volume of construction waste

[232] Zero Waste Scotland (2023) Best practice guide to improving waste management on construction sites. Available at: link

is still sent to landfill; at the upper end of the reuse rate and the lower recycling rate of 85%, this would sum to 6% of waste not going to landfill/incineration.

It may initially appear confusing that the business as usual is higher for the recycling rate than for the maximum level of efficiency. The higher recycling rate is explained by the higher reuse rate for maximum scenario compared to the business-as-usual scenario. As the reuse rate is higher, the recycling rate must be adjusted down as there is a finite amount of construction waste. Therefore, the indicators are additive and alongside waste sent to landfill and incineration, they must sum to 100%.

Furthermore, in a business-as-usual scenario, it is likely that recycling will have a higher rate compared to reuse. This difference is likely explained by the increased complexity of reusing material/structures compared to recycling of materials. Additionally, given the challenges of including reused material in construction projects as evidenced in Measure 1, there is a less developed market than the recycled material market. This is backed up by reuse rates being significantly lower than recycling rates at the time of writing. [233]

In the discussion, one stakeholder pointed out that a barrier which would take significant time to overcome is the development of new standards regarding recycling processes and prep for reuse. Furthermore, one stakeholder proposed that recycling is more ingrained in the national psyche and as a result, it will take longer for reuse to be realised. Such factors will increase the gap between the business as usual and maximum scenarios by 2035 for reuse rates. The closer proximity of business as usual and maximum levels of efficiency for the recycling rates is underpinned by the improvements, verified by stakeholders, already being made in recycling rates and technology.

[233] UKGBC (2021) Whole Life Carbon Roadmap – A pathway to net zero. Technical Report. Available at: link

7.0 Interdependencies

This report has discussed each of the measures identified for the construction sector and presented estimates for the maximum and BAU level of efficiency they could achieve independently, that is, not considering any interdependencies or interactions between measures.

However, in practice these measures are likely to occur in tandem, and the levels of efficiency that are reached in each will depend on progress against other measures. The precise nature of these interdependencies should be considered when using any of the level of efficiency estimates from this report in further research or modelling exercises that attempt to produce an estimate of the cumulative impact of these measures over time.

A summary of the key interactions/interdependencies between the measures in this report with other measures in the sector, and with measures in other sectors is presented below. Note, as Phase 2 of this research project is still in the fieldwork stage, the dependencies with other sectors reflect dependencies with other Phase 1 sectors only. The Phase 2 reports will seek to capture any further interdependencies with Phase 2 sectors.

Note, the estimates for the current level of efficiency will by their nature reflect the interactions and interdependencies between measures as they currently occur.

7.1 Interdependencies within the sector

Measure 1 & 3

- Measure 1 – Use of reused content in buildings
- Measure 3 – Reduction of over-design & delivery in building structures

The lack of trust in material properties and certification is a key barrier identified by stakeholders to Measure 1. This is linked to Measure 3, since if there is limited trust in the materials, designers, engineers or architects are likely to increase the factor of safety and thus over-design buildings.

Measure 1 & 6

- Measure 1 – Use of reused content in buildings
- Measure 6 – Recovery of building materials for reuse /recycling

These two measures are highly linked since the methods used to dismantle / demolish a building will determine whether or not materials will be of a sufficient technical level to be reused. The current reuse rate (Measure 6) is low, so it is unsurprising that the current level of reused content used in buildings (Measure 1) is also low. Some of the drivers & barriers are common across the two measures.

Measure 1 & 5

- Measure 1 – Use of reused content in buildings

- Measure 5 – Reducing the need for primary material production by building lifetime extension

With fewer buildings being dismantled at their end of life and materials being kept in the building stock, there may be a reduction in content that may be reused in other construction projects.

Measure 2 & 6

- Measure 2 – Use of materials substitution for embodied carbon reduction across the whole lifecycle
- Measure 6 – Recovery of building materials for reuse / recycling

If there is to be a significant change in the materials used by the construction sector as a result of Measure 2 (for example, an increase of timber materials), Measure 6 will require an increase the national end-of-life handling capacity for those materials (for example, end-of-life wood). Stakeholders identified there is a possibility for all wood to recycled into board products, as well as higher tier products such as cross-laminated timber.

Measure 2 & 3

- Measure 2 – Use of materials substitution for embodied carbon reduction across the whole life cycle
- Measure 3 – Reduction of over-design & delivery in building structures

Measure 2 can result in a significant change in the materials used by the construction sector (for example, an increase of timber materials). Depending on the alternative materials, it could result in a trade-off with Measure 3 as it could lead to an increase of over-design. Concerns were raised by stakeholders regarding the certification schemes used for wood products. This would raise doubts about the level of trust that could be placed in timber products, potentially leading to larger factors of safety and an increase in over design in any building using timber or cross-laminated timber.

Measure 2 & 5

- Measure 2 – Use of materials substitution for embodied carbon reduction across the whole lifecycle
- Measure 5 – Reducing the need for primary material production by building lifetime extension

Different materials can result in different lifespans, so material substitution may result in a trade-off with building life extension. For example, a timber framed building may have a different life-expectancy than a steel-framed building. Thus, retrofitting activities may be required sooner, potentially increasing the overall resource use over a given time period.

Measure 3 & 4

- Measure 3 – Reduction of over-design & delivery in building structures
- Measure 4 – Reduction of construction process wastage

There is a clear link between these two measures, as reductions in design and delivery will translate into equivalent reductions in waste. For example, if a design produces a building with 25% less resource use, the construction waste will also be reduced by 25% accordingly.

Measure 3 & 5

- Measure 3 – Reduction of over-design & delivery in building structures
- Measure 5 – Reducing the need for primary material production by building lifetime extension

The link between these two measures is a potential trade-off between light-weighting and durability. If buildings are optimised for their current use, these could be unsuitable for further loading through vertical extensions without additional structural elements. On the other hand, current over-designed buildings allow for vertical extensions to take place more easily.

Furthermore, if buildings are over-designed, they have greater flexibility with regards to repurposing in the future. Therefore, if there is over-design, it may reduce resource use nationally by avoiding the need for future new construction.

Measure 3 & 6

- Measure 3 – Reduction of over-design & delivery in building structures
- Measure 6 – Recovery of building materials for reuse / recycling

Stakeholders highlighted that reducing over-design could come at the expense of reusability or recyclability, depending on material choices. For example, if bolted joints are used, they may have a greater uncertainty regarding their safety as they do not have the historical track record that welded joints do. By contrast, a welded joint with a higher confidence level, will be able to be more efficiently designed but the welded materials could not be recycled or reused with as much ease at end of life.

Measure 4 & 6

- Measure 4 – Reduction of construction process wastage
- Measure 6 – Recovery of building materials for reuse / recycling

Many of the drivers and barriers are common to these two measures, as they are both related to construction waste and the management of this waste. As construction waste goes down, so there will be less material that will enter the waste stream and become available for processing by recycling and or reuse.

Measure 5 & 6

- Measure 5 – Reducing the need for primary material production by building lifetime extension
- Measure 6 – Recovery of building materials for reuse / recycling

Measure 5 deals with the avoided demolitions, while Measure 6 deals with the end-of-life route of the materials and components. If there are fewer buildings being demolished prematurely, there will be fewer resources reaching their end-of-life, which will impact the supply of reused/recycled materials.

7.2 Interdependencies with other sectors

The construction sector is intrinsically linked to upstream sectors, which create construction materials. Any resource efficiency measures in the construction sector (which reduce the demand for construction materials), will impact demand for these sectors products. Similarly, resource efficiency measures in these upstream sectors will impact the resource efficiency of the materials used by the construction sector.

The key upstream sectors for the construction sector are covered separately in this study, with sector specific reports available for the cement and concrete (Phase 1), steel (Phase 1), plastics (Phase 2), paper (Phase 2) and glass (Phase 2) sectors.

Construction Measure 6 (recovery of building materials for reuse/recycling) is specifically linked to cement and concrete Measure 6 (use of recycled content in concrete) – the supply chain of materials to produce recycled concrete aggregate needs to be secured for certainty in supply. Therefore, if there is a greater supply of construction site waste, then there will be a better supply of materials that can produce RCA. The same also applies to Measure 3 for the steel sector (transition from ore-based to scrap-based steel production).

There is also an overlap between Measure 3 – reduction of over-design and delivery – of this sector and Measure 4 – Lean design of concrete structures - of the cement and concrete sector. This report found a level of efficiency which included data on concrete optimisation, methods of optimising concrete reinforcement, use of flexible formworks and pre-cast concrete. Such methods of reducing over-design were also reported in the Unlocking Resource Efficiency: Phase 1 Cement and Concrete Report.

8.0 Enablers that support all measures across the sector

Throughout this report, there has been discussion of enablers, which while not delivering resource efficiency savings themselves, support the delivery of these savings. The key enablers identified for the construction sector are listed below and mapped onto the corresponding measure(s) they enable.

Design for X

Design for X, commonly referred to as DfX, is a design philosophy used to ensure that a specific characteristic, X, is reflected in a design. This characteristic may be related to any lifecycle stage, defined by BS 15978. For example, design for reliability, manufacturability or disassembly. The specific characteristics (or 'X's) that are discussed in this study are outlined below and mention which measure they are pertinent to.

Design for disassembly (DfD)

DfD is equivalent to the common construction phrase, design for deconstruction. The intention of DfD's is to minimise the loss of a construction site and its individual components value when it approaches the end of its first lifecycle. This enables a construction project, such as a building or commercial office space, to be more versatile. DfD might enable options that improve resource efficiency including the ability to re-use components or repurpose buildings spatially or technically.

Methods to do this include designing connections that are accessible and visible, such as using bolted joints instead of welding with steel frames, which will enable the frames disassembly at the end of their life.[234]

Whilst theoretically, DfD appears positive, challenges around implementing it must be considered. For example, the inclusion of connection points for the steel frames will require collaboration up the supply chain for construction. Furthermore, connection points for steel would also require more material in the form of connecting bolts. These bolts, which form joints, will entail a greater mass of material used for the project. If, due to an inability to store the materials, for example, this greater mass of material is not stored, at the end of life phase this would lead to a greater overall material usage.

Measure 5 – reducing need for primary material production through lifetime extension

Measure 5 technically, has two enabling 'layers'. First, the extension of the building lifetime is enabled by the carrying out of renovation, retrofits and refurbishments. Secondly, these three activities are enabled by the ease of disassembly. For example, when undertaking a retrofit which can include significant structural change, DfD would enable the swift disassembly of the joints.

Measure 6 – recovery of building materials for reuse and recycling

[234] Hamer Centre for Community Design (2015) DfD: Design for Disassembly in the built environment. Accessible at: link

Measure 6 is enabled by DfD by ensuring that materials can be recycled or reused. For example, with joints, if binders or glues are used, this will provide a challenge when attempting to separate out the materials. This could increase the likelihood of the materials being sent to landfill if they cannot be separated out. As DfD would recommend the use of joints which can be disassembled, the waste streams could likely be separated out and recycled or reused.

Design for Manufacture and Assembly (DfMA)

DfMA would be applied by a designer to a project to enable efficient manufacture and assembly of a product or component. This would be pertinent to the construction sector in the case of offsite construction with prefabricated modules or pre-cast concrete. DfMA aids resource efficiency by, not least, reducing the number of parts that are used.[235] By reducing the number of parts, each construction project has a lower risk of failure. The effect this would have on the entire construction industry and thus the overall resource efficiency level realised would depend on the number of projects implementing the DfMA strategy. DfMA is also inherently linked to standardisation, evidenced by RIBA recommendations.[236] Standardisation is defined in the UN Procurement Practitioner handbook as: 'the process of agreeing on a standard specification for a specific product or line of products. Usually conducted to achieve…facilitation of operation, maintenance and repair of already purchased goods'.

Measure 3 - Reduction of over-design & delivery in building structures

Measure 3 is enabled by DfMA as the methodology reduces the number of parts used and actions required to assemble them. Or, where it does not reduce the number of parts or actions required to assemble, there is a clearly defined, repeatable methodology associated with the process. Both the reduction of actions and a clear definition of the assembly process will reduce the risk of assembly errors perceived by a designer. This reduction of perceived risk will reduce over-design.

Measure 4 – Reduction of construction process wastage

In a similar vein, Measure 4 is also enabled by DfMA. With the reduced assembly error risk, there is likely less waste generated on a construction site.

Business information modelling (BIM)

BIM is a collaborative process aiming to improve the flow of information between construction sector stakeholders. A recent definition of BIM in ISO 19650:2019 states it is the 'use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions'. The National Building Specification 10th United Kingdom national report on BIM usage found that 73% of survey respondents are now using BIM.

Measure 4 - Reduction of construction process wastage

Measure 4 is enabled by BIM by allowing designers to programme and thus plan delivery more effectively. For example, scheduling of materials delivery and work packages can be organised with all necessary stakeholders involved in the conversation. In doing this, the duplication of tasks, leading to excess material use, can be avoided, reducing waste generation.

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[235] RIBA (2021) DfMA Overlay to the RIBA Plan of Work. Accessible at: link
[236] RIBA (2021) DfMA Overlay to the Plan of Work. Available at: link

Measure 5 – Reducing need for primary material production through lifetime extension

Measure 5 would benefit from BIM implementation by enabling rapid visibility on how the building was initially constructed. This will then allow the stakeholder taking on the renovation, retrofit or refurbishment to accurately plan the process.

Measure 2 – Use of materials substitution for embodied carbon reduction across the whole lifecycle

Measure 2 is enabled by BIM, albeit to a lesser extent than other measures. As interest in BIM in the construction sector has grown, there has been discussion of integrated LCA/WLCA with BIM as two digital tools.[237] By feeding model information covering a construction project from BIM to an LCA, environmental performance in terms of embodied carbon can be calculated. This streamlined process between two processes will enable informed decisions to be made on the material selection with the aim of reducing embodied carbon.

[237] Obrecht, T.P (2020) The challenge of integrating Life Cycle Assessment in the building design process – a systematic literature review of BIM-LCA workflows. Available at: link

Glossary and abbreviations

BAU	Business-as-usual
BIM	building information modelling
BS	British Standard
C&D	construction and demolition
DfD	design for disassembly
DFMA	design for manufacture and assembly
IAS	indicative applicability score
RCA	recycled concrete aggregate
SWMP	Site Waste Management Plans
WLCA	Whole Life Carbon Assessment

Appendix A: IAS Scoring Parameters

Table 21: IAS Scoring Parameters

Criteria	High	Medium	Low
Geography	Specific to UK	Non-UK but applicable to the UK	Non-UK and not applicable to the UK
Date of publication	< 10 years	10 to 20 years	> 20 years
Sector applicability	Sector and measure-specific, discusses RE and circularity	Sector and measure-specific, focus on decarbonisation	Cross-sector
Methodology	Research methodology well defined and deemed appropriate	Research methodology well defined but not deemed appropriate / Minor description of research methodology	No research methodology
Peer Review	Explicitly mentioned peer review	Not explicitly mentioned, but assumed to have been peer reviewed	Unknown

Appendix B: Search strings

- circular design AND (built environment OR construction OR building)
- circular economy AND (construction OR built environment OR building)
- concrete AND repurpo*
- construction material recovery targets
- digital tools AND (resource efficiency OR circular economy OR sustainability OR low carbon OR low-carbon) AND (built environment OR construction OR building)
- disassembly design AND (built environment OR construction OR building)
- embodied carbon AND (construction OR built environment OR building)
- lightweight* AND (construction OR built environment OR building)
- low carbon AND (built environment OR construction OR building)
- material substitution AND (built environment OR construction OR building)
- (modular design OR pre-fab design OR pre fab design) AND (built environment OR construction)
- (overdesign OR over design) AND (built environment OR construction OR building)
- (over design reduction OR overdesign reduction) AND (built environment OR construction)
- repurpo* AND (built environment OR construction OR building)
- (recycled content OR recycled material*) AND (built environment OR construction OR building)
- remanufact* AND (built environment OR construction OR building)
- repurpose* AND (built environment OR construction OR building)
- resource efficiency AND (construction OR built environment OR building)
- substitution AND (timber OR straw OR hempcrete OR renewable material*) AND (built environment OR construction OR building)
- sustainability AND (construction OR built environment OR building)
- waste minimisation AND (construction OR built environment OR building)
- waste recycling AND (construction OR built environment OR building)
- waste reduction AND (construction OR built environment OR building)

Appendix C: Literature sources

Table 22: List of literature sources for the construction sector

Title	URL	Author	Year	IAS
A definition framework for building adaption projects	link	Shahi, S	2020	3
A multi-method approach for analysing the potential employment impacts of material efficiency	link	Cooper, S et al.	2016	4
A report on the demolition protocol	link	EnviroCentre Ltd	2015	5
An industry proposed amendment to the Building Regulations	link	Part-Z	2022	3
An Overview of BIM Adoption in the Construction Industry: Benefits and Barriers	link	Ullah, K and Lill, I and Witt, E	2012	4
BeAware - Research project to reduce waste and improve efficiency	link	BeAware	2020	3
Best practice guide to improving waste management on construction sites	link	Resource Efficient Scotland	n.d.	4
BIM implementation - global strategies	link	Smith, P	2014	5
BIM uses for reversible building design: Identification, classification & elaboration	link	Marc van den Berg & Elma Durmisevic	2017	5
Bringing embodied carbon upfront	link	World Building Green Council	2019	3
Building to net zero: costing carbon in construction	link	House of Commons. Environmental Audit Committee	2022	3
Buildings and construction	link	European Commission	n.d.	3
Business Plan CEN/TC 442 Building Information Modelling (BIM)	link	European Committee for Standardisation (CEN)	2020	5
CIRCUIT - Recommendations on circularity indicators	link	Cartwright, B and Lowres, F and Turner, E and Hobbs, G	2021	5
Circular Digital Built Environment: An Emerging Framework	link	Çetin, S.; De Wolf, C.; Bocken, N.	2021	3
City policy framework for dramatically reducing embodied carbon	link	CNCA, OneClickLCA, Architecture 2030	2020	2
Construction and Demolition Waste Best Management Practice in Europe	link	José-Luis Gálvez-Martos, David Styles,	2018	5

Title	URL	Author	Year	IAS
		Harald Schoenberger, Barbara Zeschmar-Lahl		
Construction and demolition waste indicators	link	Miguel Mália, Jorge de Brito, Manuel Duarte Pinheiro, and Miguel Bravo	2013	2
Construction Sector Innovation within Absolute Zero	link	Will Hawkins, Michal Drewniok, C. F. Dunant, Philippa Horton, Paul Romain, Samuel Stephenson, Fran Sergent, Julian Allwood	2020	5
Delivering the circular economy: a toolkit for policymakers	link	Ellen MacArthur Foundation	2015	4
Design for a circular economy	link	London Mayors Office	2017	4
Design for Deconstruction - helping construction unlock the benefits of the Circular Economy	link	BRE group	n.d.	2
Designing Out Construction Waste	link	Gulland, I	2020	4
Development of a conceptual digital deconstruction platform with integrated Reversible BIM to aid decision making and facilitate a circular economy	link	Durmisevic, E and Guerriero, A and Boje, C and Domange, B and Bosch, G	2021	5
FY2004 OSWER Innovation Pilot Results Fact Sheet - Deconstruction and Design for Reuse	link	Environmental Protection Agency	2010	5
How BIM enables more sustainable construction and more energy efficiency buildings	link	Zutec	2021	4
How circular economy can drive greater sustainability and new business opportunities in construction	link	Schober, K-S	2021	2
How Does the European Recovery Target for Construction & Demolition Waste Affect Resource Management?	link	Arm, M and Wik, O and Engelsen, C.J	2017	5
It's time for construction to embrace the circular economy	link	Kai-Stefan Schober, Roland Bergers	2021	3
LA 110 Material assets and waste (LA 110)	link	Highways England	2019	4
LETI Climate Emergency Design Guide	link	Desai, P	2020	4
Low Carbon & Resource Efficient Construction Procurement	link	WRAP	2021	5

Title	URL	Author	Year	IAS
Methodology to assess the circularity in building construction and refurbishment activities	link	Gonzalez, A and Sendra, C and Herena, A and Rosquillas, m AND Vaz, D	2021	5
Modular Construction in the United Kingdom Housing Sector: Barriers and Implications	link	Araz Agha*, Abdussalam Shibani, Dyaa Hassan and Bruno Zalans	2021	5
Net Zero Whole Life Carbon Roadmap. A Pathway to Net Zero for the UK Built Environment	link	UKGBC	2021	4
Procuring Resource Efficient Construction Projects	link	Resource Efficient Scotland	2017	4
Resource efficiency in industrialized housing construction: A systematic review of current performance and future opportunities	link	Firehiwot Kedir, Daniel M. Hall	2021	5
Reversibility and Durability as Potential Indicators for Circular Building Technologies	link	Antonini, E and Boeri, A and Lauria, M and Giglio, F	2020	5
SmartWaste: Sustainability and environmental monitoring and reporting software for construction, property development, offsite and product manufacturing	link	BRE Smartsite	n.d.	2
Synthesis of the state-of-the-art -BAMB	link	BAMB	2016	5
The Advantages & Disadvantages Of Steel Frame Construction	link	GLW Engineering & Construction Ltd.	2018	4
The circular design of buildings	link	Metabolic	2022	4
The Construction Commitments: Halving Waste to Landfill	link	WRAP	2012	4
The economic and environmental benefits of resource efficiency in construction	link	Building Research Establishment / Environment Agency	2008	4
Waste prevention programme for England 2021	link	Defra	2021	4
Wood in Construction in the UK: An Analysis of Carbon Abatement Potential	link	The BioComposites Centre, Bangor University	2019	5
Zero Avoidable Waste in Construction	link	Construction Leadership Council and The Green Construction Board	2020	4

Appendix D: List of discarded resource efficiency measures for the construction sector

During the literature review, there was one measure initially identified and subsequently discarded from the final list.

Table 23: List of discarded measures

Lifecycle	Sub-theme	Measure name	Measure indicator	Reason for exclusion
Use	Collaborative consumption	Leasing productions to reduce material usage	% building components that can be leased	No direct relationship with resource efficiency

When the measure was presented to stakeholders in the first workshop, they expressed that it had not a direct relationship with resource efficiency, and that in some cases it could lead to resource inefficiency (for example, if the rotation of the products is too high). Stakeholders also mentioned that it would apply to a small proportion of the building products (fittings, furniture) and thus it would have limited impact on the construction sector overall.

However, stakeholders thought it has potential, and that it would be interesting to leverage learnings from other sectors where leasing is more common, for example, vehicles.

This publication is available from: www.gov.uk/government/publications/unlocking-resource-efficiency