Analysis of the deterring aspects of the life cycle assessment process for the embodied carbon calculation of buildings


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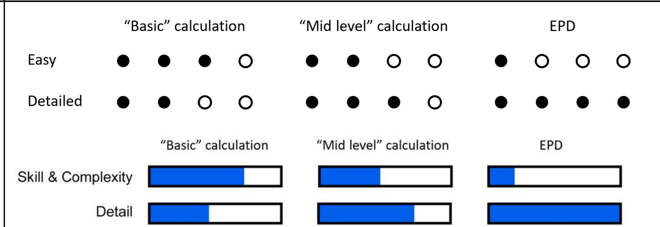
# Author’s notes following review

<table>
<tr><th>Review 2 (GS) comments</th><th>Author response</th><th>Corresponding text</th></tr>
<tr><td>Section 2.1 para 2: I suggest a counterpoint that lessons learnt from one building project can be applied to the next building project that the design team work on.</td><td>Amended</td><td>… produce a national average or aid in producing regulations. Alternatively, benefit environmental impact reduction efforts of future building projects. If the LCA goal is to reduce a building's environmental impact…</td></tr>
<tr><td>Section 2.1 para 3: please define what is meant by “hotspots”.</td><td>Amended</td><td>…hotspots (components, elements or procedures that significantly impact the environmental impact)</td></tr>
<tr><td>Section 2.2 para 3: in the final sentence you make the point that LCA slows the design process down. Could this same point not also be made about any other design consideration? E.g. the need to ensure the structure was strong enough to slow the design process down.</td><td>The point made in the text is a reference to the optional perception of inclusion of LCA in the design process. This has been amended and made clean in the text.</td><td>…As the process of an LCA, when carried out for the purpose of a process or design improvement, is recurrent, incorporation of an LCA within the design process would increase the design time and subsequently increase cost and delay construction. Given the perception that incorporating LCAs within the design process is optional, this aspect becomes a deterrent whilst it would not be considered for other design considerations that are standard practice within the industry, e.g. structural integrity.</td></tr>
<tr><td>Table 2: Please explain the difference between Aggregated data and average data.</td><td>Amended</td><td>Aggregated data: data either for the object of assessment as a whole or for major components<br><br>Average data: average data combined from different manufacturers or production sites of the same product</td></tr>
<tr><td>Figure 6: It is unclear what this diagram is showing. What is the difference between the solid and hollow circles signifying?</td><td>The figure demonstrates the level of skill and complexity needed and details of the results for each method. The figure has been edited to show bars, to better illustrate this fact.</td><td>
</td></tr>
<tr><td>Table 3: The unit is presumably kilometres; in which case the abbreviation should be km with a lowercase k.</td><td>Amended</td><td>Km by road -> Distance by road (km)<br>Km by road -> Distance by road (km)<br>Km by sea -> Distance by sea (km)</td></tr>
<tr><td>Section 2.3 para 3: reference to new mandatory requirements being introduced in Sweden in 2021 is referred to in the future tense</td><td>Amended</td><td>…Netherlands, and reporting embodied emissions for residential buildings became mandatory in Sweden in 2021 (13)…</td></tr>
<tr><td colspan="3">Comment: Embodied carbon is of much greater interest to policymakers now; there is even a Private Members Bill on the topic which is stimulating further thought on the topic. It is true that there is limited data on embodied carbon, in particular for building services components (although CIBSE TM65 is changing that), that there is no mandate for calculating embodied carbon and no widespread market call for it, yet. How could the development of TM65 be supported by some form of mandate – perhaps initially around just doing the calculations and declaring them for a project? How could this help to build knowledge and competence in embodied carbon calculations in the sector? We encourage some further thought on this by the author to reflect the growing debate about how to move us forward on this topic.</td></tr>
<tr><td colspan="3">Author response: The conclusion of this paper highlights that “…Creating mandatory legislations for EPDs, WLC or LCA in the UK would increase available data and in turn lower the inaccuracies of future assessments…” this fact can be applied to the development of TM65 as well as similar documents. And the development of TM65 as well as similar documents can aid in providing a framework for mandates as well as highlighting the need and willingness of the industry for the existence of such legislations.</td></tr>
</table>

# Analysis of the deterring aspects of the life cycle assessment process for the embodied carbon calculation of buildings

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## Abstract

The high contribution of the building sector to the global greenhouse gas (GHG) emissions places a significant responsibility on the industry for its emission reductions. Up to 50% of a building's lifetime emissions could be attributed to the emissions produced during the construction of the building or the embodied carbon of the building. Performing a life cycle assessment (LCA) is a reliable method for calculating a building's embodied carbon, a necessary step in any reduction method. Despite the consensus within the scientific community around the necessity of GHG reduction, it is not typical for LCAs to be carried out during the building construction or design process. This study examines the issues that arise while carrying out an LCA. By examining this process, the study will attempt to identify the factors of the LCA process that prevent or hinder the common use of LCAs within the industry.

**Keywords** LCA, Embodied Carbon, Whole life carbon

## 1 Introduction

Reduction of greenhouse gas (GHG) emissions is vital to combat our climate crisis and reduce the negative impacts of climate change. Data published in 2019 (1) showed that the building sector and construction industry accounted for 39% and 11% of global energy-based emissions, respectively. Therefore, the construction industry has a responsibility as well as the potential to reduce the emissions within its sector (2).

The focus of emission reduction within the construction industry has been mainly on reducing operational emissions (3,4). These are the emissions that are produced during the use phase of the building. Operational emission reduction has been achieved via several strategies, including smarter designs for reduced energy needs for the buildings, as well as increasing the efficiency of building service equipment such as cooling and heating. While these strategies are effective, recent studies have shown that operational emissions could contribute to as low as 32% (5) of whole life carbon (WLC) emissions, meaning that the operational emissions should not be the sole focus of the emissions reduction efforts. However, reduction strategies for other stages of a building’s lifetime are not as intuitive (6). In order to make fully informed decisions to reduce emissions, the emissions from all stages of the building's lifecycle must be examined. Carrying out a Life Cycle Assessment (LCA) will calculate the WLC of a building.

An LCA is a tool used to identify and evaluates the environmental impact or potential environmental impact of a product throughout its lifetime. From raw material extraction to production to use and end-of-life (7). An LCA can study over 20 different environmental impact categories including global warming potential (GWP) (measured in $CO_2$ equivalent). As an LCA provides a comprehensive view of the GHG emissions of a product in each stage of its life cycle, it can aid in identifying opportunities to decrease the impact in the different stages of its life cycle (7).

Over the years, several guidelines and standards have been published for performing an LCA. ISO14040 published in 1997, later amended in ISO14044 in 2006 and 2020 standardises the LCA process for products (7,8). BS EN 15804:2012+A2:2019, first published in 2012, provides a guideline for carrying out an LCA for building material and components to produce an Environmental Product Declarations (EPD) (9). BS EN 15978:2011, published in 2011, lays out a calculation method for assessing the environmental performance of a building (10). RICS published the Whole life carbon assessment for the built environment guideline in 2017(11). In 2020, the Institute of Structural Engineers published a guide for calculating the embodied carbon of a building structure (12). While in 2021, CIBSE published CIBSE TM65: 2021, a calculation guideline for the embodied carbon of building services (3).

As laid out in ISO14040, an LCA is primarily done in four stages. Determination of goal and scope, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and Life Cycle interpretation (7). This paper will cover the application of an LCA, examining the process and highlighting the issues that can arise while carrying out an LCA. Furthermore, this study evaluates the possible deterring effect of these issues in performing an LCA in aid of carbon emission reduction efforts in buildings.

## 2 Life Cycle Assessment

As mentioned, an LCA is typically carried out in four stages (Figure 1). During the first stage of performing an LCA, the goal and the stages included in the assessment will be determined. During the LCI stage, all input and output data needed to perform the LCIA will be identified and collected. The LCIA will evaluate the potential environmental impacts of the product within the scope defined during the first stage. Life cycle interpretation is the final stage of an LCA. In this stage, the results from the impact assessment or the inventory or both are analysed(7). This analysis will be done in aid of the goals determined in the first stage of the LCA.

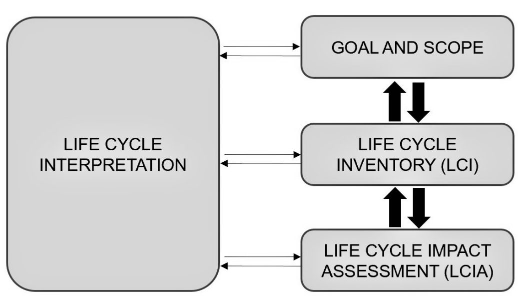


**Figure 1 - LCA stages reproduced from ISO 14040 (7)**

## *2.1 Determination of Goals and Scope and the Application of LCAs*

LCAs can be carried out for processes with various structures. The structure of the process can determine what application the LCA can have. As laid out in ISO14040, an LCA can have various applications such as product development and improvement, strategic planning, public policymaking, marketing, et cetera (7).

Many LCA studies are carried out to provide recommendations for reducing the environmental impact or performance of a product or process. When an LCA is carried out for a continuous or circular process such as product development, the optimisation of the environmental impact can be implemented in the next production cycle. When LCAs are carried out for a building, they cannot follow this structure as the production and lifecycle of a whole building is a linear process.

A study published in 2020 highlighted several usual goals for carrying out LCAs for buildings. Such as identifying hotspots (components, elements or procedures that significantly impact the environmental impact), comparing options for design improvement, sensitivity analysis, and benchmarking (13). An LCA for a building can be carried out at two different stages of a building's life cycle. It can either be carried out after the construction of the building as a case study, or it can be carried out during the design stage. If the goal of the LCA is benchmarking, the former approach must be taken. These studies can be performed to produce a national average or aid in producing regulations. Alternatively, benefit environmental impact reduction efforts of future building projects. If the LCA goal is to reduce a building's environmental impact, the LCA would need to be incorporated into the design process. As the process of an LCA, when carried out for the purpose of a process or design improvement, is recurrent, incorporation of an LCA within the design process would increase the design time and subsequently increase cost and delay construction. Given the perception that incorporating LCAs within the design process is optional, this aspect becomes a deterrent whilst it would not be considered for other design considerations that are standard practice within the industry, e.g. structural integrity.

While defining the scope of an LCA, one would need to consider the feasibility of the assessment within that scope. The definition of the scope of an LCA can be defined using different metrics. For example, for production companies, primarily, it is most appropriate to use scope 1, 2 and 3 as defined in Greenhouse Gas Protocol (14). Scope 1, 2 and 3 breakdown the environmental impact based on the level of control on the contributing factors (Figure 2). These assessments can be restricted to scope 1 and 2, which are direct emissions from owned or controlled sources (15) and still provide enough relevant information to enact significant carbon reduction. As a production company, the control over a large portion of the production is within their remit. However, when it comes to buildings, the level of control is quite limited, and most contributing factors would fall within the scope three remit.

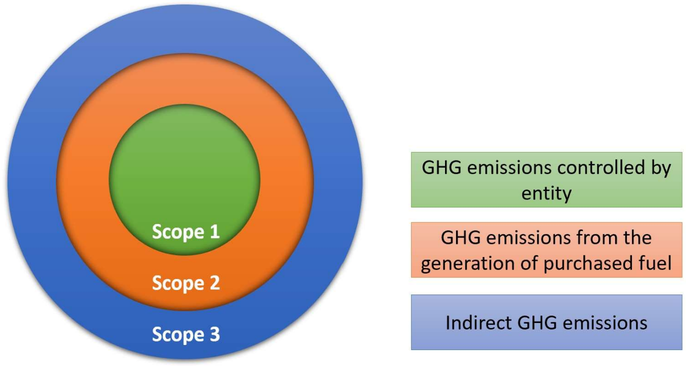


**Figure 2 – Scope 1, 2, and 3 Direct and Indirect Emissions Infographic(16)**

Another method for the breakdown of the scope for an LCA is a linear breakdown of the life cycle stages of a product. When performing an LCA for buildings, the life cycle of the building is broken down into four stages (Figure 3). 1-Material manufacturing 2- Construction 3- Use and maintenance 4-End of life (8). An LCA could include one or any number of these stages. The minimum stages that must be included in the LCA depend on the LCAs goal.

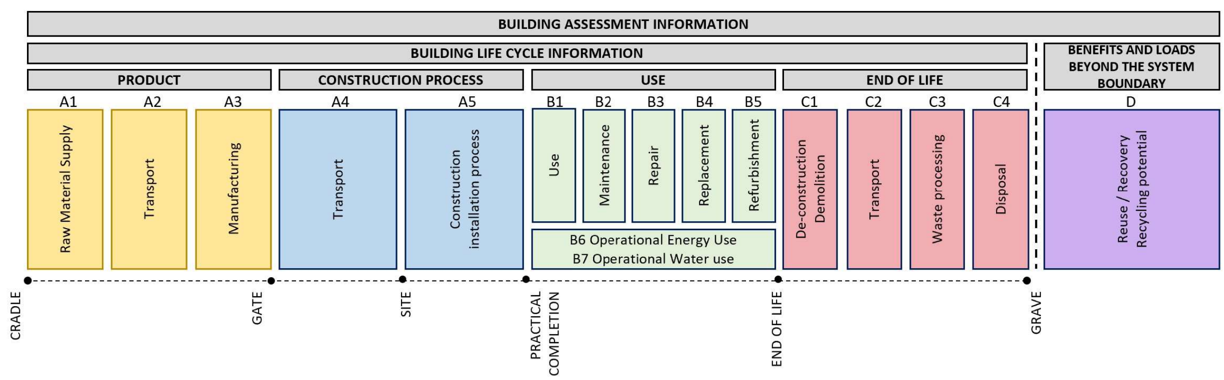


**Figure 3 - Life cycle stages reproduced from BS EN 15978:2011 (8)**

A Cradle-to-Grave assessment covers manufacturing to disposal (A-C). The GHG emissions of a building are predominantly divided into two sections, Operational Carbon (OC) and Embodied Carbon (EC). Operational carbon refers to the carbon emitted during the use phase of the building (B6-B7). Embodied carbon is all carbon emitted during material manufacturing, construction, in use refurbishment, maintenance and demolition, including the transport of all stages (A1-B5, C1-C4). Previously, embodied carbon would only refer to the A1-A5 stages, sometimes called initial embodied carbon, with the B1-B5 stages referred to as recurring embodied carbon (17). As the emissions during the B1-B5 and C1-C5 stages are majorly affected by the factors contributing to the A1-A5 emissions, all these stages must be included in the embodied carbon calculation. Currently, if only the A1-A5 emissions are calculated, it is referred to as embodied carbon to practical completion (12), upfront embodied carbon(18) or capital carbon (19). A whole life carbon assessment for a building will include all stages including D, reported separately to not aggregate the cradle-to-grave values (Table 1) (11).

| Term | Included stages |
|---|---|
| Embodied carbon to practical completion (PC-CO2e) | Comprises stages [A1–A5] |
| Embodied carbon over the life cycle (LC-CO2e) | Comprises stages [A1–A5], [B1–B5] & [C1–C4] |
| Whole life carbon (WL-CO2e) | Comprises stages [A], [B] & [C], [D] |

**Table 1 - Terminology for LCA scopes for the built environment (18).**

## *2.2 Life Cycle Inventory (LCI) and Life Cycle Impact Assessment (LCIA)*

The data acquired during the LCI is defined by the scope and goal of the LCA. The accuracy of the LCIA is highly dependent on the level of data that can be acquired during the LCI stage. Ideally, the impact assessment would be carried out with the goal of maximising the detail and accuracy of the results. This would mean that any unavoidable assumptions, scaling or simplifications would be minimised or implemented in areas that would minimally affect the detail and accuracy of the results.

### 2.2.1 Minimising the need or effects of assumptions and scaling

The data that is gathered in the LCI stage can be divided into two types of data. Firstly, are the quantities related to the specific design or model being assessed. If the LCA is carried out on an existing building, these quantities will be derived from plans and contractor records (11). However, as previously mentioned, when the goal is the reduction of the whole life carbon of the building, an LCA is carried out during the design stage of the building. Performing the LCA during the detailed design phase provides more accurate quantities minimising the assumptions made about the design (Figure 4).

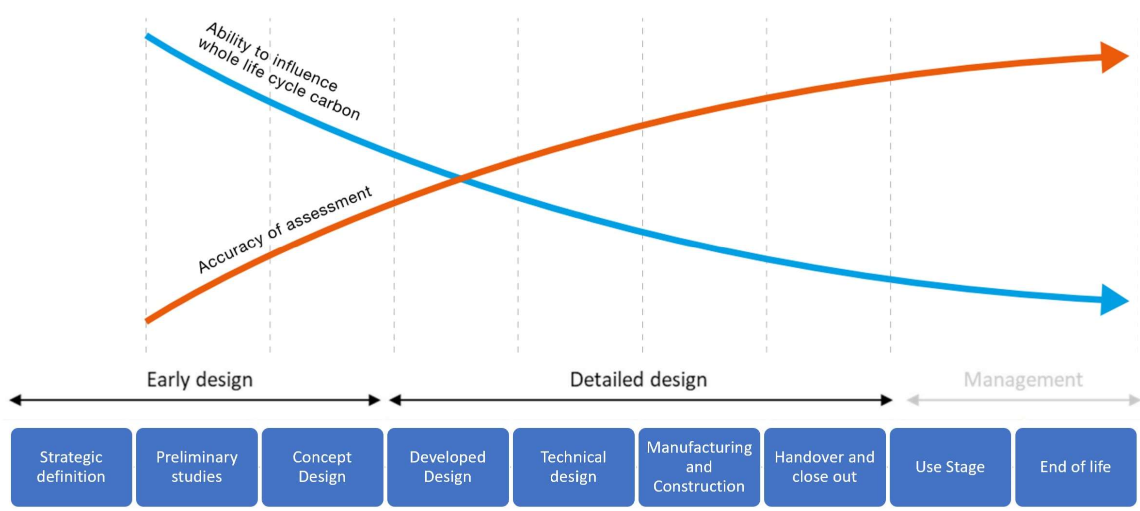


**Figure 4 - Conceptual diagram showing the ability to influence WLC reduction across the different design and life cycle stages of a building**

Secondly, are the carbon data sources of each component or process. BS EN 15978:2011 highlights the acceptable carbon data sources for each stage of the LCA (10). Carbon data or carbon factors provide an estimation of the Global Warming Potential (GWP) impact of each product or process. The most accurate data that can be used are environmental product declarations (EPD). EPDs are assessments carried out by manufacturers which must adhere to the EN15804, which states that the minimum scope to produce an EPD must declare emissions of modules A1-A3, modules C1-C4 and module D(9). Therefore, an EPD is the preferred source for all stages of the WLC assessment. However, as the production of an EPD is not currently mandated in the UK, access to EPDs is not guaranteed. Embodied Carbon Factors (ECF) provide an estimation of the GWP impact of each product or material per declared unit within the reported scope. ECFs can be used for A1-A3 EC calculation using the equation depicted in Figure 5. One of the most updated database sources in the UK for building material ECFs within the A1-A3 boundary is the Inventory of Carbon and Energy, first published in 2008 with the most recent update in 2019 (20). Within the accepted sources, many guidelines provide a hierarchy of preferred carbon data to be used for embodied carbon calculation (Table 2).

$$EC_{A13} = \sum_{i=1}^{n} \left[ Q_i \left( ECF_{A13,i} \right) \right]$$

$EC_{A13}$ = total embodied carbon for life cycle Modules A1-A3 ($kgCO_2e$)

$Q_i$ = quantity of material (kg)

$ECF_{A13,i}$ = Module A1-A3 embodied carbon factor for *i*th material ($kgCO_2e/kg$)

**Figure 5 - Embodied carbon for material production equation for A1-A3 stage (12)**

| Preferred data | Point of the time of the assessment | | | | |
|---|---|---|---|---|---|
| | Early design | Developed /Technical design | Construction | Use stage | End of life of the building |
| **Generic data:** data typical of the type of product/component | X | X | O | O | O |
| **Aggregated data:** data either for the object of assessment as a whole or for major components | X | X | | | |
| **Average data:** average data combined from different manufacturers or production sites of the same product | X | X | X | X | X |
| **Product specific data:** manufacturer provided data for specific product/component | O | X | X | X | X |

| | | | | | |
|---|---|---|---|---|---|
| **Product average data:** average data across different manufacturers for the same product/component | O | X | X | X | X |
| **Product collective data:** data collected for general product/manufacturer (BS EN 15804 complient) | O | X | X | X | X |
| **Measured data:** data derived from direct measurement | | | X | X | X |
| Other data | O | O | O | O | O |
| NOTE Cross represents the preferred use of data - Circle represents alternative sources if available. | | | | | |

**Table 2 - Preferred data for EC calculation derived from EN15978 adapted for paper (18).**

As previously mentioned, the scope and goal of an LCA must be based on the feasibility of performing that LCA. Another factor that should be considered is how labour intensive performing the LCIA would be. Additional steps and complexity in the calculations could act as a deterrent in carrying out an LCA. A paper published by the author in 2020 (21) which examined the A1-A3 EC calculating process observed that the lack of a national ECF database in the UK, partially affected by the 7-year period between the last two updates of the ICE database, in the absence of EPDs, ECFs for each component would need to be sourced separately. These additional actions increase the difficulty of carrying out an LCA.

The availability of a manufacturer provided EPD provides highly detailed and accurate data. As highlighted in CIBSE TM65: 2021, the availability of building services EPDs require the lowest amount of labour while providing the highest amount of detail. This guide highlights two alternative calculation methods in the absence of EPDs. A Mid-level calculation and a Basic calculation. For the A1-A4 stages, the mid-level calculation calculates the A1-A4 stages, and the basic calculation calculates the A1 stage using a scale-up factor for the A2-A4 stages. For the B1-B7 stages, B1 and B3 are mandatory for both, while the B2 stage for the basic calculation uses a scale-up factor.

Similarly, for the end-of-life stages (C1-C4), the mid-level calculation calculates the C1-C4 stages, and the basic calculation calculates the C1 stage using a scale-up factor for the C2-C4 stages. Given that providing end-of-life data is mandatory for an EPD, these values would not need to be calculated or scaled. Comparing the level of skill and complexity in the two different methods to an EPD (Figure 6) shows that some LICA result detail must be forgone to simplify the calculation process. Similarly, the iStructe manual states that in the absence of an EPD for a product, the C3 and C4 stages can be calculated using ECF default value equal to 0.013kg$CO_2$e per kg of waste(12).

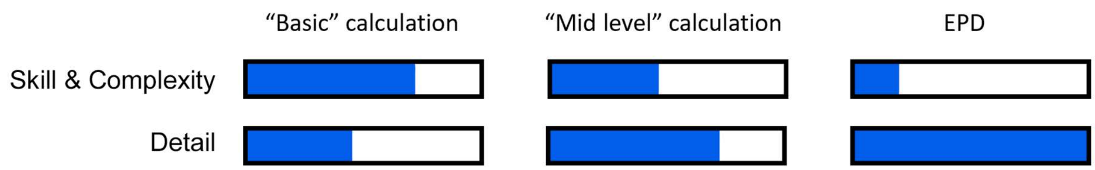


**Figure 6 - Comparison of the level of skill and complexity in the two different methods compared to an EPD recreated from CIBSE TM65(3)**

The carbon calculation for transport during the A4 and C2 can be calculated using the following equation (Figure 7). However, the exact distance for the transport will not be known until the completion of the model (12). Therefore, if the LCA goal is WLC reduction and subsequently carried out during the design stage, these values would need to be estimated using default values (Table 3).

| A4 transport scenario | Distance by road (km) | Distance by sea (km) |
|---|---|---|
| Local manufacturing | 50 | - |
| National manufacturing | 300 | - |
| European manufacturing | 1500 | - |
| Global manufacturing | 200 | 10000 |
| **EoL scenario** | **Distance by road (km)** | |
| Reuse/recycling on site | 0 | |
| Reuse/recycling elsewhere | 50 | |
| Landfill/incineration | Avg between 2 closest landfills | |

**Table 3 - Default value metrics for material transport for A4 and C2 stages derived from iStructe manual adapted for paper (12).**

$$ECF_{A4/C2,i} = \sum_{mode} (TD_{mode} \times TEF_{mode})$$

$ECF_{A4/C2,i}$ = transport to site/from site for $i$th material

$TD_{mode}$ = transport distance for each transport mode considered

$TEF_{mode}$ = transport emission factor for each transport mode considered

**Figure 7 - Carbon factor for transportation for A4/C2 stages (12)**

Similarly, for the A5 emission calculations, in the absence of accurate data, the emissions from onsite construction activities can be estimated based on construction cost using metrics in the RICS guidance of 1400kg$CO_2$e/£100k of the project value for whole buildings and 700kg$CO_2$e/£100k of the project value for superstructure and substructure (11). However, the calculation of the emissions of site material waste is more complicated. Even if the scope of the LCA is limited to cradle to practical completion, the end-of-life values for material must still be calculated. The iStructe manual and the RICS guideline (11,12) state using WRAP Net Waste Tool data to estimate the onsite material waste. While both guidelines do provide some data for general building materials, as of April 2021, the WRAP has removed this data and is no longer available (22).

### 2.2.2 Minimising the need or effects of simplifications

Replacement of materials stage (B4) as stated in the RICS guidance document must report the emissions from the replacement of Roof, External Walls, Windows, External Doors, Finishes, Fittings, furnishings & equipment and Services (MEP) (11). However, the guideline document published by the Institute of Structural Engineers (12) for calculating the embodied carbon of a structure states that the minimum stages required for the WLC calculation of a building structure must include A1-A5 and only B4 for facades. This simplification is justified by asserting that the B1 stage would be irrelevant to structural material and that there is limited data regarding the B2 and B3 stages, whilst the calculation of B4, which is the replacement of materials, can be calculated using the following equation (Figure 8). B4 calculations are performed based on the expected lifespan of a component, with the assumption of 100% replacement, including the transportation, installation and end-of-life emissions of the components (11).

$$ECF_{B4,i} = \left\lceil \frac{RSP}{CL_i} - 1 \right\rceil \times \left( ECF_{A13,i} + ECF_{A4,i} + ECF_{A5w,i} + ECF_{C2,i} + ECF_{C34,i} \right)$$

$ECF_{B4,i}$ = replacement emissions for ith material
$CL_i$ = estimated component lifespan for ith material
$RSP$ = asset reference study period
$\left\lceil \frac{RSP}{CL_i} - 1 \right\rceil$ = round-up of the $(RSP/CL_i)$-1 to the next integer
$ECF_{A13,i}$ = included carbon sequestration for any timber products replaced during the RSP

**Figure 8 - Emissions for the replacement of ith material for B4 stage (12)**

## *2.3 Life Cycle Interpretation & Reporting*

The interpretation stage of an LCA analyses the results of the LCI and LCIA stage. As demonstrated, during each stage of performing an LCA there are mitigating strategies that must be adopted in order to compensate for the lack of data or knowledge. As well as simplification or omission of stages to expedite the process. When reporting the results of an LCA these assumptions, simplifications or omissions must be mentioned (11).

It is vital to consider whether any of the mitigation factors will affect the overall goal of the LCA. It must not be forgotten that the LCA is a tool meant to aid in achieving a goal. The goal of an assessment carried out during the design stage of a building is to provide enough significant information to give the ability to reduce the embodied carbon of a future structure. If the possible inaccuracies in the results do not affect this goal, then carrying out an assessment is worthwhile.

The labour, cost and worthwhileness will always be deterrents for carrying out an LCA. However, there are a few motivating factors such as cost savings, future liabilities, environmental discussions and problems and environmental legislations (23). LCAs are required for building permits in the Netherlands, and reporting embodied emissions for residential buildings became mandatory in Sweden in 2021 (13). Furthermore, Green building certificates such as BREEAM, LEED and CEEQUAL now offer extra credit and scoring for carrying out LCAs for buildings (24).

# 3 Conclusions

Reducing GHG emissions is a vital global task, and the obligation of the construction industry in this effort cannot be overlooked. With the previous focus on operational emission and the need for whole life carbon reduction there has been a focus shift to embodied carbon reduction. Embodied carbon reduction during the design stage is not as intuitive as operational carbon reduction; therefore, integrating WLC assessments in the design process is necessary.

Lack of future knowledge will always be an unavoidable factor affecting the inaccuracy in the process and results of an LCA. As explained, this lack of knowledge is supplemented primarily by assumptions based on previous real-world data. However, mitigation in the case of limited or absence of real-world data is done via simplifying the process or scaling the available data or forgoing the calculation of certain stages of the LCA. Additionally, there is always a trade-off between the accuracy of an LCA and the labour and effort required to perform an LCA. By increasing the reliability or practicality of the results of an LCA in aid of embodied carbon reduction, reluctance for carrying out an LCA can be reduced.

In the future, reducing the hesitancy for carrying out LCAs can be achieved by reducing deterring factors and increasing drivers; drivers such as cost reduction, environmental legislations and green building certificate integration of LCA results. Creating mandatory legislations for EPDs, WLC or LCA in the UK would increase available data and in turn lower the inaccuracies of future assessments and reduce deterring factors.

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