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Practical limitations in Embodied Energy and Carbon measurement, and how to address them: a UK case study

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Abstract: *The built environment is blamed for producing the majority of carbon emissions. While policy remains focused on emissions during the operational phase, research demonstrates that embodied impacts are a significant proportion of whole life ones. This paper presents a case study of a building that integrates low-energy design features. The study was carried out during the construction phase enabling superior quality of data to be collected. The cradle-to-grave embodied impacts were modelled to the TC350 Standards using an innovative tool, and the operational impacts through simulation, incorporating future climate predictions. In spite of the data quality, the study demonstrates a high level of uncertainty due to a number of industry-wide issues. This paper identifies these issues and concludes that considerable barriers to measuring embodied impacts remain. Key recommendations are made for industry and policy, in order to gear up the measurement and reduction of embodied impacts of buildings.*

Keywords: ***embodied, energy, carbon, sustainable building, construction, energy assessment***

1 Introduction

The built environment accounts for approximately 40% of the world's total energy consumption (1). The latest regulations (2) demand that buildings produce zero net operational CO_2(e) emissions in the near future. Nevertheless, this strategy omits the Embodied Energy and Embodied Carbon (EE&EC) which constitute a considerable amount of the building total energy and carbon (E&C) of the building (2%-46%) with values up to 500MJ/m^2/year (3,4). The inclusion of those burdens is not currently a legislative requirement and only voluntary standards, such as the European TC350, "the basis of measuring embodied energy and carbon in products and projects" (5) in the UK, exist. On the other hand, there are a number of studies of individual buildings, but the inconsistencies and variations make comparison between them difficult (6). Also, it has been proved that the error in any typical embodied energy analysis may be as high as 20% (7) with 50% incompleteness for the process-based method (8). This method is also used by the TC350 standards and is "extremely complex and time-consuming" (6). To understand the issues and barriers that arise during the calculation process of the embodied energy and carbon, a school building in Cambridge, UK was chosen as a case study. There was collaboration and keen interest from all parts, leading – it would be assumed- to easily accessible data. The "Ecoclassroom" integrates low-energy features and makes extensive use of local workforce, environmentally friendly materials and sustainable construction methods while it has been designed to withstand 2080 conditions.

2 Methodology and results

The research deployed different methods to answer the questions posed. In the centre lies the case study, supported by simulation, observation and interviews. The boundaries of the investigation are shown below (Table 1). There are, as expected, limitations such as the future decarbonisation of UK mix, which was not accounted for. Also, when information about the CO_2(e) emissions was unavailable, the CO_2 data was used (9).

Building Assessment Information														
Building Life Cycle Information														**Beyond Building Life Cycle**
Product Stage			**Construction Process Stage**		**Use Stage**					**End of Life**				**Benefits and Loads**
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Raw material supply	Transport	Manufacturing	Transport	Construction-Installation process	Use	Maintenance	Repair	Refurbishment	Replacement	Deconstruction/Demolition	Transport	Waste processing	Disposal	Reuse, Recovery, Recycling Potential
					B6	Operational energy use								
					B7	Operational water use								

Table 1: The boundaries of the investigation (highlighted) [from BSEN15978:2011 (12)]

The EE&EC in the infrastructure, fuel processing, power plants and distribution systems was not included. The calculation was conducted using an in-house tool due to reasons that have been mentioned by others (10). Concerning operational energy, it was not possible to measure it and therefore simulations were run using DesignBuilder, a dynamic simulation software, incorporating 2080 climate predictions (11).

The absolute energy values for the whole lifecycle were within the range reported by other studies for low energy buildings (3,4). For operational energy, results were in good proximity with those of the building services engineers (8% difference).

The calculation resulted in a total of 7239GJ primary energy for its lifecycle, equal to $622MJ/m^2/year$ (68 years, till 2080) (Figure 1). The respective values for carbon were estimated to rise to $39kgCO_2(e)/m^2/year$. The ratio of embodied to operational energy (EE, OE) was approximately equal to 1:2 and the respective one for carbon equal to 1:1.5.

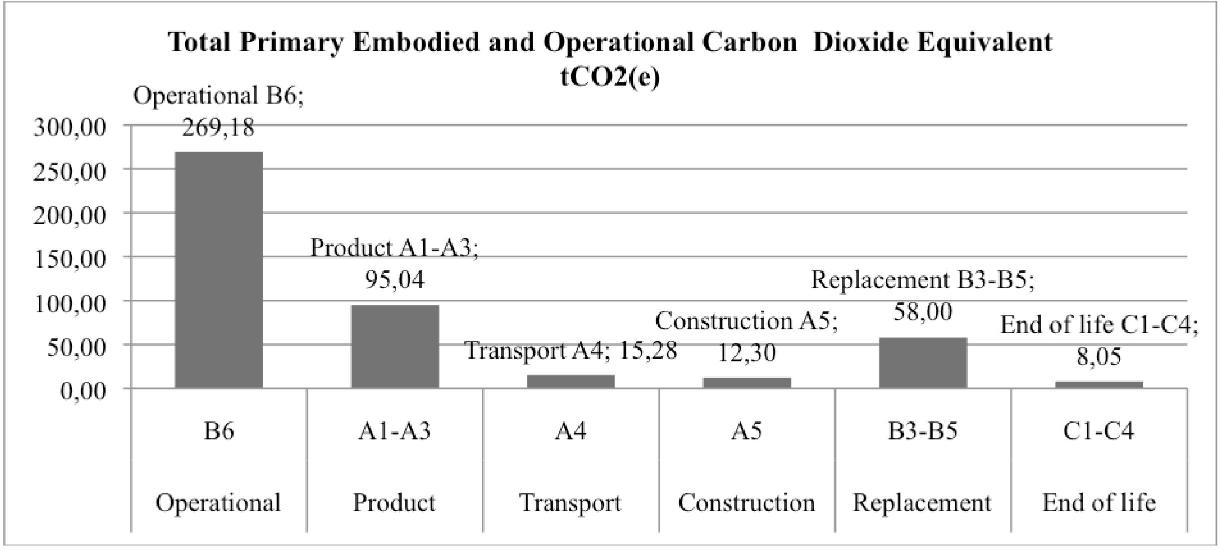

Figure 1: Total lifecycle carbon dioxide equivalent breakdown ($tCO_2e/m^2/y$)

3 Issues faced during the process

In spite of the data quality, the case study demonstrates a high level of uncertainty for the calculation of Embodied Carbon and Energy at each lifecycle stage. The main reasons are outlined below:

3.1 Lack of a data collection method for stages A1-A5

There was no standard method for the collection of data concerning the type, number and specifications of components used in a building, their transport to the site, the construction energy, the waste and their destination. The collection of data depended on personal relationships and the time since completion of the project. The speed and quality of data collection was hampered by the subcontracting culture leading to missing data, estimated by the author to be as high as 10-30% on both EE&EC. For the product stage, the study followed a number of successive ways to gather accurate and complete data, including the use of delivery tickets and drawings, contractor estimations and interviews, correspondence with manufacturers and site visits. Despite the effort, a number of components were: not identified at all; identified but out of scope; identified but not calculated because of their size or complexity; identified but not calculated due to the lack of information or identified but roughly estimated. It was calculated that if the calculation had been based only on the initial list given to the authors by the contractor, the EE values for stages A1-3 and A4 would have been underestimated by 33% and 50%. The respective underestimation for the replacement stage would have been 32%. These changes have impacts on the construction and demolition EE&EC too through the calculation of waste materials. The total underestimation would have been 30% and 25% for EE and EC, respectively.

Concerning transport, most components were either manufactured in the UK or imported from Europe. Some suppliers provided information concerning the means of transport and the route followed. The distance from the factories to the distribution centres and the final site was calculated using Google Maps. When information was not available for the means of transport, the most reasonable approach was followed. The transportation of the construction equipment to and from the site was also included, although this was a very small amount.

Finally, the Construction module A5 was given by the following components:

Production and transportation of materials lost or damaged during construction. The contractor was unable to specify the exact quantities thrown to waste and the waste management company was reluctant to share any information. There are different approaches on how to calculate the impact [e.g. (13,14)]. In this research, it was calculated as the fraction of the mass of waste to the total mass of initial materials, multiplied by the total E&C contribution of the A1-4 stage.

Construction Energy. Energy was consumed mainly at three sources: the diesel consumed on site, the school electricity consumption and the manufacturers. For the first, a crude estimation was provided by the contractor and for the second the consumption for the previous and next year were compared with that of the construction year (2012). Only the timber-frame subcontractor was able to provide approximated data corresponding to the off-site construction.

Waste (downstream):

The final on-site construction waste volume was calculated indirectly through the number of skips used but, their exact composition and mass were unknown and therefore were calculated based on pro-rata values by two reports (15,16). Only the transport of the muck-away (uncontaminated soil) and the on-site construction waste to the final site was included in the calculation. Neither the waste processing nor the disposal was included due to limited data. For the off-site waste, information was requested from the factories but -again- only the timber factory management could provide some information.

3.2 Lack of published figures for embodied impacts of components

The actual environmental impacts could only be calculated for a limited number of components as there is currently no established culture for the creation of Environmental Product Declarations (EPDs). The calculation of the EE&EC impacts of the components was conducted using inventories (9,17) and a few EPDs (only 5 out of almost 200 products identified). For some composite components, it was necessary to approximate the contribution of the constituent materials, when this was not available from the manufacturer. The transport factors used were taken from a tool (17) that uses UK and European values that have been adapted to include the empty return journey. When information on the method of transport was not available for short distances, the rigid heavy-goods vehicle was chosen to provide a good approximation. The mean of transport for the construction equipment was assumed to be the "articulated Heavy Goods Vehicle".

3.3 Uncertainties for post-construction stages

The calculation of the Use stage was based on approximations that might over-/underestimate the contribution of an element. If the life expectancy of the component was small, a replacement was assumed to be carried out. Replacement factors have been suggested [e.g (19)] but, they refer to assemblies rather than components. Instead, the authors used a report by the NAHB (20), few product specifications and design team estimates to calculate the component life expectancy. This report however, is intended for residential buildings and the replacement values might be underestimated for a classroom. The production and transportation was assumed to be similar to modules A1-4, while the construction energy was equated to the fraction of the energy and carbon impact of the specific component in the A1-3 stage to the total impact of stage A1-3, multiplied with the total construction energy A5. The impacts of excessive materials used during replacement were not included, as there was no relevant data. The total mass of waste was equal to the replaced components and only transport was included.

Previous research concerning the demolition, waste processing and loads and benefits beyond the building lifecycle is limited (18). For the End of life stage, the authors used the values of Moncaster and Symons (17) for the calculation of the deconstruction/demolition phase (C1), as it is recent and UK-relevant. The demolition waste was assumed equal to the original mass of components and only its transport was included in the final impact.

Carbon Sequestration was commented separately and was not included in the final carbon bill. It was equal to 5.9% of the whole life carbon. This was only related to wasted timber from all stages and none of its by-products. Since some building components were only 70% certified, a common approach of 70% sustainable timber was followed. The calculation was based on a paper by Symons et al. (21) who assume removal and storage of 1.8kgCO_2/kg-wood from the atmosphere. The total burden or benefit depends on the final destination of this timber. It was assumed that 33.3% was sent to Landfill and that the rest 66.6%, was reused/recycled. The mass wasted at the timber-frame factory was all recycled.

3.4 Varied boundaries, multiple calculation methods

Existing standards present differences in the method they follow, the boundaries, and the contribution and responsibility of each industry sector (10). For example, had this study been based on stages A1-3 only, as advised by some standards and the government (5,12), the embodied impacts would have been underestimated by approximately 50%. Furthermore, a common approach is missing in terms of the assemblies and components included in the calculation (22). Also, TC350 standards have inherent weaknesses (e.g. process-based method, omission of the impacts of the designer’s offices, infrastructure, etc) that should be considered.

3.5 Limited knowledge dissemination

The strategic decisions of clients, designers and contractors affect not only the current but also the future EE&EC of a building. Despite the fact that the shareholders for this case study were all informed on the importance of EE&EC, most of the industry is not and their understanding is mostly based on the initial stages (A1-3) and common perception.

4 Conclusion and discussion

Five important difficulties were faced in the process of calculating the EE&EC of this classroom. To overcome these, it is vital to create a digital database for the collection of post-construction information on EE&EC that will give each building an “Identification” and boost research. Existing databases should be enriched and updated to include more materials and especially composite components. These should be publicly available and protected from industry interests, leading to a UK National database. EPDs should be obligatory and include all lifecycle stages since the relative impact of these changes within the building lifecycle and more research should be conducted for post construction stages (i.e. use, end-of-life and beyond the building lifecycle stage). Moreover, there should be an agreement on the standard, the boundaries and the method used for the calculation of EE&EC and similar measures to the ones taken to decrease operational energy and carbon should be launched. It also needs to be clear which assemblies will be used in calculations across the UK to allow direct comparison amongst studies conducted using the same standards. Finally, all parties involved in construction should be well informed on embodied impacts ahead of the project initiation.

More than a third of the whole life energy expenditure & carbon emissions are likely to come from the embodied energy and embodied carbon (EE&EC), based on this study. Current standards and policies only encourage and do not regulate the calculation of a part of these. With the development of EU and global standards defining the methodology for measuring EE&EC, and increasing evidence that it is a significant proportion of the whole life impacts for a building, it is now time for the calculation of cradle-to-grave/cradle EE&EC impacts to be legislated. There are many alternatives for how this could become reality by, for example, creating a system similar to the one used by SAP and SBEM where a “standard” building is compared with the actual one. Another way forward would be to agree on an absolute value, depending on the type of the building. This will put considerable pressure on the industry to accelerate changes towards becoming more sustainable. This target/limit could also lead to a complete building rating system for E&C as some of the most advanced systems (e.g.BREEAM) include EE&EC impacts for a number of components but omit other, extremely important ones, such as building services.

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