5TH EURO-MEDITERRANEAN CONFERENCE FOR ENVIRONMENTAL INTEGRATION
2–5 OCTOBER 2023, RENDE (COSENZA), ITALY

Springer | Publishing Partner

UNIVERSITY OF CALABRIA | Host institution

University of Sfax | Springer | Publishing Partners

Certificate of Contribution

EMCEI steering committee wishes to express its appreciation to

Maryam Keyhani

for their **oral communication** at the Euro-Mediterranean Conference for Environmental Integration (EMCEI-23), held in Rende (Cosenza), Italy, from 2 to 5 October 2023, and for the **paper they contributed** to the conference proceedings published by Springer.

(Paper number 399) Discrepancy in Embodied Carbon Calculations for Con-crete Materials
Author(s): Maryam Keyhani, Ali Bahadori-Jahromi, Anastasia Mylona, Paulina Godfrey

Prof. Sudip Chakraborty
Local Co-Chair
University of Calabria, Rende, Italy

Prof. Mohamed Ksibi
General Chair
University of Sfax, Tunisia

5TH EURO-MEDITERRANEAN CONFERENCE FOR ENVIRONMENTAL INTEGRATION
2–5 OCTOBER 2023, RENDE (COSENZA), ITALY

Discrepancy in Embodied Carbon Calculations for Concrete Materials

Maryam Keyhani[1], Ali Bahadori-Jahromi[1], Anastasia Mylona [2], Paulina Godfrey[3]

[1] Department of Civil Engineering and Built Environment, School of Computing and Engineering, University of West London, London W5 5RF, UK
[2] Research Department, the Chartered Institution of Building Services Engineers [CIBSE], London SW12 9BS, UK
[3]Hilton, Maple Court, Reeds Crescent, Watford, Hertfordshire WD24 4QQ, UK

Abstract. Accurate assessment of embodied carbon is integral to understanding the environmental impact of building materials and promoting sustainable building practices. This process aids in prioritizing efforts to reduce emissions and mitigate climate change. Existing studies highlight discrepancies across various embodied carbon databases, causing uncertainty in assessments. Our study reveals significant differences in the calculated embodied carbon of materials, depending on whether they are assessed as a singular entity or as composed of individual components. Concrete, a major contributor to embodied carbon in construction projects, serves as our focus. We calculate the embodied carbon of concrete materials in a typical residential building using Life Cycle Assessment (LCA), a comprehensive method to evaluate environmental impacts throughout a building's life cycle. We utilize the Inventory of Carbon and Energy (ICE), one of the most reliable databases, for our assessment. Our findings indicate substantial differences when calculating embodied carbon for concrete as a singular material (first scenario) versus considering its component parts (second scenario). The first scenario results in at least a 20% increase in carbon emissions, with the exact discrepancy depending on the type of concrete materials and whether they are reinforced. Given that approximately 66% of the total quantity of our case study comprises concrete, these differences are substantial. Our study underscores the importance of incorporating embodied carbon factors into a unified database to accurately assess total embodied carbon emissions of buildings. It also highlights the potential for database uncertainty to skew interpretations of embodied carbon if an LCA is conducted for design reduction. Hence, a reliable baseline for calculating embodied carbon is crucial.

Keywords: Life Cycle Assessment, Sustainability, Embodied Carbon, Concrete, Discrepancy

1 Introduction

Despite progress towards sustainable buildings and construction, the building industry is still lagging behind and is responsible for nearly 40% of global carbon emissions [1].

In this regard, the UK's Sixth Carbon Budget necessitates a 78 percent reduction in carbon emissions by 2035 in order to reach net zero emissions by 2050 [2].

The focus of carbon reduction is shifting from operational carbon to embodied carbon as a result of improved operational energy efficiency in buildings [3]. Minimising embodied carbon requires evaluating embodied carbon emissions during various life cycle phases.

Recently, researchers have shown increased interest in assessing the environmental impacts at all stages of a building's life using Life Cycle Assessment (LCA) [4]. [5] showed that the LCA is highly appreciated in new buildings to achieve sustainable intentions. However, the scarcity and inconsistency of databases make performing LCA on buildings difficult. The Environmental Product Declaration (EPD) is the most reliable database in the UK. However, there are only a limited number of them available. The second most commonly used database is the Inventory of Carbon and Energy (ICE) database [6], which includes a database for a variety of construction materials.

Many studies showed the inconsistency of various embodied carbon databases of building materials. For instance, [7] demonstrated that there is a significant difference between the ICE database and EPDs. Also, [8] found that there is a substantial difference between Gabi and the ICE database.

Research by [9] revealed that the disparities between databases were due to different boundary definitions, varying underlying assumptions, and methodological differences in calculations. It was also revealed that Common sources of uncertainty are variability, data gaps, measurement error, and epistemic uncertainty [10].

Despite several studies on the causes of the disparity between various databases for a specific material, there is no research on the differences in embodied carbon of building materials based on whether they are regarded as a single entity or as discrete components. This research compares two sets of calculations for concrete materials, a major contributor to embodied carbon, based on the two scenarios mentioned.

2 Methods

2.1 Life Cycle Assessment

The LCA is a method for evaluating the environmental impact of products and procedures throughout their lives. BS EN 15978 divides the life cycle of a building into the following modules: product (A1–A3), construction (A4–A5), use (B), and end-of-life (C). The boundary of this research is limited to the Product Stage (A1–A3), which accounts for the greatest amount of carbon embodied in buildings throughout their lifetimes [11].

2.2 Case Introduction

As a case study, this investigation used a typical residential building in the UK. It is a detached two-story building with a timber truss roof, concrete block walls, and air-filled double-glazed windows covering 145.86 m^2. The building has been surveyed, and a standard design model has been simulated using Autodesk® Revit®, version 2023, resulting in an accurate quantity of materials for the project.

2.3 Embodied Carbon Assessment

Product stage embodied carbon, also known as cradle-to-gate embodied carbon, represents the carbon footprint of the product's entire lifecycle, from the extraction of raw materials through the manufacturing and assembly processes to the point at which the product is available for use or consumption. Using Equation (1), the total carbon emissions associated with the product stage (A1–A3) is calculated.

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

Where Q_i is the weight of material i and $ECF_{A13,i}$ is the Embodied Carbon Factor (ECF) for material i. The ICE database is used as the ECF in this research. This study investigates the disparity between embodied carbon calculations for concrete materials in two different scenarios. The first scenario is calculating the embodied carbon of concrete as a singular material, and the second scenario is calculating the embodied carbon of concrete considering its component parts. The procedure is then repeated for reinforced concrete, and the difference between concrete and reinforced concrete is calculated.

3 Results

3.1 Embodied Carbon comparison of Concrete

The data presented in Table 1 demonstrate the embodied carbon of concrete materials as a singular material, whereas Table 2 shows the embodied carbon of concrete materials considering its component parts. The results show that the embodied carbon of concrete (Cast in Situ)' in the first scenario is 7,947.75, which is 30% more than in the second scenario. Also, the first scenario increases the embodied carbon for 'Aerated Concrete Block' by almost 25%. However, the first scenario reduces the embodied carbon for 'Concrete (Sand/Cement Screed)' by approximately 14%.

Table 1. The embodied carbon of concrete as a singular material

Material	Quantity (kg)	ECF (kgCO2e/kg)	Embodied Carbon (kgCO2e)
Concrete (Cast in Situ)	70,962.04	0.112	7,947.75
Concrete (Sand/Cement Screed)	10,392.86	0.149	1,548.54
Aerated Concrete Block	16,496.15	0.28	4,618.92

Table 2. The embodied carbon of concrete as a its component parts

Material	Admixture	Quantity (kg)	ECF (kgCO2e/kg)	Embodied Carbon (kgCO2e)
Concrete (Cast in Situ)	CEM I	5999.62	0.912	5471.66
	GGBS	2849.82	0.0416	118.55
	Fly Ash	449.97	0.004	1.80
	Aggregate	57446.39	0.00747	429.12
	Water	4169.74	0.000344	1.43
	Admixture	46.50	1.67	77.47
Concrete (Sand/Cement Screed)	Sand	7627.80	0.00747	56.98
	Cement	1906.95	0.912	1739.14
	Water	858.13	0.000344	0.30
Aerated Concrete Block	Aggregate	12372.11	0.00747	92.42
	Cement	2309.46	0.912	2106.23
	Quicklime	1319.69	1.136	1499.17
	Water	494.88	0.000344	0.17

3.2 Embodied carbon comparison of Reinforced Concrete

In this section, reinforcing steel is added to the ‘Concrete (Cast in Situ)’ mixture, and its impact on our assessment is measured. The amount of reinforced steel is 7265.90 kg, and the ECF associated with rebar is 0.45 kgCO2e/kg. Also, the ECF attributed to reinforced concrete is 0.28 kgCO2e/kg. Table 3 represent the embodied carbon of reinforced concrete in two scenarios.

Table 3. The embodied carbon of reinforced concrete

Scenario	Embodied Carbon(kgCO2e)
First Scenario	22,174.68
Second Scenario	9,369.69

Comparing the embodied carbon of reinforced concrete reveals a large disparity between the two scenarios. The results indicate that utilising the first scenario increases the embodied carbon of concrete by 137% in comparison to the first scenario.

4 Discussion

The findings represent a major level of inconsistency between the two scenarios. The second scenario is likely to provide a more accurate estimate of the embodied carbon for the specific building, as it takes into account the actual mix of materials and their associated emission factors. In the context of concrete (Cast in Situ), the first scenario shows a 30% higher level of embodied carbon in comparison to the second scenario. This indicates that the first scenario overestimates the embodied carbon by 30%. In the first scenario, the Aerated Concrete Block also resulted in a 25% overestimation. However, it has been observed that in the case of 'Concrete (Sand/Cement Screed)', the first scenario underestimates the embodied carbon by 14%.

The difference between the two scenarios for the reinforced concrete is much more significant. The first scenario overestimate the amount of embodied carbon by 137%.

This large discrepancy between the two scenarios for concrete and reinforced concrete materials indicates that there is a high probability of overestimating the embodied carbon of concrete. It has a significant impact on the total embodied carbon of the building, as concrete accounts for 66% of the quantity of building materials.

Consequently, the presence of inaccurate estimations of embodied carbon poses challenges in implementing strategies to reduce embodied carbon and achieve sustainable buildings.

5 Conclusions

This research found another source of uncertainty in the embodied carbon assessment: the difference between the embodied carbon calculated for concrete as a single material or as a mixture of its parts. The results revealed that the variation in embodied carbon of concrete materials ranges from 14% to 137%, with the precise difference depending on the type of concrete materials and whether they are reinforced. The variation is significantly greater for reinforced concrete compared to other concrete mixtures. Using the ICE database, the embodied carbon of concrete materials has a high chance of being overestimated. In addition, the lack of precise estimation of concrete's embodied carbon has effects on strategies aimed at reducing carbon emissions associated with building.

References

1. 2020 Global Status Report for Buildings: Towards a Zero-emission, Efficient and Resilient Buildings Sector. United Nations Environment Programme, Nairobi (2020).
2. Cop 27. Delivering for people and the planet, https://www.un.org/en/climatechange/cop27, last accessed 2023/05/21.
3. Victoria, M., Perera, S.: Parametric embodied carbon prediction model for early stage estimating. Energy and buildings, vol. 168, 106-119 (2018).
4. Keyhani, M., Bahadori-Jahromi, A., Mylona, A., Janbey, A., Godfrey, P., Taseli, B.K.: Measuring and Mitigating Embodied Carbon in buildings: A case study in the UK. EFS (2023).
5. Bahramian, M., Yetilmezsoy, K.: Life cycle assessment of the building: An overview of two decades of research (1995–2018). Energy and buildings, vol. 219, pp. 109917 (2020).
6. Alwan, Z., Ilhan Jones, B.: IFC-based embodied carbon benchmarking for early design analysis. Automation in construction, vol. 142, pp. 104505 (2022).
7. Keyhani, M., Abbaspour, A., Bahadori-Jahromi, A., Mylona, A., Janbey, A., Godfrey, P., Zhang, H.: Whole Life Carbon Assessment of a Typical UK Residential Building Using Different Embodied Carbon Data Sources. Sustainability, vol. 15, no. 6, pp. 5115 (2023).
8. Kayaçetin, N.C., Tanyer, A.M.: Embodied carbon assessment of residential housing at urban scale. Renewable & sustainable energy reviews, vol. 117, pp. 109470 (2020).
9. Ekundayo, D., Babatunde, S.O., Ekundayo, A., Perera, S., Udeaja, C.: Life cycle carbon emissions and comparative evaluation of selected open source UK embodied carbon counting tools. Construction economics and building, vol. 19, no. 2, pp. 220-242 (2019).
10. Marsh, E., Orr, J., Ibell, T.: Quantification of uncertainty in product stage embodied carbon calculations for buildings. Energy and buildings, vol. 251, pp. 111340 (2021).
11. Gibbons, O.P., Orr, J.J., Archer-Jones, C., Arnold, W., Green, D.: How to Calculate Embodied Carbon. 2nd ed. The Institution of Structural Engineers, London, UK (2022).