

## REVIEW PAPER ON STUDYING EMBODIED ENERGY OF BUILDING MATERIALS USING LIFE CYCLE ASSESSMENT

Mohammed Hanief Shaik<sup>1</sup>, Mr. A Sheik Farid<sup>2</sup>

<sup>1</sup>Master of Technology, Department of Civil Engineering , BS Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, Tamilnadu , India

<sup>2</sup>Assistant Professor, Department of Civil Engineering , BS Abdur Rahman Crescent Institute of Science and Technology, Vandalur, Chennai 600048, Tamilnadu , India.

### ABSTRACT

Achieving low carbon emissions in buildings is essential for managing global greenhouse gas (GHG) emissions. Embodied energy from structures that is most directly related to the planning and development of the building. A process-based life cycle assessment of building materials can be utilised to investigate the embodied carbon energy emissions of buildings . The cited literatures provides an overview of the embodied energy characteristics of the building materials and proposes appropriate optimization methods by incorporating the life cycle assessment perspective. The results of the reviews give us inference on various parameters so that local data emission variables are preferred for computing embodied energy and design estimates can be utilised to calculate the quantity of building materials used.

### 1. INTRODUCTION

Embodied energy for building materials is the total amount of energy required for extraction, processing, production, and delivery of the materials to the construction site. Embodied energy is seen as a sign of a building material's total environmental impact because CO<sub>2</sub> emissions are a result of energy use. Embodied energy is taken into account when evaluating the life cycle of buildings as a measure of the sustainability of the built environment. This can be achieved by studying the energy associated with the materials by using a life cycle assessment approach.

### 2. LITERATURE REVIEW

**Abdulrahman Fnais (2022)** reviews the state-of-the art research in life cycle assessment (LCA) applied to buildings. It focuses on current research trends, and elaborates on gaps and directions for future research. This paper argues that humans can attenuate and positively control the impact of their buildings on the environment, and as such mitigate the effects of climate change. This can be achieved by a new generation of LCA methods and tools that are model based and continuously learn from real-time data, while informing effective operation and management strategies of buildings and districts. Therefore, the consideration of the time dimension in product system modeling is becoming essential to understand the resulting pollutant emissions and resource consumption. This time dimension is currently missing in life cycle inventory databases. A further combination of life cycle impact assessment (LCIA) models using time-dependent characterization factors can lead to more comprehensive and reliable LCA results. This paper promotes the concept of semantic-based dynamic (real-time) LCA, which addresses temporal and spatial variations in the local built and environmental ecosystem, and thus more effectively promotes "cradle-to-grave-to-reincarnation" environmental sustainability capability. Furthermore, it is critical to leverage digital building resources (e.g., connected objects, semantic models, and artificial intelligence) to deliver accurate and reliable environmental assessments.

**Jefferson Torres-Quezada et al (2022)** discusses the specific total embodied energy (STEE) of 40 houses built between 1980 and 2020 are quantified and To this end, four periods have been established to evaluate P1,P2,P3,P4. The results indicated in P1, the STEE average value of the Structure component reaches 695 MJ/sq.m with a minimum of 441 MJ/sq.m and a maximum of 1054 MJ/sq.m, In P2, the STEE average value of the Structure is 948 MJ/sq.m with a minimum of 630 MJ/sq.m and a maximum of 1215 MJ/sq.m, The Structure component in P3 has an STEE average value of 1979 MJ/sq.m with a minimum of 1747 MJ/sq.m and a maximum of 2390 MJ/sq.m, in P4, the STEE average value of Structure is 1487 MJ/sq.m with a minimum of 1238 MJ/sq.m and a maximum of 1860 MJ/m.

**Badr Saad Alotaibia et al (2022)** proposed a method and analyzed for the life cycle assessment of the building for the embodied carbon in the three stages, construction, operation, and demolition. Moreover, the result of the analysis is considered as the base result, and de-carbonization strategies identified through literature study for the three stages of construction, operation, and demolition are assessed with the same method to know how much each strategy will be effective in minimizing the embodied carbon. For the base case, a high-rise residential building in an urban region of India is analyzed, based on existing conditions through the building information modeling (BIM) method. The carbon

emission of the selected building comes out to be 414 kg CO<sub>2</sub>e/m<sup>2</sup>/year, and assessing different decarbonization strategies, considering the first analysis as the baseline, it can be minimized to 135 kg CO<sub>2</sub>e/m<sup>2</sup>/year.

**Roberto Minunno et al (2021)** explained how life cycle assessment, a tool to measure a product's environmental impact, has gained a lot of importance in the building industry. Given the significant embodied energy and carbon in the building sector, this backdrop is crucial. In light of this, this study has two primary goals. Making a standard for the environmental impact of buildings is the first goal. The creation of procedural guidelines to help practitioners lessen the environmental impact of buildings is the second goal. The findings from the life cycle assessments were then combined in a meta-analysis. The articles were divided into two primary categories: construction materials related and on entire building. The embodied energy and carbon associated with eight building components (concrete, reinforcing bars, structural steel, timber, tiles, insulation, and plaster) and three building types (concrete, timber, and steel) were identified. The data was then examined using descriptive and inferential statistics. The meta-conclusions analysis's influenced a regression model, which in turn influenced a procedure manual for professionals working to lessen the environmental impact of buildings. Additionally, the results of this study clarify previously murky findings about the effects of buildings and construction materials while also supporting earlier findings for structural materials. For instance, they demonstrate that using timber structures over concrete ones results in significant reductions in both embodied energy (43%) and carbon (68%).

**Elena G.Dascalaki et al (2021)** elaborates the importance of embodied energy in Hellenic residential buildings by comparing the primary energy consumption during their life cycle. Field surveys were used to collect relevant data from local manufactures and determine the embodied energy coefficients of popular construction materials. From the results it was observed that the EEI value ranged from 3.2 to 7.1 GJ/sq.m, compared with annual primary EUI of 0.3 to 3.9 GJ/sq.m. The initial and recurrent embodied energy of building construction materials over the lifetime of a building can reach up to 30%.

**Luisa F.Cabeza et al (2021)** illustrated the chronological overview from a material level point of view of embodied energy and embodied carbon through keywords analysis. It was also observed that geographical location are incompatibilities also revealed in embodied energy and embodied carbon assessments. The results concluded that systematic analysis evidences the lack of standardization and disagreement regarding the assessment of coefficients, database source, and boundary system used in the methodology assessment.

**Hossein Omrany et al (2020)** Studies the comprehensive framework in which system boundary definitions for assessments of both embodied energy and operational energy can be standardized, while providing guidelines on methods for measuring these energies. Some brief insights on the parameters such as operational energy measurement, building Life Span, assumptions made by the reviewed studies, assessment of embodied energy and operational energy, components considered for measurement of embodied energy, reuse and recycling potentials, methodological challenges. Despite the promising outlook of LCEA applications, the current state of this research area is plagued by inaccuracies accruing from incomplete definitions of system boundaries, coupled with ambiguous approaches for calculating embodied and operational energies. Hence, the process of decision-making can be affected due to inaccurate and incomplete results reported by LCEA studies.

**Ming hu et al (2020)** explores the development in the research embodied energy (EE) and environmental impact (EI) to identify fundamental influential and intellectual roots and to obtain a structured overview of the status, direction, and trends in this research domain by a bibliometric analysis. Between 1996 and 2019, 320 publications related to this research topic were found. The 320 papers cover 109 journals and 48 countries, for which bibliographic coupling map was created. Three primary research clusters were identified, of which the second cluster mostly centers on real projects and emphasizes practicality, such as embodied energy data, recycling potential, carbon emissions reduction, end-of life embodied energy, life cycle energy consumption etc.

**Manish K. Dixit (2019)** The main goal of this study is to investigate parameters specific to REE calculation that may cause its value to vary across studies. Identifying and studying these parameters is significant for multiple reasons. First, these parameters may explain the large variations in calculated annual REE values across studies, which can help researchers evaluate the calculated values before using them. In this study, we conducted a systematic survey of literature to identify parameters specifically affecting the recurring or recurrent embodied energy of built facilities. Some parameters can be controlled by a careful selection of building materials and products, whereas others are uncontrolled because they are unpredictable over an extensive and dynamic life cycle of a building. The controllable parameters can also be standardized by developing place-based datasets of material.

**Panagiotis Chastas et al (2018)** analyses 95 case studies of residential buildings, as an effort to identify the range of embodied carbon emissions and the correlation between the share of embodied energy and carbon for different levels of building's energy efficiency. The assessment identifies a range of embodied carbon emissions between 179.3

kgCO<sub>2</sub>e/sq.m-1050 kgCO<sub>2</sub>e/sq.m (50-year building lifespan) that reflects a share between 9% and 80% to the total life cycle impact. That same share follows similar trends with the respective for embodied energy and ranges between 9% and 22% for conventional, between 32% and 38% for passive and between 21% and 57% for low energy buildings. Considering the deviation of the results, even though a two-step normalisation procedure the overall building design could not be neutralised and confirm the need for further standardisation in LCA.

**Sourabh Mehta et al (2017)** studies the process LCA method is used for documenting the inventory data, which refers to energy inputs for the production phase and the operational phase of the building life cycle. This study presents the findings of life cycle energy use analysis of a multi-storey residential housing located in Chennai. Life cycle energy distribution considering a service life of 50 years and average building operation energy, indicates that the embodied energy and operation energy account for 16% and 84% of the life cycle energy respectively.

**Dissanayake et al (2017)** has performed a detailed study to determine the embodied energy of concrete wall panels. A novel walling system has been considered in this study, which uses 50% of recycled expanded polystyrene (EPS) to produce lightweight foam concrete panels. The results were based on a comparative study carried out using a typical single storey house and different building materials. It indicated that the foam concrete precast panel can be a good competitor and hence has the potential to be promoted as a mainstream walling material.

**Thong Jia Wen et al (2015)** performed an inventory analysis, An input-output oriented process was carried out to determine components included in the analysis. Flows of assembly phase was modelled in Gabi 6.0 software to further interpret the life cycle impact and to determine the hotspot between the processes. Finally, a sensitivity analysis was conducted. The identified hotspots for materials gave better understanding on contribution of energy and carbon emissions especially precast concrete, reinforced steel and concrete. In this case, concrete and steel are the major contributors to the embodied energy and emissions to the environment. The study concluded that IBS has a better advantage in terms of reducing embodied energy (MJ) and GWP (kg CO<sub>2</sub>-Equiv.) towards a low carbon development.

**Wahidul K Biwas (2014)** explained a life cycle assessment (LCA) methodology, to present present life cycle greenhouse gas (GHG) emissions and energy analysis of the Engineering Pavilion, at Curtin University Western Australia. The University utilises a Building Management System (BMS) to reduce its overall operational energy consumption. This LCA analysis employed a 'mining to use' approach, in other words, the analysis takes into account all of the stages up to the utilisation stage. The life cycle GHG emissions and embodied energy of Building 216 were calculated to be 14,229 tonne CO<sub>2</sub>-e and 172 TJ, respectively. This paper identified the 'hotspots', or the stages in production and operation of Building 216 that were the cause of the majority of the GHG emissions. From this, proposals for further improvements in environmental management may be made. The usage stage of the building produces 63% less GHG emissions than the University average, due to the implementation of the BMS. This system has played a significant role in reducing the total embodied energy consumption of the building i.e., 20% less than the University average.

**Moncaster et al (2013)** describes the detailed method used by a new design decision tool, ECEB, to calculate the whole life embodied energy and carbon of buildings. The main difficulty in obtaining the results was found to be the lack of data, and the paper suggests that the construction and manufacturing industries now have a responsibility to develop new data in order to support this task. Calculations of impacts at each life cycle stage in ECEB i.e product stage, transport stage, construction stage, repair and refurbishment stage, and end life stage have been explained clearly.

**Manish K. Dixit et al (2012)** reveals a list of parameters that are responsible for causing data variation and inconsistent results in the calculation of embodied energy. The paper points out various important aspects such as Geographic location of the study, Primary and delivered energy, age of data, current standards used for embodied energy measurement, feedstock energy consideration and so on. This paper emphasizes and updates a list of parameters that are responsible for causing data variation and inconsistent results. This literature indicates a need to develop an embodied energy protocol that could help streamline the embodied energy analysis process.

**Ignacio Zabalza Bribián (2011)** performed a study and stated that building industry uses great quantities of raw materials that also involve high energy consumption. Choosing materials with high content in embodied energy entails an initial high level of energy consumption in the building production stage but also determines future energy consumption in order to fulfil heating, ventilation and air conditioning demands. This paper presents the results of an LCA study comparing the most commonly used building materials with some eco-materials using three different impact categories. The aim is to deepen the knowledge of energy and environmental specifications of building materials, analysing their possibilities for improvement and providing guidelines for materials selection in the eco-design of new buildings and rehabilitation of existing buildings. The study proves that the impact of construction products can be significantly reduced by promoting the use of the best techniques available and eco-innovation in

production plants, substituting the use of finite natural resources for waste generated in other production processes, preferably available locally. This would stimulate competition between manufacturers to launch more eco-efficient products and encourage the use of the Environmental Product Declarations. This paper has been developed within the framework of the LoRe-LCA Project co-financed by the European Commission's Intelligent Energy for Europe Program and the PSE CICLOPE Project co-financed by the Spanish Ministry of Science and Technology and the European Regional Development Fund.

**Geoffrey P. Hammond et al (2010)** studied the emission of energy-related pollutants, like CO<sub>2</sub> that is a concern in the context of global warming and climate change, may be viewed over their life cycle by creating a Domestic Building Model. The model operates in a bottom-up manner; therefore allowing buildings to be reconstructed through the selection of walls, floors, roofs, etc. In the case of non-energy-consuming products, for example, buildings materials, the energy result of an environmental life cycle assessment can often be taken to be its 'embodied energy'. The latter is often confined within the boundaries of cradle to site to separate it from the operational energy. However, end-of-life impacts are inevitable and as such are often integrated into the boundaries of embodied energy studies.

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