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Establishment of Building Material Carbon Emission Coefficient Database and Application in Architectural Cases: Energy Conservation and Carbon Reduction Big Data Project

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Abstract: In environmental engineering, the carbon footprint is the assessment of the total greenhouse gas emissions, directly or indirectly, caused by individuals, organizations, activities, or products. These emissions are converted into equivalent amounts of carbon dioxide (CO2e) to measure the impact of human activities on the environment. Consequently, the scope of carbon footprint calculation encompasses emissions generated throughout the entire lifecycle – from raw material extraction and manufacturing to usage, all the way to product disposal and recycling processes. The construction industry consumes significant energy and resources during its operational processes, resulting in substantial environmental impact. According to international literature, carbon emissions from the production of construction materials and the construction process account for 11% of the global total, while the operational phase of buildings contributes 28%. This underscores the immense potential for improvement in carbon emissions throughout the entire lifecycle of buildings. To achieve the net-zero emissions goal by 2050, the construction industry should establish sustainable development objectives, transition towards green construction practices, enhance energy efficiency, strengthen environmental protection measures, and elevate technological capabilities. Integrating carbon emissions calculations, especially during the planning and design stages, should be integrated into the construction process to serve as a reference for relevant stakeholders. Furthermore, third-party assistance is crucial for credible carbon emissions assessment, as it provides concrete evidence regarding material benefits and evaluates carbon coefficients at various stages. Establishing a dedicated carbon emissions database within Liming Construction will expedite future calculation processes.

Keywords: Carbon Footprint, Construction Industry, Carbon Reduction, Carbon Emission Coefficient, Circular Economy

I. INTRODUCTION

The construction industry should establish sustainable development goals in global trends, transitioning from traditional construction practices to green construction. This entails enhancing energy efficiency, environmental awareness, and technical expertise to achieve the net-zero emissions target by 2050. Simultaneously, there's a need to drive the calculation and reduction of carbon dioxide emissions across the entire lifecycle of buildings and integrate these efforts throughout the construction process. This is particularly crucial during the architectural planning and design stages, serving as a reference for stakeholders.

There's an urgent necessity for the construction sector to calculate carbon emissions. To ensure reliability, third-party involvement is essential to enhance credibility. For instance, the benefits of new materials in reducing carbon emissions need robust documentation. Buildings' overall carbon reduction benefits encompass carbon emission coefficients at various stages, from raw material production and transportation to construction, use, maintenance, and demolition. Accessing appropriate coefficients from international or domestic carbon emission coefficient databases is challenging. Moreover, due to process and material source variations, carbon emission coefficients often fluctuate between different years. Hence, establishing and maintaining a carbon emission coefficient database is invaluable for addressing carbon emissions calculations across diverse projects.

In light of the challenges mentioned earlier and requirements, the project team, represented by the "Taiwan Construction Research Institute," possesses extensive experience in developing construction materials. Recent research achievements in circular economy and carbon emissions related to construction materials further contribute to this expertise. Leveraging this experience, the team can assist Liming Construction as a third-party entity in calculating the carbon emissions of different building materials. Furthermore, establishing a dedicated carbon emission coefficient database specific to Liming Construction will facilitate calculating carbon reduction data for projects throughout the year. Ultimately, this initiative will bolster the construction industry's emphasis and demands on energy efficiency. Liming Construction will serve as a benchmark, rallying market recognition and motivation, driving relevant firms to invest early in enhancing quality and technical capabilities, thus reinvigorating the industry's competitiveness.

II. LITERATURE REVIEW

2.1Establishment of Building Material Carbon Emission Coefficients: Confirmation of Analysis Scope and Methods

In accordance with the definition provided by PAS2050, conducting an assessment of the carbon footprint of building materials requires a consideration of the building's entire lifecycle. Generally, in the evaluation of a product or service's carbon footprint, the lifecycle perspective can be categorized into two types: Cradle to Gate and Cradle to Grave. Cradle to Gate refers to material suppliers delivering building materials to the construction site's entrance. The assessment should encompass carbon emissions from processes such as raw material extraction, product manufacturing and assembly, and transportation (typically covered by existing carbon coefficient databases in the market).

Cradle to Grave extends further to cover emissions generated during construction and the operational maintenance stages. During the construction phase, the "Embodied Carbon in Construction Calculator" (such as EC3, as illustrated in Figure 1) can be employed for assessment. The logic behind this tool involves multiplying the quantities of various building materials (usually by weight or volume) by their respective carbon emissions (over the lifecycle) and summing them up to determine the total carbon emissions for the project. As for emissions during the operational maintenance stage, calculations often employ scenario analysis, referencing data like the average annual energy consumption of equipment and the frequency of maintenance updates. When a building reaches the end of its useful life, the emissions from the dismantling and disposal processes are determined by referencing the average energy consumption calculation from relevant literature.

The confirmation of these analysis scopes and methods will contribute to the establishment of comprehensive building material carbon emission coefficients, providing more accurate results for assessing the carbon footprint of construction projects. In turn, it supports the goals of green construction and sustainable development.

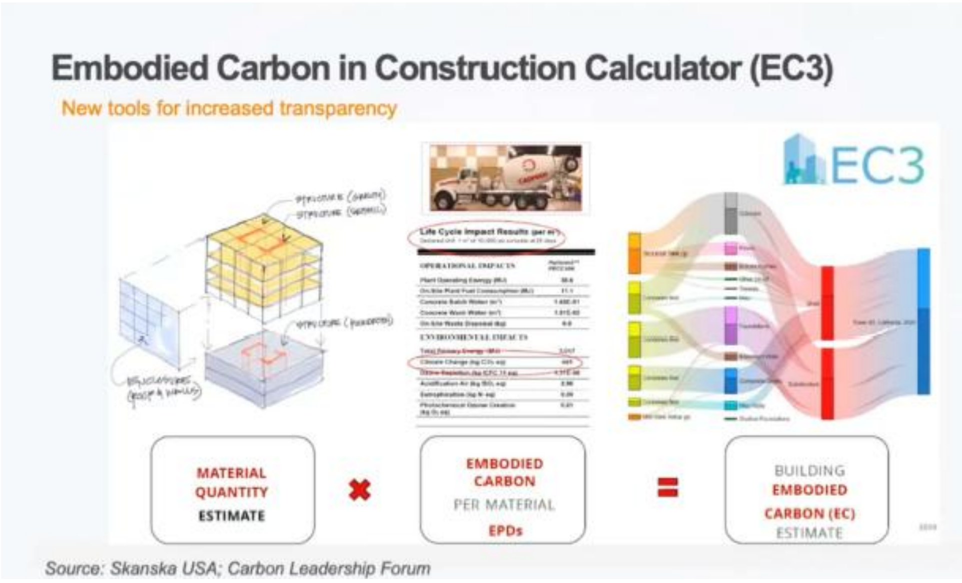

Figure 1 Concept Diagram of Embodied Carbon in Construction Calculator (EC3) for Construction Carbon Emission Calculation

2.2 Collection of Carbon Coefficients

In this phase, three selected cases will be based on Liming's choice, including two patients with reinforced concrete (RC) structures and one with a steel structure. The basic information for these cases is presented in Table 1 below.

Table 1 Basic Information Form for Building Case

Project Name	Structure	Total Floor Area	Owner	Project Duration
Taichung Hui Guo Post Office	B4F/13F R.C	13,990.5M2	Chunghwa Post Co., Ltd	Commencement Date: October 110 (October 2021) Expected Completion Date: January 114 (January 2023)
Taipei Shilin Paper Factory Hotel	B3F/12F R.C	13,617.14M2	Shilin Environmental Purification Co., Ltd.	Commencement Date: July 110 (July 2021) Expected Completion Date: June 113 (June 2022)
Zhu Bei Hui Rong Building	B4F/21F R.C/S.C	51,884M2	Hui Rong Technology Co., Ltd.	Commencement Date: December 109 (December 2020) Expected Completion Date: December 112 (December 2023)

Liming will provide essential case information during the data collection process, including construction site location, diagrams, and material cost analysis sheets. Each construction item should include materials used, suppliers, weight or volume, construction duration, and cost. Additionally, annual electricity and fuel consumption records for on-site activities (including machinery and vehicles) must be furnished. If the data above is unavailable, carbon emissions will be calculated using industry averages or referenced literature. After summarizing the building materials used in these three cases, further data collection will involve establishing carbon emission coefficients. Sources will be drawn from domestic and international publicly available databases such as the International BATH database (Figure 2), SimaPro, Taiwan's Environmental Protection Administration's Product Carbon Footprint Information website, and the LCBA database. However, considering the extensive range of construction projects without literature or applicable databases, the research team will compile credible carbon emission coefficients based on publicly disclosed component combinations.

Cement

Materials	Embodied Carbon -	Comments	DQI Total - %
General (UK average)	0.832	Mixture taken from average UK sector cement EPD. 86.1% clinker, 0.04% ggbs, 3.4% fly ash, 4.8% gypsum, 5.1% limestone, 0.56% MACs. By weight. Estimated from ICE Cement, Mortar, Concrete model.	76%
CEM I, Ordinary Portland Cement (OPC)	0.912	CEM I is a 'pure' cement, Ordinary Portland Cement (OPC). Estimated from ICE Cement, Mortar, Concrete model.	76%
CEM II - Portland-slag cement			DQI Total - %
CEM II-A-S - 13% GGBs	0.803	This cement permits between 6-20% ggbs Estimated from ICE Cement, Mortar, Concrete model.	75%
CEM II/B-S - 28% GGBs	0.672	This cement permits between 21-35% ggbs Estimated from ICE Cement, Mortar, Concrete model.	75%
CEM II - Portland-pozzolana cement			DQI Total - %
CEM II/A-P - 13% natural pozzolanic ash	0.798	This cement permits between 6-20% natural pozzolanic ash Estimated from ICE Cement, Mortar, Concrete model.	74%
CEM II/B-P 28%	[illegible]	This cement permits between 21-35% natural pozzolanic ash	[illegible]

... | Aggregates_Sand | Aluminium | Asphalt | Bitumen | Cement_and_Mortar | Clay_Bricks | Concre ...

Figure 2 BATH Carbon Emission Data Illustration

2.3 Establishment of Building Material Carbon Emission Coefficient Data

As shown in Figure 3, carbon emission coefficient data will be collected from open databases such as BATH, the Environmental Protection Administration, or LCBA. This data will be used to create a digital carbon emission coefficient file (e.g., an Excel file), which will be available for subsequent calculations of building carbon emissions.

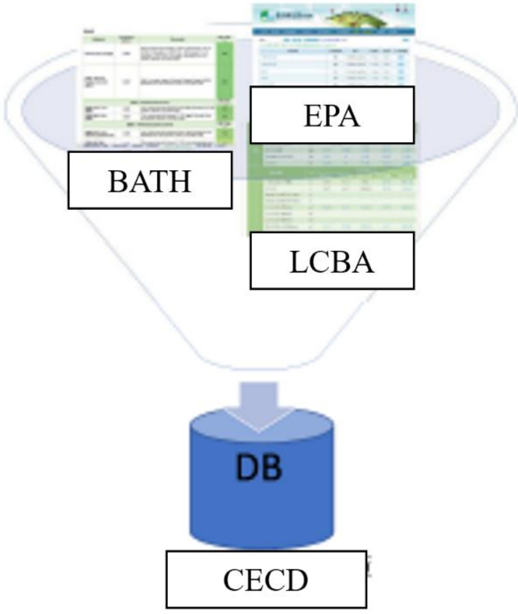

Figure 3 Carbon Emission Coefficient Data Diagram

III. INTRODUCTION TO THE METHOD

1. **Calculation Analysis of Carbon Emission Reduction in Architectural Projects:**
   - **(a)** Selection of Case Subjects and Data Collection In this calculation analysis process, our focus will be on three selected cases by Liming Construction. Guided by the Low Carbon Building Alliance (LCBA) principles, we will conduct a comparative analysis between the baseline design and the carbon reduction design for each case. We will implement practical strategies such as using low-carbon cement, structural carbon reduction, and durability enhancement to calculate the impact of each system on carbon emissions. The entire process will be divided into multiple stages, and we plan to employ a breakdown of carbon calculation by project components, subdividing the architectural structure into various major engineering components for assessment.
   - **(b)** Selection of Calculation Standards and Carbon Emission Analysis During the calculation process, we will refer to internationally recognized carbon emissions calculation standards such as those from the British Standards Institution (BSI) or domestic mechanisms like the LCBA. Additionally, we will reference the carbon coefficient data confirmed in the earlier mentioned Phase 1 (Figure 3). The carbon coefficient data in these databases are typically set with a Cradle-to-Gate boundary. Consequently, for the construction phase, we will calculate carbon emissions based on the machinery used and the working hours. For the usage, maintenance, and dismantling phases, a scenario analysis approach will be adopted to estimate carbon emissions, considering factors such as renovation frequency, equipment maintenance rates, electricity consumption, and energy consumption during dismantling. Through this comprehensive calculation analysis, we can thoroughly evaluate the impact of different strategies on carbon emission reduction in architectural projects. This assessment will aid in understanding the carbon emission profiles of each case and allow us to propose effective carbon reduction strategies tailored to each situation, thus promoting more environmentally-friendly architectural design and construction. Furthermore, this analytical approach will contribute to the targeted reduction of carbon emissions in future building projects, aligning with sustainable development goals.

2. **Expansion and Maintenance of Carbon Coefficient Database:**
   - (a) Expansion of Carbon Coefficient Database In addition to analyzing the materials used in the three cases provided by Liming Construction, we will continuously expand the carbon coefficient database to encompass materials used in other benchmark projects. This expansion will ensure we can provide the necessary carbon coefficient data when analyzing various cases.
   - (b) Maintenance and Updates of Existing Carbon Coefficients Considering the constant evolution of construction methods, the introduction of new materials, potential improvements to existing materials,

and the possibility of annual revisions in referenced domestic and international literature, the existing carbon emission coefficient values may change. To ensure the accuracy of carbon coefficient data, our team will assist Liming Construction in establishing a mechanism for annual updates and maintenance of carbon emission coefficients. This will ensure that the calculated total carbon emissions align with the latest definitions of market carbon coefficients. We can provide a more comprehensive and accurate carbon coefficient database through these expansion and maintenance measures. This will contribute to ensuring the accuracy and reliability of our calculation analyses. Additionally, these efforts will enable us to continue offering valuable carbon emission assessment services within the ever-changing landscape of the construction industry.

IV. RESULTS AND DISCUSSION

1. Recommendations for Low-Carbon Building Materials:

(a) Defining Material Levels and Collecting Literature on Low Carbon Building Materials The carbon emissions during the construction phase of a building can be calculated based on the following stages: 1. Production process of building materials, 2. Transportation process of building materials, 3. The on-site construction process of the building. The main structural components contribute the most to the overall carbon emissions, accounting for approximately 80% of the total construction. Therefore, in this phase, we will initially review the materials used in the main structural components and gather literature to compile information on low-carbon building materials.

(b) Recommendations for Low Carbon Building Materials Based on the three construction projects provided by Liming Construction, discussions will be focused on commonly used materials for the main structural components (2 reinforced concrete and one steel structure). We will offer recommendations for low-carbon building materials and provide analysis results for their carbon reduction benefits.

2. Importing Carbon Emission Parameter Data and Rules:

(a) Implementation of Carbon Emission Parameter Data Rules In response to the impacts of global warming, major economies like the European Union and China have set goals for carbon peak and neutrality. This trend has prompted financial institutions worldwide to adopt carbon pricing mechanisms. Hence, in addition to establishing analytical and computational methodologies, developing a precise analytical system is imperative. This system will systematically organize and integrate relevant carbon parameters into a building materials carbon emission database. This database can serve as a reference for Liming Construction material and construction method carbon coefficients. It can also facilitate calculations of carbon emissions using different building materials and methods, providing decision-makers with data to select environmentally friendly, cost-effective construction methods and annual carbon reduction figures for projects.

The rules governing carbon parameter data within the building materials carbon emission database will be formulated based on the previously mentioned carbon parameter collection, updating, and maintenance methods. The preliminary framework will categorize information according to project cases provided by Liming Construction. Relevant foundational data and illustrations will be integrated, followed by the organization based on project components such as main structures, scaffolding, exterior facades, external windows, interior partition walls, etc. In addition to manually importing carbon emission parameters, plans will incorporate data from Building Information Modeling (BIM) export formats, specifically the Construction Operations Building Information Exchange (COBie) forms. This approach ensures more accurate carbon emission assessments while adhering to international standards.

(b) Testing the Import of Carbon Emission Parameter Data After establishing the parameter data import rules, these rules will be integrated into the prototype system of the building materials carbon emission database. We will then test the manual input of carbon emission parameters and the import of COBie forms generated from BIM models. Subsequently, a platform for carbon reduction statistics and analysis will be developed, extracting carbon emission parameters from the building materials' carbon emission database. This ensures the seamless execution of subsequent calculation and analysis processes.

V. CONCLUSIONS

Establishing a Carbon Reduction Statistical Analysis Platform:

(a) Integration of Selected Calculation Standards and Carbon Emission Analysis Methods The calculation standards and analysis methods for carbon emissions will be aligned with the procedures outlined in Section 2.1. It will extend from the established execution of calculation analysis. We will create a carbon reduction calculation approach by drawing from the data extraction rules of the building materials carbon emission database and referencing international carbon calculation methods such as BSI or domestic LCBA mechanisms. This approach will be categorized based on project cases and tailored to scenarios ranging from construction to maintenance and dismantling, utilizing project-specific data. Additionally, the platform can incorporate BIM models and COBie parameters for a comprehensive project-level carbon emission analysis.

(b) Testing the Building Carbon Emission Analysis System Upon adopting and implementing the chosen calculation and analysis methods, we will conduct testing using the project cases provided by Liming Construction. Two testing approaches will be employed: the first involves manual analysis of the issues, while the second incorporates BIM models and COBie forms. These two approaches will be compared to validate the accuracy of the calculation analysis. c. Establishment of the Building Carbon Reduction Statistical Analysis Platform The analysis platform will categorize project cases as provided by Liming Construction, offering the ability to examine coefficient details based on project-specific calculation results. This phase will integrate carbon emission coefficients and calculation analysis methods from the building carbon emission database, establishing a carbon reduction statistical analysis database.

Furthermore, the platform will offer more comprehensive data visualization through detailed charts and graphics. This segment will involve creating templates through interviews to facilitate Liming utilization. In conclusion, developing a complete carbon reduction statistical analysis platform aligns with international trends of carbon neutrality. It integrates calculation standards, analysis methods, and real-world project scenarios to provide decision-makers with accurate and detailed data for informed construction choices. This platform will serve as a crucial tool in contributing to environmentally sustainable practices within the construction industry, ultimately aiding in pursuing carbon reduction goals.

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