A Strategy to Estimate & Optimise Carbon Footprint for Foundations

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ABSTRACT

In response to the Paris Agreement with its Climate Action Plan 2030+, The Hong Kong government aims at 26% to 36% absolute carbon reduction by 2030 and achieve carbon neutrality by 2050. As the construction industry accounts for a significant amount of carbon emission, engineering practitioners have begun searching for ways to reduce the industry's impacts through greener construction processes. Understanding and assessing the carbon footprint of the construction process enables benchmarking how "green" currently our works are. It provides insights on areas for improvement including reducing carbon emissions. While the methodology of carbon footprint assessment has been developed and adopted for superstructure, the same for underground elements such as foundations have yet been discussed and proposed. This is due to the great variety of substructure, the uniqueness of geological and geotechnical conditions in different regions, as well as the influence of local practices and regulations. The above makes the standardization and benchmarking of carbon emissions for substructure a challenge.

In this paper, the authors attempt to develop a strategy for the assessment of embodied carbon on substructures in Hong Kong. Current obstacles and difficulties, as compared to those for other structures and structural elements are discussed. A strategy to look into the carbon footprint systematically and logically for foundations is then proposed and explained. The authors discuss possibilities to reduce and optimise carbon footprint of foundation works through careful decisions in early-stage planning, design, and construction control.

Keywords: Decarbonization, Foundation, Substructure

1 Introduction

1.1 Greenhouse Gases and CO_2e

According to the Kyoto Protocol, there are seven types of greenhouse gases (GHG) found to have effects on our climate system, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). CO_2 and N_2O are emitted during fossil fuel combustion, while CH_4 would be generated from decomposition of organic materials, e.g., paper waste. HFCs and PFCs mainly come from leakage from refrigeration / air-conditioning plants which is not common if there is proper maintenance of the systems, while SF_6 and NF_3 mainly come from industrial processes.

Emissions of the direct greenhouse gases are calculated as carbon dioxide equivalent (CO_2e), which is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP). The carbon dioxide equivalent for a gas is obtained by multiplying the mass and the GWP of the gas. It is a normalised term for accounting the carbon emission from a source with different GHG generation.

1.2 Objective

Several studies have addressed the issue of embodied carbon for superstructures, while excluding foundations. This is because foundation design is heavily influenced by the unique ground conditions

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of each site. (Chau *et al.*, 2012; Hart *et al.*, 2021) This paper aims to develop a strategy for the assessment of embodied carbon on substructures in Hong Kong. Current obstacles and difficulties, as compared to those for other structures and structural elements are discussed. A strategy to investigate the carbon footprint systematically and logically for foundations is then proposed and explained.

2 Current Methodology for Carbon Management

2.1 Modular Approach for Whole Lifecycle Carbon Assessment

Several guidelines provide framework on how to manage carbon footprint of development. (PAS 2080,2016; IStructE, 2020) The quantification of GHG emissions for an infrastructure or building asset can be undertaken using a modular structure which is consistent with the principles set out in BS EN 15978: 2011 (Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method) and BS EN 15804: 2012 (Sustainability of construction works - environmental product declarations). Such approach can be visually illustrated as shown in Figure 1.

Figure 2 illustrates the general trend of carbon emissions of an infrastructure or building asset during its whole life cycle. It can be clearly seen that the construction products and processes stage accounts for a significant proportion of carbon emissions. Also known as Upfront Carbon as shown in Figure 1, this stage can be divided into sub-categories as follows:

A1-A3: This accounts for raw materials of substructure and superstructure for the carbon emissions associated with the "cradle to gate" processes: raw material supply, transportation and manufacturing processes.

A4-A5: Construction stage process – accounting for the carbon emissions associated with the transportation of the materials to site and the construction itself (material wastes, construction plant and machineries). The term transportation also includes all movement of equipment and materials from intermediate storage to site. Waste management activities (transport, processing, final disposal) associated with waste arising from the construction site should also be accounted for.

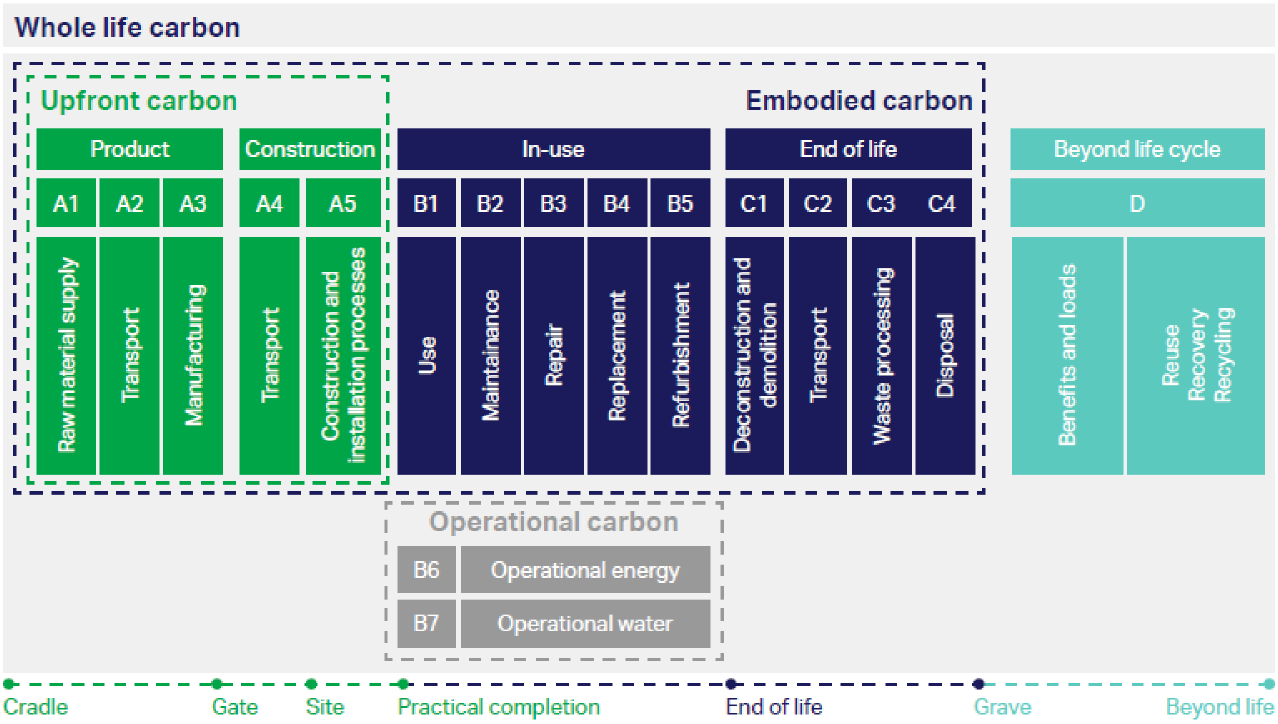

Figure 1: *Modular approach in Whole life cycle stages, EN 15978 (2011)*

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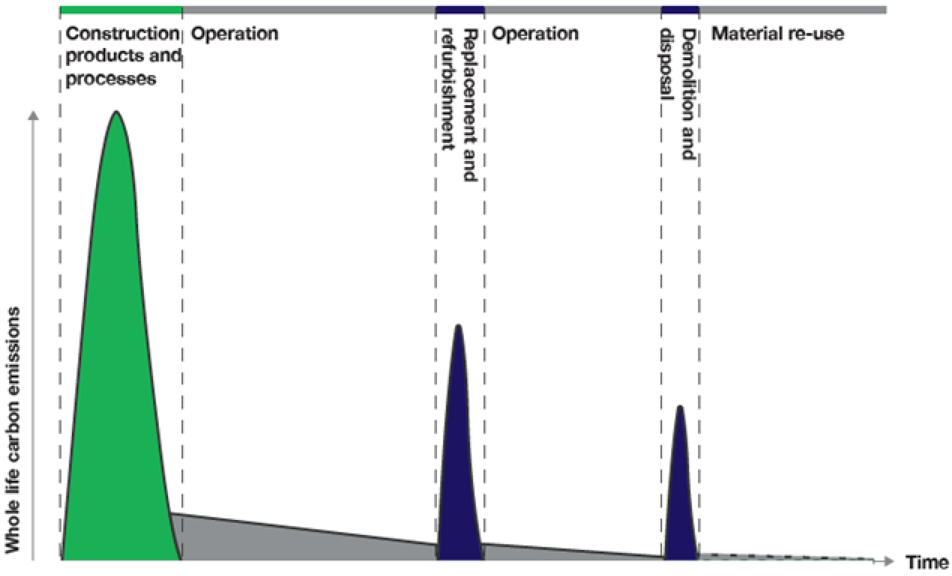

Figure 2: *Whole Life cycle stages Carbon Emissions*

2.2 Upfront Carbon Quantification and Benchmarking

In general, the GHG emission can be calculated using the following formula:

*Emission = Activity Rate * Emission Factor*

In Hong Kong, the Construction Industry Council (CIC) Carbon Assessment Tool (CAT) (Figure 3) can be adopted for estimating upfront carbon emissions. It is a platform to evaluate the carbon accounting for construction works (i.e. A1 to A5) into different attributes as defined as permanent works, temporary works, site impacts. The CAT is currently providing two platforms for design and construction stages namely, "Design Tool" and "Construction Tool".

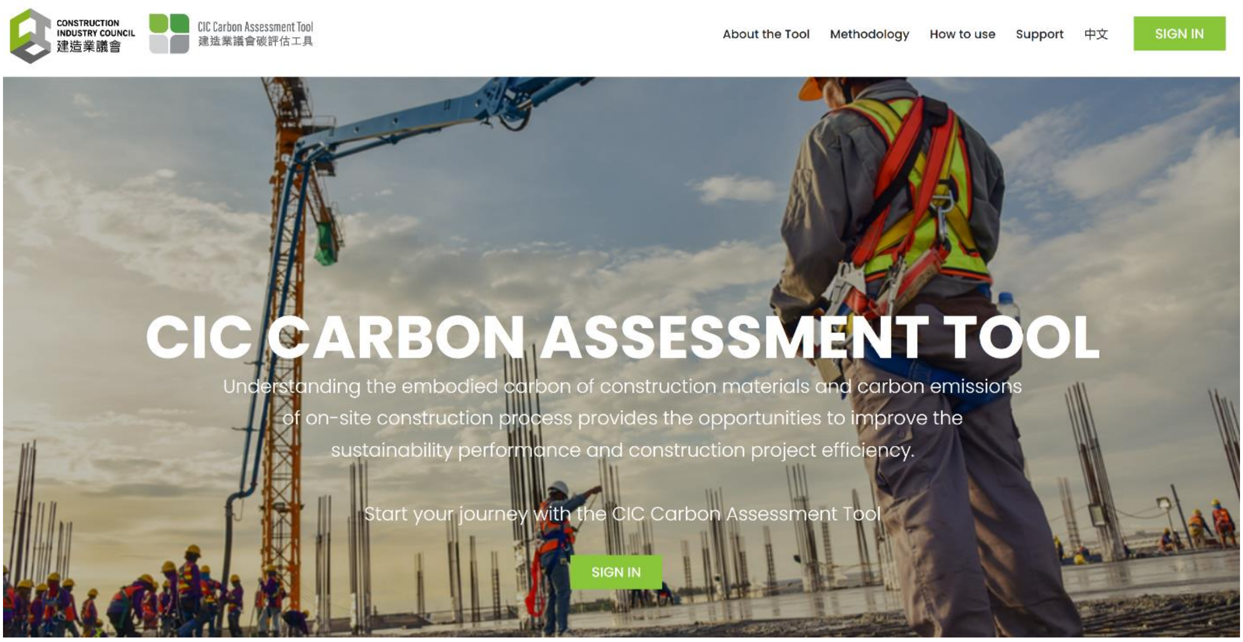

Figure 3: *CIC Carbon Assessment Tool (CAT) Platform for Embodied Carbon A1-A5*

"Design Tool" accounts for A1-A3, while "Construction Tool" also accounts for site impact activities to cover for A1-A5. CAT provides most of the emission factors data for major materials in the CIC Green Product Certification scheme. Additional research work will have to be undertaken when emission factors are not available in CAT database.

By quantifying the upfront carbon emission of different infrastructure or structure assets, benchmarks and databases can be developed to allow designers to assess the performance of their design in terms of anticipated carbon footprint. Such information enables designers to find ways to improve their design and deliver embodied carbon efficiency. It is an important step towards the goal of net zero building, as only when such data are available, suitable and appropriate carbon offsetting plans can be planned, designed and implemented.

3 Limitations on Carbon Assessment for Foundations

3.1 Carbon Emissions Generated by Foundation Works

Substructure, including foundations, ground bearing slab and basement retaining walls, typically contributes to approximately 20-30% of embodied carbon emission in whole building. (LETI, 2020). From the authors' previous studies, substructure contributes 25 % of total embodied carbon emission in our local project and results in 191kg CO_2e/GFA. The rule of thumb on embodied carbon distribution in selected types of structures is illustrated in Figure 4. Within the category of substructure, it is considered that foundations (including pile cap and piling) contain the largest proportion of the embodied carbon.

A worked sample on substructure embodied carbon is given in Table 1 for a 30-storey residential building, which is supported by 2.5m diameter Bored Piling and site area at 15,000m^2 located in in New Territories, HKSAR. This sample shows the embodied carbon quantification assessment during the design stage for the proposed foundation with the defined category, activities, materials, quantity and unit as tabulated. These data are taken from the building information modelling, then integrated with the CIC CAT for quantification.

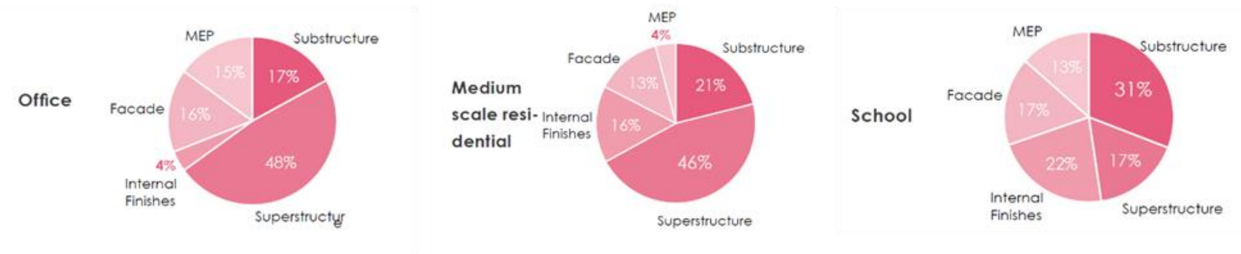

Figure 4: *Rule of Thumb on Embodied Carbon Distribution in Buildings (LETI, 2020)*

Table 1: *Sample of foundation quantity and embodied carbon quantification*

Category	Activities	Material	Quantity	Unit	Tonnes CO_2e
A1-3	Bored Piling	Concrete grade C45, OPC	2983	m^3	1275
A1-3	Bored Piling	Reinforcement Bar, General	144586	kg	310

		Reinforcement Bar			
A1-3	Pile Cap	Concrete grade C45, OPC	2393	m^3	1023
A1-3	Pile Cap	Concrete grade C60, OPC	6	m^3	3
A1-3	Pile Cap	Reinforcement Bar, General Reinforcement Bar	475458	kg	1020
A1-3	Pile Cap	Timber	1172	m^2	5
				Total	3636

3.2 Difficulties in Baselining Carbon Emissions in FoundationsF

Figure 4 demonstrates that the substructure accounts for the second largest carbon emissions impact in embodied carbon, hence, it shall be considered during planning and design stage to assess the reduction measures. Although carbon auditing and estimate for foundation can be done in similar fashion as the superstructure elements of an infrastructure or structure asset, baselining on carbon emissions for foundations have not been undertaken. This hinders designers from reaching the goal of moving towards net zero or carbon neutrality target.

The calculated embodied carbon on substructure, particularly the foundation, is more complicated to set out the baseline when comparing with superstructure with typical floor function space and per area. The major obstacle is that the choice of foundation and its scale are not only influenced by the superstructure type and height, but also highly influenced by the geological condition as well as the groundwater table. For instance, the same commercial building will have an entirely different foundation scheme when it is located on a newly reclaimed land with substantial thickness of soft deposits as compared to located in an ex-quarry site where competent engineering rockhead can be encountered at shallow depth from the existing ground level.

4 Carbon Strategy for Foundations

4.1 Alternative Way of Assessment

Ideally, in order to have a meaningful comparison on carbon emissions for foundations, designers should consider baselining their proposed schemes against shortlisted samples with superstructures with similar functionality as well as similar geological condition. However, this could be difficult to achieve in the short term as there may not be enough data with such categorizations. Prior to such database becoming mature, it is suggested that effort should be made on treating carbon reduction as one of the targets in value-engineering activities. For a particular type of foundation, for example in-situ cast concrete bored piles, there would be a common range of carbon emission per unit volume of the pile structure. Focus should then be put on ways to achieve a lower CO_2e per unit volume, or in other words, a higher embodied carbon efficiency.

4.2 Carbon Reduction Initiatives

A majority of substructure elements including foundations are reinforced concrete product and will remain prominent over the next decade, there are several ways to reduce the carbon impact of reinforced concrete structures whereas most effective to reduce embodied carbon is to use less of the heaviest polluting elements, for instance, less cement and less reinforcing steel. The breakdown of the reinforced concrete material carbon impact breakdown is presented in Figure 5.

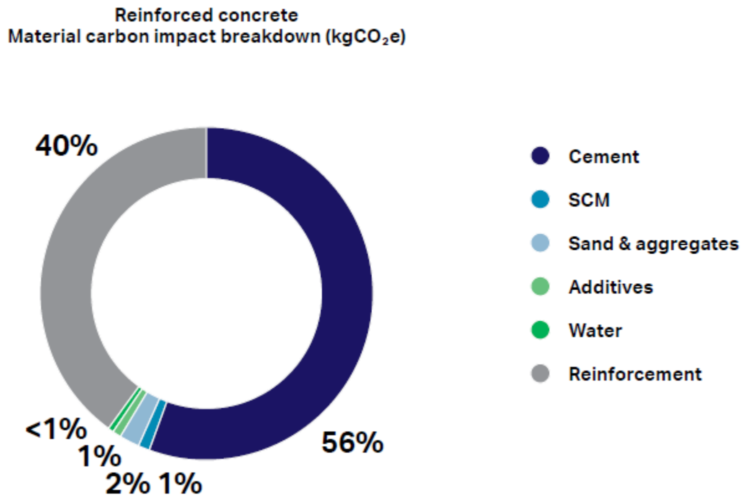

Figure 5: *Reinforced concrete Material carbon impact breakdown (kgCO_2e).(Arup, 2023)*

4.2.1 Green Concrete

Use of GGBS (Ground Granulated Blast Furnace Slag) could be one of the ways to reduce embodied carbon in structural components in both substructure and superstructure, which have been recently adopted in recent projects. Study suggests that GGBS can replace up to 70% of cement while PFA can only replace up to 35% of cement. (W H Chung *et al.*, 2022) (These substitutes can contribute to further

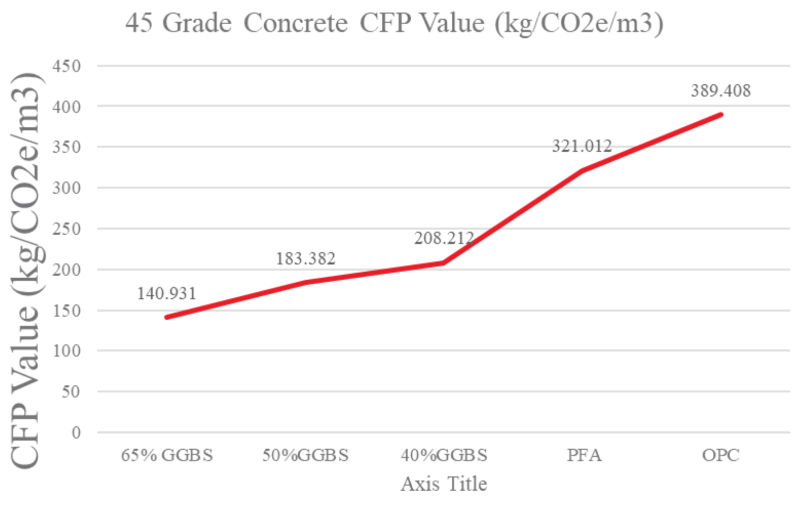

Figure 6: *Carbon Footprint Value (CFP) in 45 Grade Concrete*

CO_2 reduction. According to the Carbon Assessment Tool established by CIC and as illustrated in Figure 6, 63.8% of CO_2 reduction can be achieved by using 65% GGBS concrete mixture to replace Portland Cement.)

4.2.2 Recycled Steel Supplier

With the advancement of Electric-arc-furnace (EAF) technology, the rate of recycling of steel scrap has increased to 94%, reducing the environmental effects of iron mining without compromising social or economic development. For instance, O-PARK2 is an example of making use of rebar that is 100% recycled, and it has a 67% potential to reduce carbon emissions.

4.2.3 Improvement in Design Approaches and Methodologies

The overall carbon emissions of foundation are generally proportional to the construction material e.g. concrete, rebars, steel, etc. Therefore, improvements in design approaches and methodologies that results in reduction of construction materials used would have a significant impact on the embodied carbon efficiency of the foundation system. For example, the recent enhancement of allowable bearing capacity of Category 1(c) rock as per Code of Practice for Foundations potentially enables the same structures to be supported by smaller size or fewer numbers of piles, hence providing the opportunity for substantial reduction in carbon emissions. It is suggested that the industry should collaborate with the statutory bodies and look into the possibilities of adopting more technological advanced foundation solutions in local projects.

5 Conclusion

This paper has presented the carbon management process, standards, methodology, boundary setting and carbon accounting tools for embodied carbon on infrastructure and structure asset. Its applicability on substructures, in particular foundations, is studied and discussed. The study shows despite the limitations on providing benchmarking for assessing carbon footprint for foundations, immediate improvements can be achieved with the use of greener construction material and better design approaches & methodologies. In the longer-term baselines can be developed for foundations with the consideration of geological conditions and groundwater conditions.

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