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A SIMPLIFIED GUIDE TOWARDS INCENTIVISING EMBODIED CARBON ASSESSMENT: A CASE OF HIGH-RISE RESIDENTIAL BUILDING

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ABSTRACT

In recent decades, the increasing threat of global warming has emphasised the importance of reducing carbon emissions within construction sector due to its significant impact. Despite efforts to mitigate climate change, the construction industry faces a critical gap in effectively evaluating the carbon emissions and costing it. The major reasons could be attributed to lack of awareness of carbon performance and commitment, lack of data availability and inconsistent methodologies. Hence, this study aims to develop a simplified guide, as an extension to the typical cost estimation practice towards addressing the above concerns with respect to embodied carbon (EC). This study primarily involved a quantitative assessment of EC emission of a typical high-rise residential building in Sri Lanka. Therefore, BOQ of the selected building and additional information such as material and machinery requirements, EC co-efficient, fuel consumption and transportation distance were obtained from technical specifications, industry practiced norms and databases. Accordingly, the EC emission of the selected building was derived as 873KgCO$_2$/m^2 of GFA. Of this, 94% is due to material production stage, while remaining 6% is in transportation and construction stages. Key materials contributed include: paint, cement and reinforcement. The steps followed in deriving the above estimation is presented as a simplified guide that would promote and account the construction clients for the EC emission of their proposed building constructions. By integrating EC assessment (ECA) into the construction cost estimation process, this guide seeks to empower decision-makers to choose among carbon alternatives and aid in carbon taxation in the Sri Lankan context.

Keywords: *Carbon Taxation; Embodied Carbon Assessment; Residential Buildings.*

1. INTRODUCTION

In recent decades, global warming has emerged as a significant challenge, predominantly driven by greenhouse gases (GHGs), with carbon dioxide (CO_2). According to the United Nations Environment Programme (UNEP, 2021), energy consumption in buildings remained constant and increased embodied carbon (EC) emission to 9.95 giga-tons

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globally. However, according to UNEP (2022), building energy demand has experienced a notable rise of approximately 4% since 2020, reaching 135 exajoules (EJ), marking the most substantial increase observed in the past decade. Significantly, in 2021, the building sector has shown a 5% surge in operational CO_2 emissions compared to 2020, surpassing the previous peak in 2019 by 2%. Further, buildings utilise a variety of materials that consume energy and emit CO_2 throughout their life cycle, collectively known as embodied energy and EC (Ahmed Ali et al., 2020). The latest study reveals that the built environment stands out as a major contributor, accounting for over 37% of CO_2 emissions linked to global energy consumption (Arenas & Shafique, 2024). Authors further stated that the utilisation of construction materials, already responsible for 9% of total energy-related CO_2 emissions, is projected to double by 2060.

As part of mitigation strategies, evaluating the EC of buildings stands out as a fundamental approach with the potential to significantly reduce carbon footprint. Assessing the carbon emissions associated with the material production, transportation, and construction would enable informed decisions to prioritise low-carbon alternatives (Myint & Shafique, 2024). In addition, a sound environmental tax system would require carbon emission reduction to gain long-term cost benefits in the building sector (Bai et al., 2024). Although the tax is charged from end-users of buildings, it will be distributed among manufacturers and contractors to reverse the cost flow (Bertoldi et al., 2010). Therefore, identification of potential risks in terms of EC emission and its cost is vital throughout the building's lifetime (Pomponi & Moncaster, 2016).

To date, number of studies have aimed to assess the carbon emission in various contexts and concluded, differently. For instance, EC emission assessments conducted for office buildings in UK, Korea, China and Greece reported 595 $kgCO_2eq/m^2$, 674 $kgCO_2eq/m^2$, 715 $kgCO_2eq/m^2$ and 200 $kgCO_2eq/m^2$ of emissions, respectively (Chau et al., 2015; Kumanayake & Luo, 2018b; Victoria et al., 2015). However, it is important to note that while these studies focus on a specific type of building, the emission levels can vary due to differences in location and construction methodology. Additionally, although these studies provide detailed analysis of emission, which lack its reference to derive the carbon emissions of other buildings in future. On a similar note, Kumanayake et al. (2018) concluded that in the Sri Lankan context, the life cycle energy and carbon emission of residential buildings varies depending on the material and utilised construction techniques. Based on the study, authors developed carbon emission estimator tool towards increasing the awareness of low-carbon building construction for a sustainable future (Kumanayake & Luo, 2018a) using MySQL database management software. However, this may pose challenges for users with limited computer literacy. Further, the database comprised of materials contributing to over 85% of the total CO_2 emissions of typical Sri Lankan buildings. Since this is the first attempt to develop a life cycle CO_2 emission estimator tool for Sri Lanka, it lacks flexibility in the assessment of EC. Similarly, Nawarathna et al. (2019) proposed a conceptual methodology to assess EC in Sri Lankan building construction complying with life cycle assessment (LCA) and EC estimation process. While this methodology provides a conceptual framework, its actual adoption and feasibility for carbon assessment may be questionable.

Despite the foregoing study findings, industry practitioners remain hesitant to assess the carbon emissions of buildings (Jackson & Kaesehage, 2020). This reluctance is largely attributed to lack of awareness on the impact of carbon emissions (Abeydeera et al., 2019), commitment to mitigation and absence of comprehensive guidance regarding carbon assessment in construction sector (Jayathilaka et al., 2023). Further, review of 33 construction LCA software found that most ECA tools adopt a process-based LCA (PLCA) method, following ISO 14040/14044 and PAS 2050 standards (Ariyaratne & Moncaster, 2014). While LCA tools vary from Cradle-to-gate to Cradle-to-grave, those focusing on embodied carbon Cradle-to-end of construction can be complex and time-consuming, requiring detailed data and expertise, thus limiting their applicability for quick decision-making in industry settings (Kumanayake et al., 2018; Nawarathna et al., 2019; Victoria et al., 2015). Although some of these tools offer convenience and automation, they may lack transparency regarding underlying assumptions and data sources, leading to uncertainty of results. Hence, industry practitioners perceive such assessment as time-consuming due to the absence of consistent methods and benchmarks (De Wolf et al., 2017).

As one of the party countries in the Paris Agreement, Sri Lanka has signed to combat climatic changes where achieving low-carbon economy is one of the main objectives (De Silva, 2017). Therefore, the Ministry of Environment (2021) set targets introducing national policies to reduce carbon emission, approximately 15% by 2030 targeting the main six sectors namely, power, transport, waste, industry, agriculture, and forestry. To that end, construction practices disregarding carbon emission would impinge the achievement of the set goal. Given that, it is vital to account the potential carbon emission of proposed construction projects and thereby seek low-carbon alternatives towards mitigating carbon emission. In that context, this paper aims to propose a simplified guide that enables assessing the embodied carbon emission from cradle to construction stage, where significant amount of embodied carbon is emitted.

2. RESEARCH METHODOLOGY

This research aims to develop a guide for carbon estimation by analysing EC emission of a typical high-rise residential building to facilitate the carbon costing in future construction. Accordingly, this research employed a quantitative approach to collect required data for the assessment of EC emission and developing the said simplified guide. A high-rise residential apartment with the gross internal floor area (GIFA) of 5,500m^2, located in Colombo was selected as case example. Furthermore, a review was conducted into BOQ, technical specifications, manufacturers' catalogues, and details on construction and industry norms such as NRM1, NRM2, SLS 573 and Building Schedules of Rates (BSR). The emission coefficients were extracted from the Inventory of Carbon and Energy (ICE) database and the Hutchins UK Building Blackbook. In accordance with previous studies, in the absence of specific EC coefficient data for Sri Lanka, a mean location factor of 0.76 extracted from the above sources was employed in this study (Kumanayake et al., 2018; Nawarathna et al., 2019). Using the data collected, EC emissions related to material production & transport, and construction were calculated as per the following steps. According to RICS (2017), EC is emitted in different stages of a construction project; Cradle-to-gate, Cradle-to-site, Cradle-to-end of construction, Cradle-to-grave, and Cradle-to-cradle. When it comes to EC emission, Cradle-to-end of construction is vital, early stages where most of the design and construction decisions are finalised.

Step I: Extract the typical construction activities and respective quantities by referring to selected BOQ

Step II: Derive the appropriate norms for construction activities by referring to norms used by the leading construction companies

Step III: Calculate the quantity of each material used each construction activity and derive the aggregate quantity for each material

Step IV: Derive the total EC emission in material production stage by applying EC coefficient factors on aggregate quantity of each material

Step V: Identify the required vehicle for each material transportation and the average distance of transportation, and EC coefficient of each vehicle. Derive the total EC emission in material transportation stage

Step VI: Derive the EC coefficient factors for each material and calculate the EC emission in construction stage

Step VII: Assess the total carbon emission of the project from cradle to construction stage by aggregating outcomes of steps IV, V and VI.

The above steps have been integrated into an Excel spreadsheet for convenient navigation through the proposed ECA process, as depicted in Figure 1.

A SIMPLIFIED GUIDE FOR EMBODIED CARBON COST ESTIMATION		
STEP 1	Extract typical construction activities and quantities from the chosen BOQ	BOQ
STEP 2	Determine industry norms for each activity from leading construction companies.	Construction Activities
STEP 3	Calculate material quantities for each construction activity based on the BOQ.	Building Norms
STEP 4	Establish EC coefficient factors for materials and calculate EC emissions during production.	EC - Materials Production
STEP 5	Identify required vehicles for material transportation, determine average distances, establish EC coefficients for each vehicle, and calculate EC emissions during transportation.	EC - Materials Transport
STEP 6	Establish EC coefficient factors for materials and calculate EC emissions during construction.	EC - Construction
STEP 7	Assess total carbon emissions of the project from cradle-to-construction stage.	EC - Total

Project Name:	Nine storey residential building for Mr.XYZ
Location:	Colombo - 03
GIFA (Sq.m):	5500

Figure 1: Menu sheet of the proposed simplified ECA guide

Following the steps described, the ECA of the proposed high-rise building was assessed and presented in the subsequent sub-sections.

3. RESULTS

Initially, BOQ of the selected building was referred and the activities involved along with their respective quantities were extracted. Then, appropriate building norms derived by considering norms used by the leading contractors in Sri Lanka were applied to quantities extracted. This process resulted in quantities of each material consumed in the selected activity of the selected building. Based on the materials consumed, the EC in material production, transportation and construction stages was assessed and presented in following sub-sections.

3.1 EC EMISSION DURING THE MATERIAL PRODUCTION PHASE

The material production phase mainly focused on the calculation of material production related EC emission as the EC coefficients cover the scope of cradle to gate. According to the ICE database, the EC coefficient is given for the unit of kgCO_2e/kg. Therefore, the average quantity of materials was converted into its volume (m^3) and multiplied by its density to obtain mass (kg) as shown in Equation 1.

$$Mass\ of\ material\ (kg) = Average\ volume\ (m3) \times Density\ (kg/m3) \qquad (Eq.\ 1)$$

After determining the average mass of each material, EC emission was calculated by multiplying the mass by 0.76 to convert the coefficient into the Sri Lankan context. This method was followed to calculate EC emission for each activity. Accordingly, the EC emission in material production related to concrete work was calculated as illustrated in Table 1. Similarly, EC emissions in all activities involved in the construction of selected residential building were calculated and added to Table 1.

Table 1: Activity-based EC emission during the material production phase

Material	Unit	Qty per GIFA	Volume (m^3)	Density (kg/m^3)	Mass (kg)	EC Coefficient ($kgCO_2/kg$)	EC Emission ($kgCO_2/ m^2$)
Cement	Bag	7.15			357.55	0.9100	247.28
Sand	Cube	0.10	0.00	1,400.00	4.07	0.0075	0.02
Aggregate	Cube	0.22	0.01	1,600.00	10.09	0.0049	0.04
Water	Gal	71.79	0.29	1,000.00	287.15	0.0003	0.08
Total emission in concrete work							**247.42**

Emission in all construction activities				
Activities	**Unit**	**Quantity**	**Emission ($KgCO_2/ m^2$)**	**%**
Painting	sqr	3,961	280.39	34%
Concrete	cube	1282	247.42	30%
Reinforcement	cwt	8,914	213.90	26%
Finishes	sqr	3,775	36.15	4%
Masonry	sqr	906	30.54	4%
Formwork	sqr	3,083	6.63	1%
Waterproofing	sqr	623.90	3.23	0%
Excavation	cube	64	0.00	0%
Total emission in material production (per GIFA)				**820.24**
GIFA (m^2)				**5,500**
Total emission in material production				**4,511,327**

Emission in major construction materials		
Material	**Emission ($KgCO_2/m^2$)**	**%**
Paint	1121.56	68%
Cement	291.12	18%
Reinforcement	213.89	13%
Blocks	27.27	2%
Round Timber 3" dia. (10'-0")	3.96	0.2%
Timber Planks 1" Class 111	1.41	0.1%
Timber 2"x 2" Cl.111	0.80	0.1%
Sand	0.37	0.0%

As shown in the table, the top emitting activity is painting, which is 34% of the total emission of material production. Secondly, concrete and reinforcement activities contributed 30% and 26% of the total material production emission, respectively. In the context of construction materials, paint emerges as a substantial contributor, constituting

68% of total emissions from material production. Cement and reinforcement followed, contributing 18% and 13% respectively to these emissions. Although concrete production is a major contributor to material production emissions, cement is the predominant factor, accounting for 38% of the total emissions, overshadowing the relatively negligible contributions of sand and aggregate.

3.2 EC EMISSION DURING MATERIAL TRANSPORTATION

Materials produced so as explained above, to be used in proposed building, were transported to proposed building site using appropriate vehicles. The vehicles used and their capacities were obtained from the records maintained by the site store. However, due to unavailability of exact details regarding certain material suppliers and factories, the research opted to consider the vehicles used as per the general industry practice and the suppliers who based in close proximity to the selected project site. For each material, the average distance to the site from the suppliers around were calculated, and used to estimate the EC emissions during material transportation. Table 2 presents the calculation of EC emission at the material transportation stage in concrete work. Similarly, EC emissions in all materials transportation were calculated and added to Table 2.

Table 2: Calculation of EC emission from material transportation stage

Material	Vehicle Type	Capacity	Mass per GIFA (kg)	Average Distance (km)	EC Coefficient (kgCO^2/kg)	EC Emission (kgCO^2/m^2)
Concrete mixing						
Cement	Truck	8 ton	358	0.6	0.241	0.11
Sand	Truck	8 ton	4	13.4	0.241	2.45
Aggregate	Truck	8 ton	10	9.0	0.241	1.65
Concrete placing						
Concrete	Mixture truck	4m^3		8.8	1.099	7.35
Total emission in concrete work						**11.56**
Emission in all construction activities						
Activities					**EC Emission (kgCO$_2$/m^2)**	**%**
Concrete					11.56	23%
Masonry					8.17	16%
Earthwork					6.66	13%
Finishes					6.51	13%
Reinforcement					5.26	10%
Waterproofing					5.15	10%
Formwork					3.86	8%
Roof work					3.72	7%
Painting					0.07	0%
Total emission in material transportation (per GIFA)						**50.96**
GIFA (m^2)						**5500**
Total emission in material transportation						**280,301**

As per the table, the concrete work is responsible for 23% of the total emission. Further, masonry, earthwork and finishes contributed significantly, collectively for over 40% of total emission.

3.3 EC EMISSION DURING CONSTRUCTION PHASE

The EC emission in construction phase is limited to activities where heavy machinery involved. Accordingly, amongst the typical construction activities of the proposed high-rise building, concrete, excavation and reinforcing activities were considered as responsible for emission in this stage. Depending on the type of machinery used, fuel-based/electricity-based EC emissions was to be calculated. Therefore, the energy usage rates of each machinery need to be identified along with material quantities to determine the fuel usage in each construction activity. Energy usage factors were extracted from the literature and technical specifications for building construction. Accordingly, 2.68 $kgCO_2/l$ and 0.5845 $kgCO_2/kWh$ were considered as EC coefficients for fuel and electricity, respectively (Kumanayake et al., 2018; Nawarathna et al., 2019; Victoria et al., 2015). Using the above information, EC emissions for the above said activities are calculated and presented in Table 3.

Table 3: EC emission at the construction stage

Machinery	Unit	Quantity per GIFA	Energy Use Rate	EC coefficient	EC emission ($kgCO_2/m^2$)
			Concrete		
Pump Car	m^3	0.66	0.770 l/m^3	2.680 $kgCO_2/l$	1.20
Vibrator	m^3	0.66	0.210 l/m^3	2.680 $kgCO_2/l$	0.34
Material hoisting	kg	0.12	0.003 kwh/kg	0.5845 $kgCO_2/kwh$	0.00
Total EC emission of concrete work					**1.55**
			Excavation		
Pump Car	m^3	0.03	0.770 l/m^3	2.680 $kgCO_2/l$	0.06
Vibrator	m^3	0.03	0.210 l/m^3	2.680 $kgCO_2/l$	0.02
Material hoisting	kg	0.00	0.003 kwh/kg	0.5845 $kgCO_2/kwh$	0.00
Total EC emission of excavation					**0.08**
			Reinforcement		
Rebar processing machine	kg	81.04	0.002 kWh/kg	0.5845 $kgCO_2/kWh$	0.09
Material hoist	kg	81.04	0.003 kWh/kg	0.5845 $kgCO_2/kWh$	0.14
Total EC emission of reinforcement					**0.24**
Total emission in physical construction					**1.86**
GIFA (m^2)					**5,500**
Total emission in physical construction					**10,244**

The highest EC emission was resulted in concrete work due to its higher mass and higher energy capacity of pump cars and other types of machinery like mechanical vibrators. Even though reinforcement has a comparatively higher mass, the lesser energy usage rate of rebar processing machine and material hoisting resulted in the least EC emission in the construction phase. Therefore, above results highlights that the mass and energy usage rate of machinery directly influence the amount of EC emission.

3.4 TOTAL EC EMISSION

The total EC emissions of activities from the cradle to construction include cumulative emission of material production, transportation, and construction stages. Total EC emission from cradle to construction stage of the selected high-rise building is tabulated in Table 4.

Table 4: Total EC emission

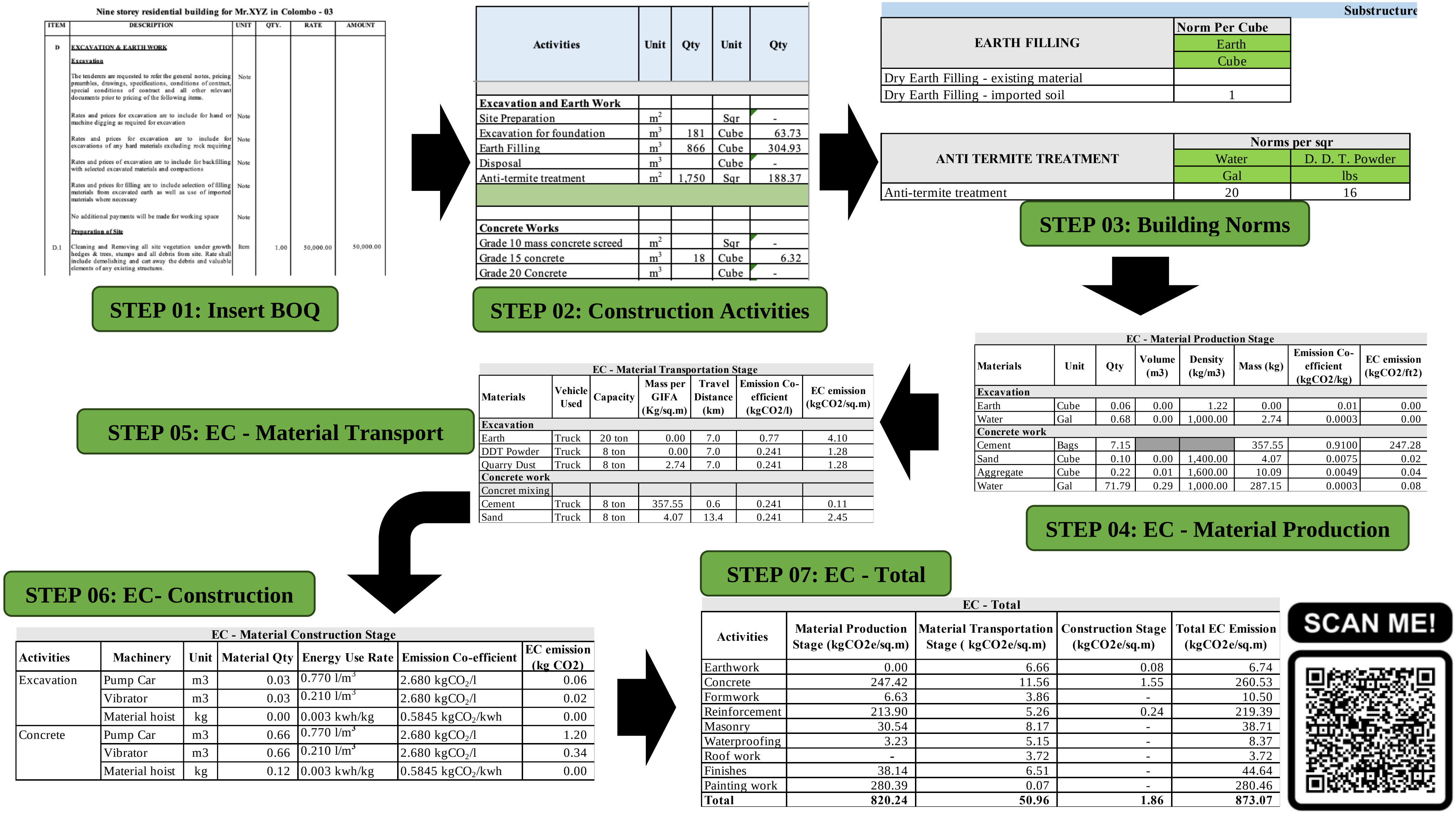
Activities	EC Emission ($kgCO_2/m^2$)			Total	Share of total EC Emission
	Production	Transportation	Construction		
Painting work	280.39	0.07	0.00	280.46	32%
Concrete	247.42	11.56	1.55	260.53	30%
Reinforcement	213.90	5.26	0.24	219.39	25%
Finishes	38.14	6.51	0.00	44.64	5%
Masonry	30.54	8.17	0.00	38.71	4%
Formwork	6.63	3.86	0.00	10.50	1%
Waterproofing	3.23	5.15	0.00	8.37	1%
Earthwork	0.00	6.66	0.08	6.74	1%
Roof work	0.00	3.72	0.00	3.72	0%
Total EC per GIFA	**820.24**	**50.96**	**1.86**	**873.07**	**100%**
Total EC	**4,511,327**	**280,301**	**10,244**	**4,801,872**	

As seen from Table 4, of the total EC emission from cradle to construction site, material production stage is responsible for 94% (820 out of 873 $kgCO_2/m^2$) while remaining 6% is attributed to transportation and construction stages. This shows that material production plays a pivotal role in mitigating embodied carbon emission effects.

The above analysis further shows that over 80% of emissions are due to painting, reinforcement and masonry works. Notably, painting work has the highest EC emission of 32% (280.46 out of 873.07) of the total EC emission. The concrete and reinforcement are the next highest contributors with 30% and 25% contributions, respectively. Hence, these activities are recognised as carbon hotspots. Other activities namely, finishes, masonry, formwork, waterproofing, earthwork and roof work have a marginal contribution of less than 5% each to the total EC emission at the material production phase.

3.5 A SIMPLIFIED GUIDE FOR THE ASSESSMENT OF CARBON EMISSION

A simplified guide to assist the EC emission is developed based on the outcome derived from the steps described in section 2 and sections 3.1 to 3.4 and depicted in Figure 2, together with a QR code to access the developed simplified tool for ECA. As seen, the guide requires to pass through 7 simple self-directed steps to derive the total emission in any proposed building construction.



Nine storey residential building for Mr.XYZ in Colombo - 03

ITEM	DESCRIPTION	UNIT	QTY.	RATE	AMOUNT
D	EXCAVATION & EARTH WORK				
	Excavation				
	The tenderers are requested to refer the general notes, pricing preambles, drawings, specifications, conditions of contract, special conditions of contract and all other relevant documents prior to pricing of the following items.	Note			
	Rates and prices for excavation are to include for hand or machine digging as required for excavation	Note			
	Rates and prices for excavation are to include for excavations of any hard materials excluding rock requiring	Note			
	Rates and prices of excavation are to include for backfilling with selected excavated materials and compactions	Note			
	Rates and prices for filling are to include selection of filling materials from excavated earth as well as use of imported materials where necessary	Note			
	No additional payments will be made for working space	Note			
	Preparation of Site				
D.1	Cleaning and Removing all site vegetation under growth hedges & trees, stumps and all debris from site. Rate shall include demolishing and cart away the debris and valuable elements of any existing structures.	Item	1.00	50,000.00	50,000.00

Activities	Unit	Qty	Unit	Qty
Excavation and Earth Work				
Site Preparation	m^2		Sqr	-
Excavation for foundation	m^3	181	Cube	63.73
Earth Filling	m^3	866	Cube	304.93
Disposal	m^3		Cube	-
Anti-termite treatment	m^2	1,750	Sqr	188.37
Concrete Works				
Grade 10 mass concrete screed	m^2		Sqr	-
Grade 15 concrete	m^3	18	Cube	6.32
Grade 20 Concrete	m^3		Cube	-

EARTH FILLING	Norm Per Cube
	Earth
	Cube
Dry Earth Filling - existing material	
Dry Earth Filling - imported soil	1

ANTI TERMITE TREATMENT	Norms per sqr	
	Water	D. D. T. Powder
	Gal	lbs
Anti-termite treatment	20	16

EC - Material Production Stage

Materials	Unit	Qty	Volume (m3)	Density (kg/m3)	Mass (kg)	Emission Co-efficient (kgCO2/kg)	EC emission (kgCO2/ft2)
Excavation							
Earth	Cube	0.06	0.00	1.22	0.00	0.01	0.00
Water	Gal	0.68	0.00	1,000.00	2.74	0.0003	0.00
Concrete work							
Cement	Bags	7.15			357.55	0.9100	247.28
Sand	Cube	0.10	0.00	1,400.00	4.07	0.0075	0.02
Aggregate	Cube	0.22	0.01	1,600.00	10.09	0.0049	0.04
Water	Gal	71.79	0.29	1,000.00	287.15	0.0003	0.08

EC - Material Transportation Stage

Materials	Vehicle Used	Capacity	Mass per GIFA (Kg/sq.m)	Travel Distance (km)	Emission Co-efficient (kgCO2/l)	EC emission (kgCO2/sq.m)
Excavation						
Earth	Truck	20 ton	0.00	7.0	0.77	4.10
DDT Powder	Truck	8 ton	0.00	7.0	0.241	1.28
Quarry Dust	Truck	8 ton	2.74	7.0	0.241	1.28
Concrete work						
Concret mixing						
Cement	Truck	8 ton	357.55	0.6	0.241	0.11
Sand	Truck	8 ton	4.07	13.4	0.241	2.45

EC - Material Construction Stage

Activities	Machinery	Unit	Material Qty	Energy Use Rate	Emission Co-efficient	EC emission (kg CO2)
Excavation	Pump Car	m3	0.03	0.770 l/m^3	2.680 $kgCO_2/l$	0.06
	Vibrator	m3	0.03	0.210 l/m^3	2.680 $kgCO_2/l$	0.02
	Material hoist	kg	0.00	0.003 kwh/kg	0.5845 $kgCO_2/kwh$	0.00
Concrete	Pump Car	m3	0.66	0.770 l/m^3	2.680 $kgCO_2/l$	1.20
	Vibrator	m3	0.66	0.210 l/m^3	2.680 $kgCO_2/l$	0.34
	Material hoist	kg	0.12	0.003 kwh/kg	0.5845 $kgCO_2/kwh$	0.00

EC - Total

Activities	Material Production Stage (kgCO2e/sq.m)	Material Transportation Stage (kgCO2e/sq.m)	Construction Stage (kgCO2e/sq.m)	Total EC Emission (kgCO2e/sq.m)
Earthwork	0.00	6.66	0.08	6.74
Concrete	247.42	11.56	1.55	260.53
Formwork	6.63	3.86	-	10.50
Reinforcement	213.90	5.26	0.24	219.39
Masonry	30.54	8.17	-	38.71
Waterproofing	3.23	5.15	-	8.37
Roof work	-	3.72	-	3.72
Finishes	38.14	6.51	-	44.64
Painting work	280.39	0.07	-	280.46
Total	**820.24**	**50.96**	**1.86**	**873.07**

Figure 2: An illustration of the proposed simplified guide for ECA (Scan the QR code to access the digital tool)

4. DISCUSSION AND CONCLUSIONS

The study has assessed the EC emission of a typical high-rise building by a taking a case of a nine-storey residential building. The evaluation concludes that on average, construction of a nine-storey residential building in Sri Lanka results in total EC emission of 873 $kgCO_2$ per m^2 (81.14 $kgCO_2/ft^2$) during cradle to construction stage activities. A similar study was conducted in China for residential building where the EC was 388 $kgCO_2e/ft^2$ (Li et al., 2013). Another study by Kumanayake et al. (2018) identified that the EC of four-storey office building was responsible for 630 $kgCO_2/m^2$ of emission. These significant differences in carbon emissions could be attributed to several factors such as type of construction, materials & machinery used, emission coefficients, methodology used, etc. Accordingly, the current study contributes to knowledge base that the emission varies across geographical contexts and it warrants an assessment specific to a given location. To this end, the study provides a self-directed simplified guide that enables assessment of EC to any kind proposed building in the local as well as global context. Further, the study provides a detailed assessment at each stage of the process. This would enable construction clients and professionals to consider alternatives where possible to mitigate EC emission.

In terms of findings, the current study concludes that the material production stage is significant, responsible for 94% of total EC emission. The activities, such as painting, concrete and reinforcement were responsible for 87% of materials production emission. Materials such as paint, cement and reinforcement are responsible for 99% of the total emission from material production stage. Therefore, material selection should be done with due consideration to their emission subject to cost implications and other factors deciding the feasibility of the materials.

However, these findings are subject to limitations in terms of co-efficient factors, travel distance, machinery used etc. Thus, the developed simplified guide would enable to derive the EC emission of proposed project using the appropriate and available information of a given project in future.

This research has contributed to the field by developing a simplified EC assessment guide designed for Sri Lankan building construction. Although this study focused on Sri Lankan construction industry, the guide can serve as a valuable reference for other countries aiming to assess the EC emission of building construction. By incorporating their own coefficient factors and local materials and vehicles, similar assessments can be conducted globally.

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