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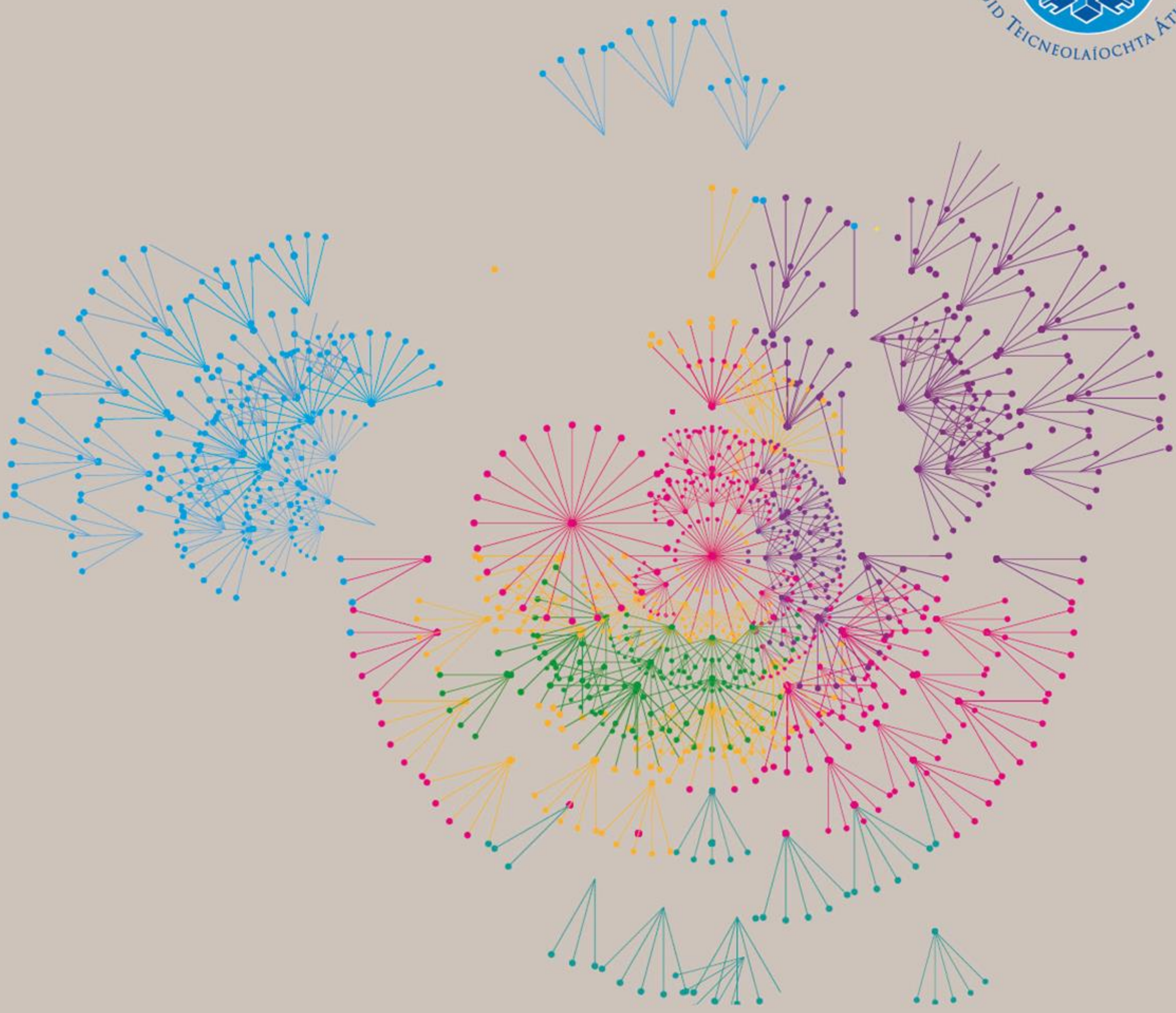

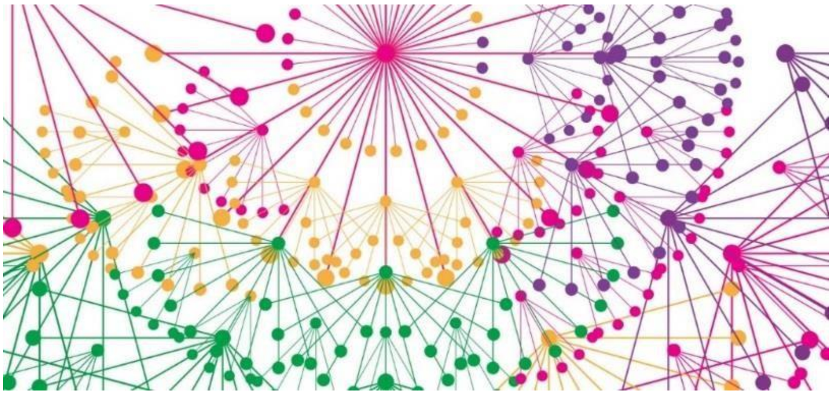

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ESTIMATING EMBODIED CARBON EMISSIONS OF BUILDINGS IN DEVELOPING COUNTRIES: A CASE STUDY FROM SRI LANKA

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Abstract

Even with the increasing attention on reduction of Embodied Carbon (EC) emissions in the global built environment sector, yet most of the developing countries focus only on reduction of Operational Carbon (OC) through improved operational energy performance. The significance of EC estimation and reduction in buildings in these countries are yet to be fully realised. Therefore, this paper provides a case study of an office building located in Western province in Sri Lanka, which is used as a drive to identify the potential for estimating EC emissions of buildings in developing countries. Accordingly, the estimation was carried out confining to the cradle to gate system boundary and structural elements of a building. The estimation process revealed that the EC estimation is a challenging process for a developing country like Sri Lanka as it encountered many challenges such as lack of accurate and up to date EC co-efficient for building materials, time consuming and work intensive nature of estimation, difficulty in choosing a system boundary and unavailability of an appropriate estimation tool. The case study findings revealed that the total structural elemental EC emission per gross floor area is 191.11 kgCO2/m2. Similar to many previous studies, it was identified that the top most EC intensive element of this building is also substructure. However, this study was carried out as a pilot study of a further research and can be extended to incorporate all the elements of the building to provide an accurate value for the overall and elemental EC emissions.

INTRODUCTION

The building sector is known to be one of the largest contributors to global carbon emissions. It is responsible for more than one third of total global energy use and carbon emissions (Peng, 2015). In the light of that fact, the building sector has been targeted as a major sector in achieving the global carbon emission reduction targets introduced in Kyoto protocol and then Paris agreement by UNFCC, 1998, 2012 and 2016 (IPCC, 2014). Accordingly, low carbon/green building transition plans have been put forth around the world as one of the main building carbon reduction strategies. Though it has allowed most of the developed and developing countries to reduce the share of OC through increasing operational energy efficiency, it has caused the proportion of EC in the total carbon emission of buildings to increase (RICS, 2012). With the recognition of that, reducing EC emissions of buildings has presently received much attention of environmentally advanced developed countries (RICS, 2012). However, the existing literature indicates that the impact of EC emissions has not yet been fully recognised in developing countries and as a result, EC estimation and reduction have been overlooked.

Being identified that EC estimation is the drive towards EC reduction, this paper attempts to identify the potential for estimating EC emissions of buildings in developing countries. For that purpose, the paper explores a case study of office building located in Western Province in Sri Lanka.

Sri Lanka is a developing country which has recently taken number of initiatives in promoting sustainable/green buildings in the country (Green Building Council, 2015). That can be considered as a prudent step in achieving the carbon reduction target (20% from energy sector and 10% from other sectors by 2030) which has been set in compliance with Paris Agreement in 2016 (Climate Change Secretariat, SL, 2017). As a main initiative, Green Building Council of Sri Lanka, the leading authorised body in promoting green buildings has introduced Green SL rating system for built environments in 2015. Though, there are many provisions for OC emission reduction, there are no direct provisions to account EC emissions. Therefore, it was considered Sri Lanka as an appropriate developing country to conduct this study.

The paper is organised into six main sections. The first section briefly introduces the aim of the study. Then, it discusses the literature findings in two sections as significance of EC in buildings and EC estimation. The methodology adopted to conduct the research is presented under the research method section. The subsequent section presents the research findings and analysis and final section draws the conclusions.

SIGNIFICANCE OF EMBODIED CARBON IN BUILDINGS

A building, within its whole life cycle emits two types of carbon namely; operational and embodied carbon (RICS, 2012). Operational Carbon (OC) is the emission occurs during the operational phase of a building and is typically generated from operational energy use for heating, cooling, ventilation, lighting, ICT equipment, cooking and refrigeration appliances etc. (RICS, 2014). Due to various measures that have been taken to regulate operational carbon of buildings during last few decades, building owners have been able to increase the efficiency of operational energy and carbon, creating the EC share of whole life cycle carbon of buildings to increase largely (RICS, 2014).

EC is the emission released during the production of a building material, component, or the entire building. It encompasses carbon emitted during material extraction, transportation, manufacturing, distribution, construction/assembly, building maintenance, construction demolition and disposal (RICS, 2012). Unlike OC which has the opportunity to improve at any point in the lifetime of a building by implementing a range of energy efficiency measures, embodied carbon cannot be reversed. Once they have been released the opportunity for improvement has passed (Jones, 2016).

Figure 1 indicates the proportion of OC and EC to the whole life cycle carbon of three types of buildings. According to that, typical buildings (Office, supermarkets and semi-detached houses) account for 80% of OC and only 20% of EC. However, when the buildings transform from typical buildings to either low carbon or zero carbon buildings, it indicates that the EC proportion has increased, making it as the main type of carbon to be managed.

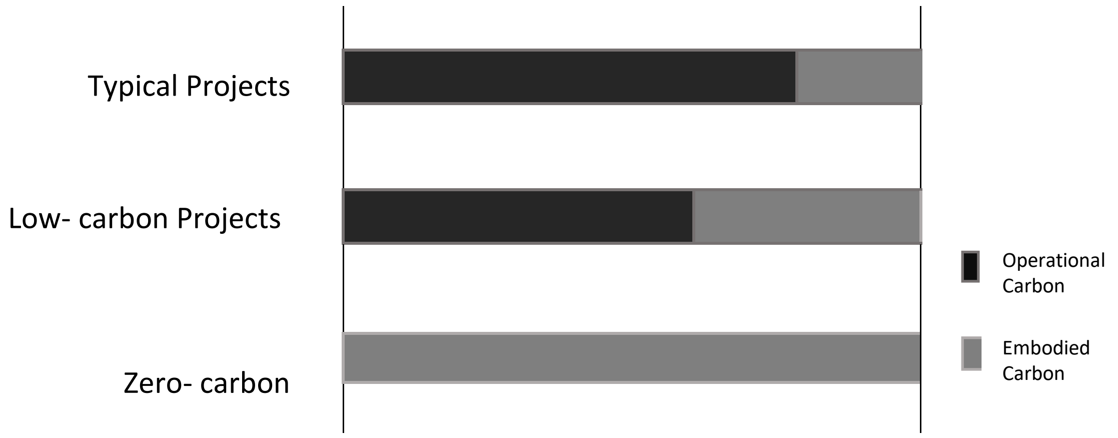

Figure 1: Proportion of OC to EC
(Adapted from: RICS, 2012)

Another factor that makes the EC important is the target set by Paris Agreement (UNFCC, 2016) to ensure that every single building produces zero carbon emissions by 2050. It has been able to gain the attention of both the construction sector and the governments of environmentally advanced countries such as the Western Europe, Australia, New Zealand, Canada, and the USA towards EC reduction (WGBC, 2017).

Embodied Carbon Estimation

The main drive towards EC reduction is carbon estimation (Nawarathna et al., 2018). Unlike OC estimation practices, EC estimating is not yet a developed process (Victoria and Perera, 2018). Despite a growing set of guidance that have been introduced by European standards, national organisations and professional bodies (Giesekam and Pomponi,2017), the existing literature presents many challenges in estimating EC such as unavailability of a standardised methodology, difficulty in choosing an estimation boundary, lack of national databases for carbon emission factors, out of date assessment tools, lack of open source assessment tools, benchmarks and EC data (Nawarathna et al., 2018).

EC emission is associated with all the phases of a building life cycle. Although it is important to account all lifecycle stages in the assessment to get an accurate total EC emission for a building, limited data availability (mainly the EC co-efficient values of building materials and activities) has made to define a measurement boundary prior the estimation. As it is illustrated in Figure 2, there are five system boundaries in EC estimation namely; cradle (earth) to gate (manufacturing factory gate), cradle to site (construction site), cradle to end of construction, cradle to grave (demolition), or even cradle (earth) to cradle (reuse, recycle and recovery) (RICS,2012).

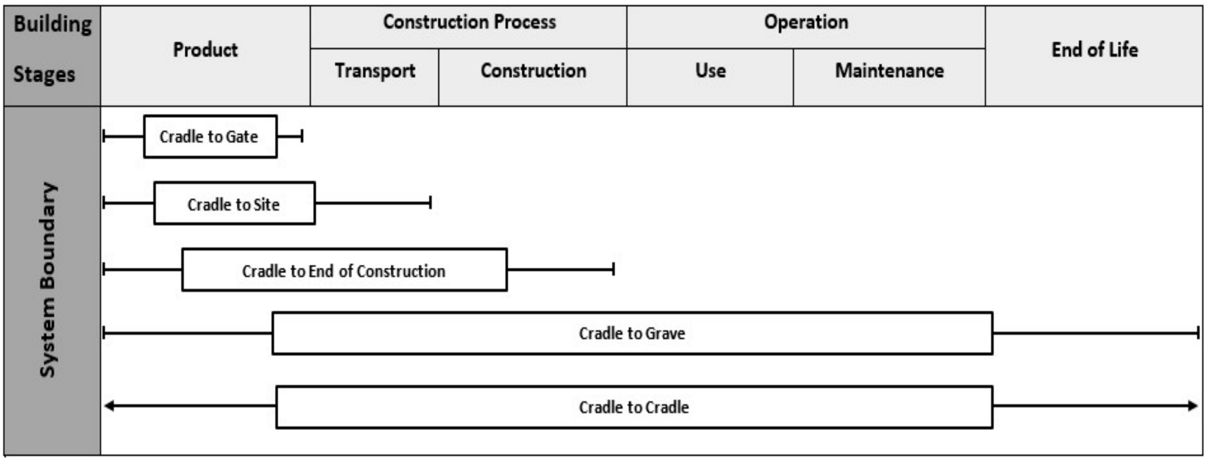

Figure 2: System Boundaries of EC Estimation
Adapted from: RICS (2012)

In association with EC estimation, few EC coefficient databases have been developed. However, almost all of them cover only the cradle to gate system boundary and they have failed to include emissions from latter stages of life cycle (such as construction, operation & maintenance and demolition & disposal) as they are project specific emissions (Hammond and Jones, 2011). Few examples of EC inventories are shown in Table 1.

Table 1: EC Inventories
Adapted from: Nawarathna et al., (2018)

Inventory/Database	Access	System Boundary	Country
Bath Inventory of Carbon and Energy	Open	Cradle to Gate	UK
Athena Life Cycle Inventory Product Databases	Licensed	Cradle to Gate	USA, Canada
New Zealand Building Materials Embodied Energy Database	Open	Cradle to Gate	New Zealand
Hutchins UK Building Black book	Licensed	Cradle to Gate	UK
European Life Cycle Database (ELCD)	Open	Cradle to Gate	Europe
EcoInvent 3.3	Licensed	Cradle to Gate	Switzerland
ÖKOBAUDAT (German National Database)	Open	Cradle to Gate	Germany
AusLCI	Open	Cradle to Gate	Australia

Even with many challenges and limitations as mentioned above, studies are being conducted to estimate the EC in various buildings under different system boundaries. Table 2 summarises some of those prior studies that have been conducted to the UK context.

The scope of all these studies have mainly limited to the carbon hotspots which have been mentioned by the RICS (2014). RICS (2014) recommends that substructure (foundations, basement retaining walls and ground floor construction), superstructure (frame, upper floors, roof, stairs and ramps, external walls, windows and external doors, internal walls and partitions), internal finishes (wall finishes, floor finishes, ceiling finishes) and external works as carbon hotspots that fundamentally need to be included in EC calculations.

It is to be further noted that all these assessments have been conducted during the use stage of buildings due to the data availability. Though it is easy to estimate the EC at this stage as most of the required data are available, it limits the opportunity to implement EC reduction strategies. Therefore, RICS (2012) recommends to exercise EC estimation during early stage of design in order to achieve high EC emission reduction.

Table 2: Previous EC Studies

Study	System Boundary	Type of Buildings
Pomponi, Moncaster and Wolf (2018)	Cradle to Gate	An Office building Refurbished residential Transport Infrastructure, Residential and a Retail
Hakkinen et al. (2015)	Cradle to Gate	A Residential building
Victoria et al. (2015)	Cradle to Gate	An Office building
Sansome and Pope (2012)	Cradle to Grave (excl. maintenance and deconstruction)	Five types of commercial buildings (Distribution Warehouse, Supermarket, Secondary School, Office, Mix Development)
Target Zero (2012)	Cradle to Grave	An Office building
Bennett (2010)	Cradle to Site	Two typical office buildings
Sturgis and Roberts (2010)	Cradle to Grave	An Office building

RESEARCH METHOD

This study analysed the EC of an office building located in the Western province in Sri Lanka. Since most of the prevailing EC studies have been conducted to carbon intensive building elements, this study was also focused on carbon hotspots, but limited to main structural elements that make the skeleton of a building. Accordingly, it was selected the substructure, frame, upper floors, external walls and roof in compliance with BCIS element classification.

This study was limited to the cradle to gate system boundary. The Bills of Quantities (BOQs) and architectural drawings of the building were refereed to obtain the building specific data such as used building materials with their quantities and building morphology parameters.

Due to the unavailability of an up-to-date country specific EC- coefficient database, two databases were adapted; an international level one (the Inventory of Carbon and Energy (ICE) version 2.0, 2011) and a national level one which has been developed by Poliyadda (2000). Although the latter is a national level database, it is relatively an older database which has not been recently updated and does not provide EC co-efficient for all materials. Therefore, only the data of country specific production materials such as sand, random rubble, bricks and timber were taken from that and the rest were extracted from ICE (2011). The materials and their quantities which were provided in various units (m^3, m^2, tonnes, and m) were converted in to mass in kilogram to comply with adapted EC databases and to maintain the consistency of the estimation. The conversion was based on the BS 648:1964: Schedule of weights of building materials. Eventually, the estimation was conducted using Equation *(1)* and MS- Excel software.

$$TEC_{SE} = EC_{sub} + EC_{fr} + EC_{uf} + EC_{Ew} + EC_{rf} \quad (1)$$

Where, TEC_{SE} is Total Embodied Carbon of structural elements; EC_{sub} is Embodied Carbon of substructure; EC_{uf} is Embodied Carbon of upper floors; EC_{fr} is Embodied Carbon of frame; EC_{ew} is Embodied Carbon of external walls and EC_{rf} is Embodied Carbon of roof

RESEARCH FINDINGS AND ANALYSIS

Case Description

The selected building was an office building located in the Colombo suburbs, Western province in Sri Lanka. It is a building in which the building foot print covers 866.29 m^2 and extended vertically over 19.017 m. It accommodates 4 stories including the ground floor while providing internal total gross floor area of 2629.26 m^2. The vertical and horizontal structural beams and columns have been strengthened using reinforced concrete in which a raft foundation width stand the structural load of the building and its other associate forces. Calicut tiles have been used to cover the roof area of 615.29 m^2 of the building while brick work being used to cover the building face area of 607.13 m^2. The main building materials that have been used for the selected structural elements are listed in Table 3.

Table 3: Building Materials used for Structural Elements

Building Element	Main Building Materials
Substructure	Concrete (G 15), Reinforced Concrete (G 25) Mortar, Rubble, Sand, DPC
Frame	Reinforced Concrete (G 25)
Upper floors	Reinforced Concrete (G 25), DPM
External Walls	Bricks, Mortar
Roof	Reinforced Concrete (G 25), Steel, Timber, Calicut Clay Tiles, PVC (110mm)

Elemental EC Emissions

Table 4 and Figure 3 present the total elemental EC and EC per Gross Internal Floor Area (GIFA) of the building. As per RICS (2012), GIFA is used as a standard metric for benchmarking, estimating and cost planning purposes in the construction sector. Further, they mention that it is a clear measure for comparison across all buildings all buildings regardless of their function, design or specification. Therefore, EC per GIFA of the elements of this building was also calculated for the purpose of comparison with other studies.

Table 4: Elemental EC emissions

Elements	Elemental EC ($kgCO_2$)	EC per GIFA ($kgCO_2$/m2)
Substructure	**217,407**	**82.68**
Frame	**95,977**	**36.50**
Upper floors	**150,760**	**57.33**
Roof	**29,111**	**11.072**
External Walls	**9,268**	**3.525**
Total	**502,523**	**191.11**

The fingdings revealed that substructure emits 82.68 of EC $kgCO_2/m^2$, placing it on the top of the elemental embodied carbon emission hierarchy of this case study. This is mainly due to the heavy use of steel and concrete (two types of high carbon intensive materials) in the substructure compared to other elements. The rest of the structural elements; upper floors, frame, roof and external walls placed respectively in the hierarchical order. Accordingly, it was identified that the highest carbon intensive element of this building is the substructure.

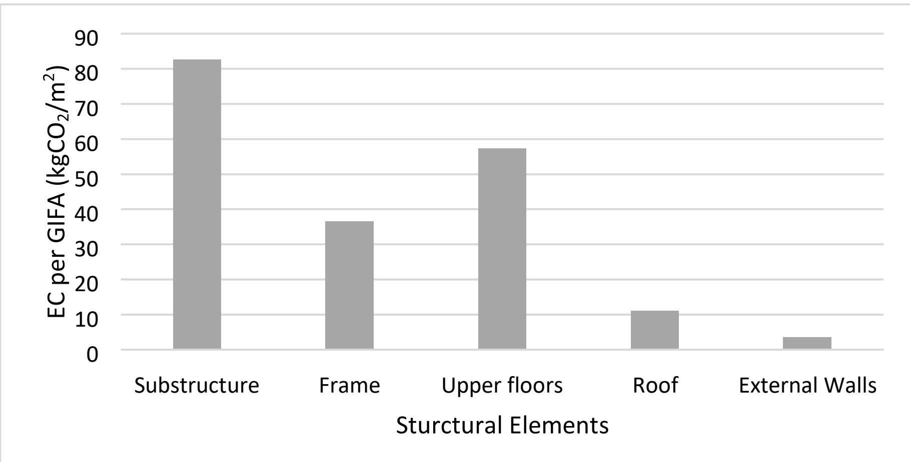

Figure 3: Elemental EC Emissions

Even when analysing the studies that have been mentioned in the Table 2, it was noted that substructure is the highest carbon intensive element among these five main structural elements, regardless of the type, location of the building and the system boundary of the estimation. However, it was difficult to understand the elemental hierarchy of these studies, as most of them have considered upper floors, external walls, frame and roof under the category of superstructure.

For the purpose of comparison, author was able to find out a similar type of case study which has been carried out for an office building located in the UK by Victoria et al., (2015) under the same system boundary of cradle to gate. Compared values are presented in Table 5. It indicates that the hierarchy of the carbon hotspots is different, though the both studies have been carried out to the same type of building within the same system boundary. RICS (2014) mentions that carbon hotspots and the hierarchy may vary from one project to the other and from one building to the other due to heterogeneity of projects.

Table 5: Hierarchy of Elements

Base Case Study (SL)		**Victoria (2015) UK**	
Substructure	43%	Substructure	47%
Upper Floors	30%	Upper Floors	22%
Frame	19%	Frame	21%
Roof	6%	External Walls	9%
External Walls	2%	Roof	1%

Challenges Encountered

The main purpose of this study was to understand the potential for estimating the EC of buildings in developing countries. Such estimation was not straightforward, and several challenges were encountered.

First, the major challenge was the unavailability of an up- to- date EC co- efficient database with all building materials for Sri Lankan context. Therefore, the study adopted two databases as necessary. This emphasised the necessity of a new national level database to estimate the EC accurately.

Another challenge confronted was the need to identify building materials and separate them into structural elements and then convert the various material unit quantities in to mass (kg) to comply with EC databases. This was time consuming and work intensive activity. As the BOQs of the selected case study was in compliance with NRM and the EC values in the inventories were for building materials, there might be missed materials in the estimation.
However, care was given not to exclude any significant item or material from the estimation.

CONCLUSIONS

The significance of EC estimation and reduction of buildings in the developing countries are yet to be fully realised. Therefore, this study was conducted to understand the possibility of conducting EC estimation to developing countries.

The EC estimation process revealed that estimation is yet a challenging process to a developing country like Sri Lanka. It pointed out the necessity of a country specific, up to date database for material EC co-efficient in order to achieve realistic EC estimation. Therefore, further researches are required to explore and develop the existing country specific database. Further, it emphasised the necessity of a straightforward estimation method as the method used in this study was complex and time consuming.

Similar to previous studies, the findings of this study also revealed that the highest embodied carbon intensive structural element is substructure. That may be mainly due to use of extensive amount of concrete and steel in which the carbon contents are very high. Therefore, it is recommended to design the buildings with less quantities of materials and use alternative low carbon materials to save EC emissions in substructure. Few studies have been conducted in Sri Lanka to identify alternative materials with lower embodied carbon emissions yet, further researches are required to explore more design and material alternatives.

This study was conducted as a pilot study of an ongoing research. It limited to cradle to gate system boundary and structural elements of the selected building. Stairs and ramps, doors and windows, internal walls and partitions, internal finishes, fittings, furnishings and equipment, services and external works were excluded. Therefore, future work can be extended to incorporate these areas as well to provide more representative value for the overall and elemental EC emissions of the building.

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