AUTHOR(S): FERNANDO, N.G., EKUNDAYO, D.O. and VICTORIA, M.F.

TITLE: Embodied carbon emissions of buildings : a case study of an apartment building in the UK.

YEAR: 2018

Publisher citation: FERNANDO, N.G., EKUNDAYO, D.O. and VICTORIA, M.F. 2018. Embodied carbon emissions of buildings : a case study of an apartment building in the UK. Presented at the 7th World construction symposium 2018: built asset sustainability; rethinking design, construction and operations, 29 June - 01 July 2018, Colombo, Sri Lanka.

OpenAIR citation: FERNANDO, N.G., EKUNDAYO, D.O. and VICTORIA, M.F. 2018. Embodied carbon emissions of buildings : a case study of an apartment building in the UK. Presented at the 7th World construction symposium 2018: built asset sustainability; rethinking design, construction and operations, 29 June - 01 July 2018, Colombo, Sri Lanka. Held on OpenAIR [online]. Available from: https://openair.rgu.ac.uk

EMBODIED CARBON EMISSIONS OF BUILDINGS: A CASE STUDY OF AN APRARTMENT BUILDING IN THE UK

Nirodha Gayani Fernando* and Damilola Ekundayo
School of the Built Environment, University of Salford, UK

Michele Florencia Victoria
School of Architecture and Built Environment, Robert Gordon University, UK

*Corresponding Author: E-mail-N.G.Fernando1@salford.ac.uk, Tel-0161 2954382

EMBODIED CARBON EMISSIONS OF BUILDINGS: A CASE STUDY OF AN APRARTMENT BUILDING IN THE UK

ABSTRACT

The UK government has set a target to significantly reduce UK greenhouse gas emissions by 2050. 47% of all UK CO2 emissions are linked to the construction and operation of the built environment. Buildings emit two types of carbon namely operational carbon (OC) and embodied carbon(EC). Operational carbon is regulated in the UK as it contributes up to 70-80% of total emissions. Further, EC reduction is top priority with the rise of demand for zero carbon buildings and EC is unregulated at present. EC can be controlled by vigilant building designs, selection of low carbon materials and technologies. Estimating EC of building will provide better understanding of the carbon significant elements and enable designers to make informed decisions. Accordingly, a case study of an apartment building located in Sunderland in the UK is selected for the study. EC estimates were prepared using priced Bill of Quantities of the building and carbon blackbook. Then, the building elements were classified as per BCIS (Building Cost Information Services) element classification and the carbon significant elements were identified in the case study building. Frame was identified as the most carbon significant element. External walls including windows and doors, upper floors, substructure, internal finishes, roof and internal walls & partitions were identified in descending order of carbon significant elements. Further, comparative analysis of EC between an apartment building and an office building was conducted. The office building carbon significant elements were found to be different from that of an apartment building. Findings of the case study building can inform designers about the elements that has an immense reduction potential and worth investing in low carbon technologies and materials. However, the findings are based on a single case study and, hence, cannot be generalised but can be seen as an exemplar for further research.

Keywords: *Apartment Building, Building Elements, Carbon Significant, Embodied Carbon*

1. INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC) (2014) report states that continued emissions of carbon will lead to a drastic change in climate and increase in temperature by 1.5 °C – 2 °C by the end of the 21st century. Therefore, it has become an utmost priority in the world to reduce carbon emissions (Chau *et al*., 2015). Further to the Kyoto protocol and then the Paris agreement by UNFCC in 1998, 2012 and 2016 respectively, building sector was identified as an inevitable sector with regard to its high emission contribution and high emission saving potential in the short term (IPCC, 2014). Accordingly, low carbon building transition plans started all around the world allowing most of the developed and developing countries to reduce the operational carbon emitted from buildings through increasing operational energy efficiency (RICS, 2014). However, it caused the proportion of embodied carbon in the total carbon emission of buildings to increase. With the recognition of that, the attention of environmentally advanced developed countries has now shifted towards reducing embodied carbon emissions of buildings (RICS, 2014). Building sector is known to be one of the largest contributors to the global carbon emissions. It is responsible for more than one- third of total energy use and 30% of global carbon emissions (Peng, 2015).

Embodied Carbon is the total greenhouse gas (GHG) emissions (often simplified to "carbon") generated to produce a built asset (UK Green Building Council, 2017). This includes emissions caused by extraction, manufacture/processing, transportation and assembly of every product and element in an asset. In some cases, depending on the boundary of an assessment, it may also include the maintenance, replacement, deconstruction, disposal and end-of-life aspects of the materials and systems that make up the asset (UK Green Building Council, 2017). Energy use in residential in the UK accounts for 27 percent of carbon emissions. Therefore, improving energy efficiency and using renewable energy in housing stock presents a great opportunity to contribute towards the 2050 target of an 80 per cent reduction of greenhouse gas emissions. In 2007 the UK government proposed tightening building regulations to achieve the carbon reduction from residential sector - first by 25%

in 2010, and then by 44% three years later. However, it is not yet achieved due to numerous barriers. This paper attempts to identify the possibility of estimating embodied carbon emissions of apartment buildings in the UK, so that necessary actions can be taken to manage the environmental impact of buildings and therefore increase the awareness/significance of embodied carbon counting. The paper also explores and compares the embodied carbon of an apartment building with that of an office building in the UK.

2. EMBODIED CARBON

A building emits two types of carbon during its life cycle, i.e. operational and embodied carbon (RICS, 2014). Operational Carbon (OC) is the emission generated during the operational phase of a building as a result of the operational energy used for heating, cooling, ventilation, lighting, ICT equipment, cooking and refrigeration appliances etc. (RICS, 2014). Embodied Carbon (EC) is 'Carbon emissions associated with energy consumption (embodied energy) and chemical processes during the extraction, manufacture, transportation, assembly, replacement and deconstruction of construction materials or products' RICS (2014, p. 5). EC emission during the lifetime of a building is shown in Figure 2.1. EC can be categorised into three types such as Initial EC (raw material extraction, manufacturing, transport and construction), recurring EC (in-use EC such as repair, maintenance and replacement) and Demolition EC (EC during demolition). EC can be minimised due to recycling of scrap materials or products after demolition.

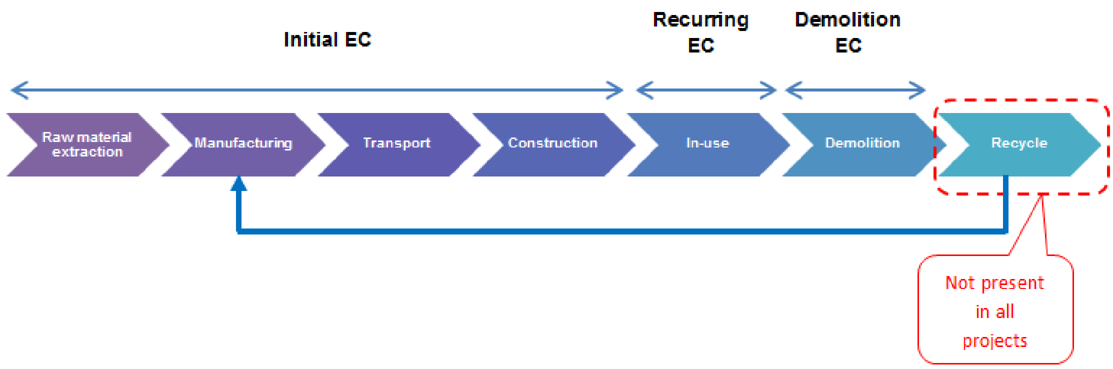

Figure 2.1: EC in a building life cycle

Source: Victoria (2015)

According to RICS (2014), EC emissions are calculated from cradle (earth)-to-gate, cradle-to-site, cradle-to-end of construction, cradle-to-grave or cradle-to-cradle stages (See Figure 2.2). There are many EC datasets available in the UK (Hammond and Jones, 2011a). Hammond & Jones (2011b) and Sansom & Pope (2012) highlighted that many embodied carbon datasets available are cradle-to-gate and they opined that it can be unsuccessful to include emissions from later stages of life cycle (such as construction, operation & maintenance and demolition & disposal) due to project specific emissions. Mode of transport and type of fuel also plays a significant role, in reducing carbon emissions, other than the distance of travel (RICS, 2014; Sundarakani *et al.*, 2010).

Stages	Product	Construction Process		Operation		End of Life
		Transport	Construction	Use	Maintenance	

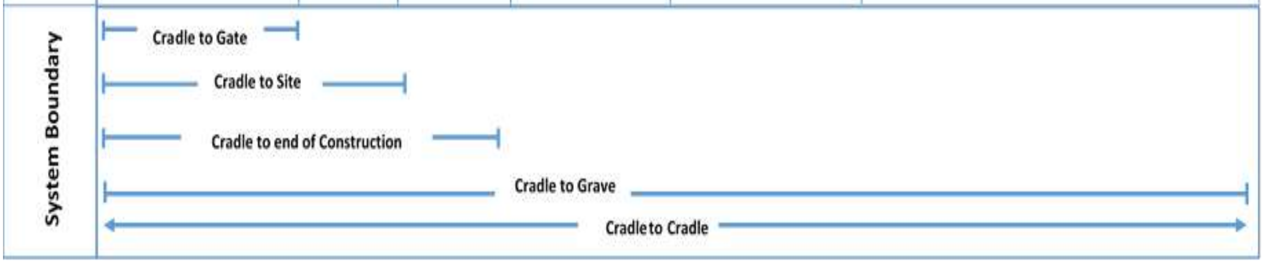

Figure 1.2: System Boundaries of EC Estimation

Adapted from: RICS (2014)

According to Figure 2.3, approximately 80% of initial EC can be reduced before construction commenced (Asiedu & Gu, 1998). As more carbon is committed into the project, the reduction potential decreases rapidly as possible design solutions are constrained by previous design decisions. Then, during construction phase, the reduction potential can be considered as nearly zero unless there is a design change. Therefore, EC reduction action has to be considered during the initial stage of a project before construction commences. In order to reduce EC in a project, careful investigation is essential to identify the most carbon intensive elements and materials used for those elements. Accordingly, this study was conducted to identify the EC intensive building elements and materials used for those elements.

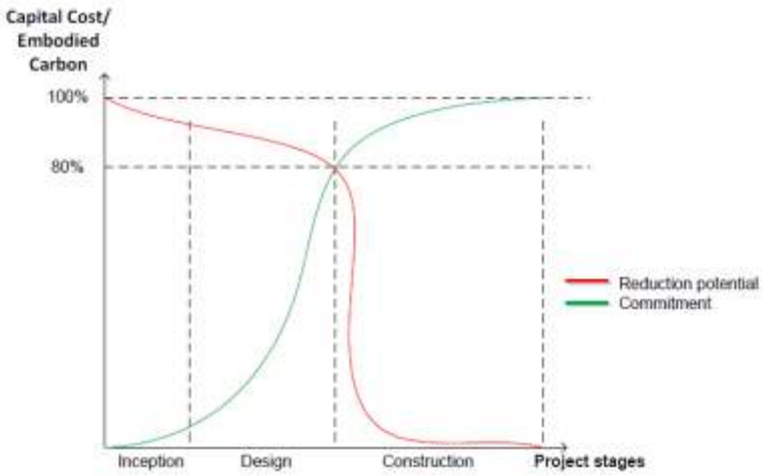

Figure 2.3: EC over project stages

Source: Victoria (2015)

3. RESEARCH METHOD

Research approaches can be mainly categorised as quantitative, qualitative and mixed approaches. According to Fellows and Lui (2003) quantitative approach is inclined to collect factual data and to study relationships between facts and how such facts relate to theories and the findings of any research executed previously. The study analysed the embodied carbon of an apartment building located in Sunderland, UK. Hence, quantitative approach has been selected for the study as the most suitable approach as the study intends to collect factual data. An apartment building has selected as a case study and this provides an in-depth enquiry of the research problem. Furthermore, Yin (2009) found that case studies would provide an opportunity to gain holistic view of the research problem. This approach also helps to understand and explain a research problem or situation (Baxter and Jack, 2008). Hence, the justification for the single case study approach used in this paper and subsequent research in this area can build on this work.

The main building elements such as substructure, frame, upper floors, roof, external walls, internal walls & partitions and internal finishes were considered to calculate the embodied carbon in the study. The selected elements are compliant with BCIS element classification. This study was limited to the cradle to gate system boundary for a residential and a commercial building, and not all building elements were selected due to resource constraints including data availability. The details required to calculate the embodied carbon were obtained from priced Bills of Quantities (BoQs), and technical specifications of the case. Building Blackbook was used to calculate the embodied carbon of building elements. This is one of the limited available resources produced in BoQ format for calculating building embodied carbon (Franklin and Andrews, 2011).

Firstly, building items of works from BoQ were identified for each work section. After that, the building blackbook was used to calculate each work item's embodied carbon. The following formula has been used to calculate the total EC for each element.

$$CO_2\ embodied\ of\ an\ element = \sum_1^i CO2 embodied\ of\ a\ BoQ\ item, i$$

Here;

CO2 embodied of an element is embodied carbon of an element

CO2 embodied of BoQ item *i* is the amount of embodied carbon of the *i* th BoQ item in the building

4. RESEARCH FINDINGS

The building studied is a three-storey apartment building in Sunderland, UK. The newly constructed building has a reinforced concrete structure, L shape building and it includes three floors. Ground floor and first floor have 6 flats each and the second floor has 5 flats. There are three lifts in the building. The main characteristics of the case study building are given in Table 1.

Table1: characteristics of the case study building

Building Parameter	Specifications
Building area	12660 m^2
No. of floors	Three- storey apartment building
Foundation	Pad foundation with Reinforced in situ concrete Grade C35, 20mm
Frame	Streel frame and concrete
Upper floors	In situ concrete grade C35 with A193 mesh reinforcement, to holorib decking
External walls	Cavity wall brick and blockworks- Engineering brickwork, Class B, mortar (1:4), stretcher bond, half brick thick external face of external wall. Concrete blockwork, 7N/mm2 compressive strength, mortar (1:4) , 140mm thick internal face of the external wall
Internal walls	Gyproc Gypwall metal stud partition system as K10-129
Roof	Pitched roof 40^0 angle, Interlocking concrete roof tiling, Marley Modern, 50x25mm battens, metal roof cladding tile support panel system, H65-120
Internal finishes	Wall lining, 12.5mm thick plasterboard fixed to blockwork with adhesive dabs, 3mm thick plaster skim coat finish

	Quarry tiling, 150 x 150 x 12mm units, fixing with approved adhesive, white grout, concrete surfaces Fitted carpeting, basic cost £20.00/m2, adhesive taped joints, laid loose on and including approved underlay, concrete surfaces Suspended ceiling system lay in grid 600 x 600mm in Trulok 24 grid Armstrong Dune Max Tegular K40 - 115

The embodied carbon content of a three-storey apartment building was considered as the case study and the implications of the results were discussed in this section.

Table 2 presents the elemental EC and EC per Gross Internal Floor Area (GIFA) of each element 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. It is a clear measure for comparison across 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 2: embodied carbon of each building element

Building Element	Total EC	EC per GIFA	% of total EC
Substructure	900,180.07	71.1	17%
Frame	1,470,573.79	116.2	27%
Upper Floors	958,598.86	75.7	18%
Roof	263,800.08	20.8	5%
External Walls including Curtain Wall, External Windows and Doors	1,163,574.24	91.9	22%
Internal Walls & Partitions	50,670.29	4.0	1%
Internal Finishes Including Floor Wall and Ceiling Finishes	587,885.94	46.4	11%

The findings revealed that frame emits 116.2 of EC kgCO2/m2, 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 frame compared to other elements. The remaining elements such as external walls including external doors and windows, upper floors, substructure, internal finishes, roof, and internal walls and partitions place respectively in the hierarchical order. Further, Table 3 presented the different items included in the “frame” element and the embodied carbon of each item. According to Table 3, structural steel frame identified as the highest EC among other components in the frame. Main reason is steel is a major carbon hotspot.

Table 3: Items included in the frame

Components included in the Frame	EC- KgCO2
Structural Steel Frame	893,772.744
Timber Glulam beams to Main Entrance Foyer and Main Hall	25,088.660
Connections between steel and Glulam Structures	85.897

Components included in the Frame	EC- KgCO2
Fire protection Intumescent paint to steel members to give 1Hr protection	
203x203x52UC columns	164,747.544
406x178x54UB columns	18,039.802
Underside of first floor or roof slab	
178x102x22 UB	19,012.963
254x102x22 UB	29,038.706
305x102x25 UB	35,041.080
305x102x28 UB	4,778.659
305x102x33 UB	107,547.066
406x140x39 UB	50,628.006
406x140x46 UB	19,793.671
457x152x52 UB	62,028.158
457x152x60 UB	21,787.200
356x127x39 UB	5,735.480
457x152x67 UB	4,500.872
838x292x176 UB	8,947.277

According to Table 2, the second highest EC element is external walls including curtain wall, external windows and doors. The external wall is a cavity wall comprising brick and blockwork. Aluminum doors, windows and glazing curtain walls are also included in this element. Due to the high EC of glazing and aluminium, the second highest carbon hotspot element of the building is external wall including external doors and windows.

For the purpose of comparison between embodied carbon of an office building and an apartment building in the UK, a similar type case study was used. The previous case study, by Victoria *et al*. (2015), examined an office building located in the UK under the same system boundary of cradle to gate. Although both studies have been carried using the same system boundary, the hierarchy of the carbon hotspots vary from building to building (see Table 4). This aligns with previous study in this area. It was highlighted in RICS (2014) that carbon intensive elements and their hierarchy may vary from one project to the other and from one building to the other due to heterogeneity of projects. According to the comparison between apartment building and office building “frame” was identified as the highest EC building element. For both projects, the “frame” consists of steel and concrete, which are carbon hotspots. The second highest EC element is external wall (including Curtain wall, external doors and windows) in an apartment building and substructure in the office building. The eight-storey office building has a GIFA of 11,320 m2 with a basement. The basement consists of concrete and steel, which gives the high EC. The third highest EC element was upper floors in both buildings. While the least EC building element was internal wall and partition in the apartment building and roof in the office building. The variance in the carbon hotspots is mainly due to the different types of materials used in the apartment building and office building. For example, the apartment building has a pitched roof with an interlocking concrete roof tiling while the office building has a flat roof. However, considering both the office building and the apartment building, EC KgCO2 per m2 is higher in the apartment building than in the office building, mainly due to the building footprint of the apartment building being greater than that of the office building.

Table 4: Comparison of EC between Apartment building and office buildings

Building Element	**Apartment Building EC per GIFA ($KgCO_2/m^2$)-current study**	**Office Building EC per GIFA ($KgCO_2/m^2$)- Victoria *et al*. (2015)**
Substructure	71.1	179.9
Frame	116.2	203.9
Upper Floors	75.7	97.5
Roof	20.8	16.4
External Walls including (Curtain wall, external doors and windows)	91.9	27.3
Internal Walls & Partitions	4.0	34.1
Internal Finishes Including Floor Wall and Ceiling Finishes	46.4	36.3

5. CONCLUSIONS

The research findings identified that the highest EC element in the case study apartment building is frame, due to high usage of steel and concrete. The lowest EC element was identified as internal walls and partitions, constructed using Gyproc Gypwall. Gyproc Gypwall emits less carbon. When comparing apartment building and office building, order of carbon significant elements is different. However, it is evident that when high amount of steel and concrete is used in any element, it increases the EC. However, the apartment building GIFA is lower than that of the office building, KGCO2/m2 of element in the apartment building is higher than that of the office building. The research findings highlighted the building elements that has high carbon reduction potential over the others that need more focus during the design development. The hierarchy of carbon significance of elements varies between different types of buildings with similar design features due to the difference in their specifications. This displays the complexity of achieving carbon optimum design solutions. In order to reduce carbon, careful selection of building materials and optimum design solutions is recommended. This is because carbon reduction potential can be maximised if the building envelope uses low carbon intensive materials other than steel and/or concrete, which are considered as carbon hotspots.

6. REFERENCES

Asiedu, Y., & Gu, P. (1998). Product life cycle cost analysis: State of the art review. International Journal of Production Research, 36(4), 883-908. doi: 10.1080/002075498193444

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report*, *13*(4), 544-559.

Chau, C.K., Leung, T.M. and Ng, W.Y., (2015). A review on life cycle assessment, life cycle energy assessment and life cycle carbon emissions assessment on buildings. *Applied Energy*, 143, 395- 413.

Fellows, R. and Liu, A., (2003. *Research methods for construction* (2nd ed.). Oxford: Blackwell publishing.

Franklin & Andrews. (2011). Hutchins UK Building Blackbook: The Cost and Carbon Guide : Hutchins' 2011: Small and Major Works. Croydon: Franklin & Andrews.

Hammond, G.P. & Jones, C.I. (2011a). A BSRIA guide Embodied Carbon The Inventory of Carbon and Energy (ICE). UK: BSRIA.

Hammond, G.P. and Jones, C.I. (2011b) *Embodied carbon. The inventory of carbon and energy (ICE)*, in Lowrie, F and Tse, P. (ed.), BSRIA.

Intergovernmental Panel on Climate Change (IPCC) (2014) *Climate change 2014; Impacts, adaptability and vulnerability*. IPCC WGII AR5.

Peng, C. and Wu, X. (2015). Case study of carbon emissions from a building's life cycle based on BIM and Ecotect. *Advances in Materials Science and Engineering*. 2015.

RICS (2012) Elemental standard form of cost analysis principles, instructions, elements and definitions. 4th (NRM) ed. London: BCIS.

Royal Institution of Chartered Surveyors (2014) Methodology to calculate embodied carbon, RICS professional guide, 1st ed. Coventry: RICS.

Sansom, M., & Pope, R. J. (2012). A comparative embodied carbon assessment of commercial buildings. The Structural Engineer, October, 38-49.

Sundarakani, B., de Souza, R., Goh, M., Wagner, S. M., & Manikandan, S. (2010). Modeling carbon footprints across the supply chain. International Journal of Production Economics, 128(1), 43-50. doi: 10.1016/j.ijpe.2010.01.018

UK Green Building Council, 2017. Embodied Carbon: Developing a Client Brief [online]. UK green building council, available from: https://webcache.googleusercontent.com/search?q=cache:fHCmvR6mM6cJ:https://www.ukgbc.org/sites/default/files/UK-GBC%2520EC%2520Developing%2520Client%2520Brief.pdf+&cd=1&hl=en&ct=clnk&gl=uk&client=safari [Accessed 16th May 2018].

Victoria, M. F., Perera, S and Davies, A. (2015) Developing an early design stage embodied carbon prediction model: A case study In: Raidén, A B and Aboagye-Nimo, E (Eds) Procs 31st Annual ARCOM Conference, 7-9 September 2015, Lincoln, UK, Association of Researchers in Construction Management, 267-276.

Yin, R. K. (2009). *Case study research: Design and methods*, 4th ed. Thousand Oaks, CA: Sage.