Reasons for the Slow Uptake of Embodied Carbon Estimation in the Sri Lankan Building Sector

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***Abstract*—**Global carbon reduction is not merely a responsibility of environmentally advanced developed countries, but also a responsibility of developing countries regardless of their less impact on global carbon emissions. In recognition of that, Sri Lanka as a developing country has initiated promoting green building construction as one reduction strategy. However, notwithstanding the increasing attention on Embodied Carbon (EC) reduction in the global building sector, they still mostly focus on Operational Carbon (OC) reduction (through improving operational energy). An adequate attention has not yet been given on EC estimation and reduction. Therefore, this study aims to identify the reasons for the slow uptake of EC estimation in the Sri Lankan building sector. To achieve this aim, 16 numbers of global barriers to estimate EC were identified through existing literature. They were then subjected to a pilot survey to identify the significant reasons for the slow uptake of EC estimation in the Sri Lankan building sector. A questionnaire with a three-point Likert scale was used to this end. The collected data were analysed using descriptive statistics. The findings revealed that 11 out of 16 challenges/ barriers are highly relevant as reasons for the slow uptake in estimating EC in buildings in Sri Lanka while the other five challenges/ barriers remain as moderately relevant reasons. Further, the findings revealed that there are no low relevant reasons. Eventually, the paper concluded that all the known reasons are significant to the Sri Lankan building sector and it is necessary to address them in order to upturn the attention on EC reduction.

***Keywords*—**Embodied carbon emissions, embodied carbon estimation, global carbon reduction, Sri Lankan building sector.

I. Introduction

THE building sector is considered as a major energy consumer as well as a major culprit for the high presence of atmospheric carbon. At the global level, buildings account for 40% of energy use and 30% of energy based GHG emissions [1]. It has been estimated that these emissions will continue to rise further under a business- as- usual scenario [2].

A building, within its whole life cycle emits two types of carbon; namely, operational and embodied [3]. In a typical building, carbon in operation accounts about 70-80% of total life cycle while the difference remains as EC [3]. Owing to the larger share of OC, traditionally considerable efforts have been put forth to reduce the operational emissions [4]. However, the present evidences prove that the successful reductions of OC (due to improved operational performance) have tended to increase the share of EC in whole life cycle [5], [6]. As a result of that, EC emission estimation and reduction have become a great interest in sustainable and green building construction at present [7].

EC estimation is an initial step towards reducing EC of buildings. In view of that, many standards, assessment methods, tools and databases have been developed worldwide [8]. However, unlike the OC estimation, estimating EC is challenging.

Sri Lanka is a developing country which has initiated promoting sustainable/green buildings within the country in order to achieve its local and global carbon reduction targets [9]. However, most of its strategies have focused on reducing operational energy (and thus OC reduction) and the focus on EC reduction found very little in the existing literature. Other than few strategies introduced by Green Building Council [9] for EC reduction, no researches or any initiation found on EC estimation of buildings. The research conducted by Pooliyadda [10] on estimating EC values of few building materials is also not up-to-date and no further researches were conducted on it. Therefore, this study attempts to identify the reasons for this slow uptake of EC estimation, so that the necessary actions can be taken to mitigate them and increase the attention on EC reduction in Sri Lankan building sector.

This paper is organised into six main sections. Section I briefly introduces the aim of this paper. Section II presents the findings of literature review; mainly the challenges for/barriers to estimating EC in buildings. The methodology adopted to conduct the research is presented in Section III, while Section IV discusses the findings. Section V draws the conclusions, study limitations and future research, and eventually Section VI provides the list of references.

II. Literature Review

A. EC in Buildings

In the existing literature, EC has been subjected to various definitions and interpretations. According to RICS [3], EC is "the emissions associated with energy consumption (embodied energy) and chemical processes during the extraction, manufacture, transportation, assembly, replacement and deconstruction of construction materials or products are identified as embodied carbon". Moreover, WRAP [12] defines EC as "the carbon dioxide emissions associated with making a building, more precisely the greenhouse gas emissions that arise from the energy and industrial processes used in the processing, manufacture, and delivery of the materials, products and components required to construct a

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building". In addition, there are many other interpretations derived from many studies. Reference [6] has reviewed some of them and the review demonstrates that all these definitions represent the differences of opinion about the system boundaries used in the EC assessment.

Unlike the OC generation during the operational phase of a building, EC generates in all four phases of a building (product, construction, operation and end of life). Therefore, in estimating the EC of a building, measurement boundaries need to be defined. That is called system boundary of EC calculations and they are; cradle (earth)-to-gate (factory gate), cradle to-site, cradle-to-end of construction, cradle-to-grave, or even cradle-to-cradle (includes recycle, reuse etc.) [3].

The literature presents wide range of studies carried out to assess the present-day proportion of EC content of various types of buildings in many countries. A study conducted by RICS [3] to the UK context reveals that typical buildings such as supermarkets, offices and semi -detached houses are associated with 20-30% of EC of the total life cycle emissions. Further, researches conducted by [13], [14] also mention that about 20-30% of carbon emissions of typical residential and office buildings are from embodied emissions.

Accordingly, it is proved that OC emissions are much higher than embodied emissions in typical buildings. Contrary to typical buildings, RICS [3] mentions that the low energy incentive facilities such as warehouses accounts for 80% of EC emissions. Reference [13] further confirms this, stating that the low carbon buildings accounts for 9–46% of EC where the OC remains in a lesser value. Unlike both typical and low carbon buildings, zero carbon buildings emit zero OC in which the total carbon emits as EC [3].

B. EC Estimation: Existing Methodologies, Tools and Databases

Subsequent to the development of Inventory of Carbon and Energy (ICE) in 2008 and the initial information paper of Royal Institution of Chartered Surveyors (RICS) on EC calculation methodology in 2012, various methodologies, tools, data and databases in relation to EC estimation have been gradually developed [15].

TABLE I
EC ASSESSMENT TOOLS AND DATABASES/INVENTORIES

	Tools and Inventories	Access	System Boundary	Method	Countries	Reference
Tools	Athena Eco Calculator and Athena Impact Estimator	Open	Cradle to Gate/ Cradle to Grave	Process based	USA, Canada	[16]
	Building for Environmental and Economic Sustainability (BEES)	Open	Cradle to Gate	Process based	USA	[17]
	Environment Agency Carbon Calculator	Open	Cradle to Gate	Input-Output based	UK	[18]
	Global Emissions Model for integrated Systems (GEMIS)	Licensed	Cradle to Gate	Process based	Germany	[19]
	EQUER	Licensed	Cradle to Grave	Process based	France	[20]
	SimaPro	Licensed	Cradle to Grave	Process based	Netherlands	[21]
Inventory/ Databases/ Reports	Bath Inventory of Carbon and Energy	Open	Cradle to Gate	Process based	UK	[22]
	Athena Life Cycle Inventory Product Databases	Licensed	Cradle to Gate	Process based	USA, Canada	[23]
	New Zealand Building Materials Embodied Energy Database	Open	Cradle to Gate	Process based hybrid method	New Zealand	[24]
	Hutchins UK Building Black book	Licensed	Cradle to Gate	Input-Output based	UK	[25]
	European Life Cycle Database (ELCD)	Open	Cradle to Gate	Process based	Europe	[26]
	EcoInvent 3.3	Licensed	Cradle to Gate	Process based	Switzerland	[27]
	ÖKOBAUDAT (German National Database)	Open	Cradle to Gate	Process based	Germany	[28]
	AusLCI	Open	Cradle to Gate	Process based	Australia	[29]

According to Moncaster and Song [30], there are three common methods available to estimate EC in whole life cycle of a building namely;

- Process based method
- input- output method and
- hybrid method

Process based analysis is one of the most widely used methods in the literature as it delivers more accurate and reliable data [31]. Some of the studies done by [32]-[34] have adopted this method. However, this method is impractical and incomplete due to the exclusion of many upstream processes [7].

Input-output life cycle assessment is an alternative to process based method which calculates the total impact of construction, including the areas omitted by the process method [30]. Therefore, this method is assumed to be comprehensive and complete [7]. The studies done by [35], [36] are two examples for the input-output analysis method adopted in EC estimation. However, this method also suffers from issues such as assumption of homogeneity and proportionality, errors and uncertainty of data which ultimately lead to the unreliable and erroneous outcomes [37].

As a result of that, hybrid method has been evolved. Reference [38] discusses on two hybrid methods; namely, process based hybrid analysis and input-output based hybrid analysis which have been designed to eliminate fundamental errors of and limitations of other two methods. However, the same authors further mention that no method available is fully efficient and errors are unavoidable in all methods.

In association with these methods, many EC assessment tools and supportive databases/inventories have been developed to facilitate the process of EC estimation. The Table I provides few examples for EC assessment tools and databases/inventories available worldwide. Although there are many tools and the databases as such, the literature reveals that most of them are not transparent, up-to-date and not freely available [8].

C. Challenges for/Barriers to Estimating EC

Despite the various methodologies, tools, data and databases available in the practice, the built environment professionals yet confront many challenges and barriers to estimating EC [33]. In view of this, the authors were able to identify 16 different challenges and barriers from the existing literature and summarised them as in Table II.

TABLE II
CHALLENGES FOR/BARRIERS TO ESTIMATING EC

No	Challenges/Barriers	Description	References
1	no regulations mandating the EC estimation in buildings	There are no regulations yet announced to estimate and reduce EC	[30], [33]
2	inconsistencies in the EC estimation methods	Multiple calculation methods are available in the practice, but they are lack in consistency and transparency	[30], [39]-[41]
3	difficulty in choosing an estimation boundary	The existing literature identifies five system boundaries namely; cradle to gate, cradle to site, cradle to end of construction, cradle to grave and cradle to cradle. Among them, it is quite challenging to choose an appropriate boundary for an assessment.	[33], [39], [40], [42]
4	unavailability of a standard data collection and maintenance procedure	High level of uncertainty is inevitable in collection and maintenance of data due to unavailability of a standard data collection and maintenance.	[39], [42]
5	unavailability of national databases for carbon emission factors	Despite the IPCC Emission Factor Database for global practice and EMEP/EEA Guidebook 2016 for European countries etc., it is hard to find out national specific carbon emission factor databases. Lack of national specific databases possibly will reduce the accuracy of final outcome.	[12]
6	limited knowledge dissemination	Despite the increasing research and development on reducing the EC impact of buildings in developed countries, it is very little in developing countries.	[39], [43]
7	out of date assessment tools	Most of the available assessment tools have not updated after its first introduction	[8]
8	lack of open source assessment tools and software	The majority of the assessment tools and software available for calculating EC in the industry practice are either country or region specific, as well as not freely available.	[8]
9	lack of benchmarks	Once the EC emissions are calculated, benchmarks should be available, enabling the comparisons to be drawn. However, there are no widely accepted benchmarks.	[8], [40]
10	lack of accurate and transparent data	Lack of and/or unavailability of published data on the embodied impact of components or materials, and Environment Product Declaration databases, unreliable, aged and incomplete data followed by access restrictions and geographic variations is another major challenge estimating EC.	[13], [30], [40], [44]-[47]
11	high data demands	Depending on the boundary of EC estimation, the demand for data varies. However, in general EC estimation requires large quantity of energy data.	[48]
12	complex and work intensive nature of estimation procedure	Data collection and analysis of a large quantity of data is complex and work intensive. Therefore, it requires more labour.	[49]
13	time consuming nature of EC estimation	It is apparent that when the procedure is complex and work intensive, it consumes more time	[40], [45], [49]
14	lack of skilled personnel	This is a major challenge, mainly in developing countries where the technology and the knowledge has not been disseminated or shared.	[43]
15	limited environmental awareness	Limited awareness on climate change and its impacts in developing countries has overlooked the significance of estimating EC emissions and implementing reduction strategies.	[48]
16	lack of interest in the embodied impacts by the public and the industry stakeholders	Lack of interest on the EC reduction among both internal (i.e. engineers, architects, facility managers) and external (i.e. public, government) stakeholders of the construction sector.	[6]

III. RESEARCH METHODOLOGY

This paper is based on a pilot survey which was supported by a literature review and a questionnaire. Conducting a pilot survey prior to the actual survey using a smaller sample of respondents enables to obtain some assessment of the questions' validity and the likely reliability of the data that will be collected later in large scale [50]. The literature review enabled the identification of 16 challenges for/barriers to estimating EC in building sectors in many countries. The questionnaire then supported in identifying the relevant reasons among them for slow uptake in EC estimation in Sri Lankan building sector. Seven experts who were purposively selected based on the experience and the involvement in sustainable/green construction related activities were used to conduct the survey. The questionnaire included two main sections. In the first section, the respondents were asked to provide background information of them that included current designation, academic qualifications, industry experience and involvement in sustainable construction related activities. The second section was designed in line with the purpose of the study. The identified challenges/barriers were put into a three - point Likert scale (1= low relevant, 2= moderately relevant, 3= high relevant) and the respondents were asked to rate them. The collected data were subsequently analyzed using descriptive statistics and due to the small-scale of this survey, the method of *Mode* was used. The mode is the value that occurs most frequently in a distribution [51]. Pertaining to that the relevance level of each challenge/barrier to the Sri Lankan context was identified.

IV. FINDINGS

A. Overview of Respondents

All the selected respondents were contacted, indicating the contact and the respond rate of 100%. Out of seven respondents, three were academics and four were industrial practitioners. Four of them have PhDs, two have masters and one has bachelor's degree. The years of industrial experience indicated that all of them have more than 05 years' experience. The academics have involved in green construction related researches while industrial practitioners have involved in the green building consultancy projects. Thus, this indicates that the selected respondents are well educated, experienced as well as in a capacity to make a contribution to this study.

B. Reasons for the Slow Uptake of EC Estimation in Sri Lankan Building Sector

Fig. 1 graphically presents how the respondents have rated each reason. It indicates the relevance rates given for each reason as a percentage of total respondents. Based on their ratings, the mode value of each reason was derived and eventually, it was able to categorize them as high, moderate, and low relevant reasons.

Table III discloses the mode values and the classification clearly. It identifies 11 numbers of high relevant reasons and the remaining five 05 as moderately relevant reasons for the slow uptake of EC estimation in Sri Lankan building sector. It further indicates that there are no low relevant reasons for the slow uptake of EC estimation.

According to Table III, the following 11 reasons were identified as highly relevant reasons: 1) no regulations mandating the EC estimation in buildings; 4) unavailability of a standard data collection, estimation and maintenance procedure; 5) unavailability of national database for carbon emission factors; 6) limited knowledge dissemination; 8) lack of open source assessment tools and software; 10) lack of accurate and transparent data; 11) complex and work intensive nature of estimation procedure; 13) time consuming nature of EC estimation; 14) lack of skilled personnel; 15) limited environmental awareness; 16) lack of interest in the embodied impacts by the public and the industry stakeholders; Following 5 reasons were identified as moderately relevant reasons for the Sri Lankan context; 2) inconsistencies in the EC estimation methods; 3) difficulty in choosing an estimation boundary; 7) out of date assessment tools; 9) lack of benchmarks and 11) high data demands.

V. Conclusions and the Way Forward

With the reduction of OC emissions in the global building sector, the attention has now shifted towards EC reduction. However, Sri Lanka as a developing country which promotes sustainable/green building construction has not yet extensively looked into the EC estimation and thereby EC reduction. Therefore, it created a necessity to identify the main reasons which has caused for the slow uptake of EC estimation in Sri Lankan building sector. The findings revealed that there are 11 high and 05 moderately relevant reasons. Accordingly, it concluded that all the known global challenges and barriers are significant reasons for the slow uptake of EC estimation in Sri Lankan building sector and they need to be addressed in order to encourage the EC estimation and then reduce the EC.

This paper was limited to a pilot survey in which the conclusions were derived based on few experts. This indicates that the conclusions are subjective and the study is not conclusive enough. However, the findings lead to a broader scale study in future. Accordingly, the survey will be repeated in a large scale and the findings will be tested again. Further, the future work of this study will look in to provide probable suggestions to overcome the significant reasons, so then the necessary actions can be taken to estimate and reduce the EC of buildings in Sri Lanka.

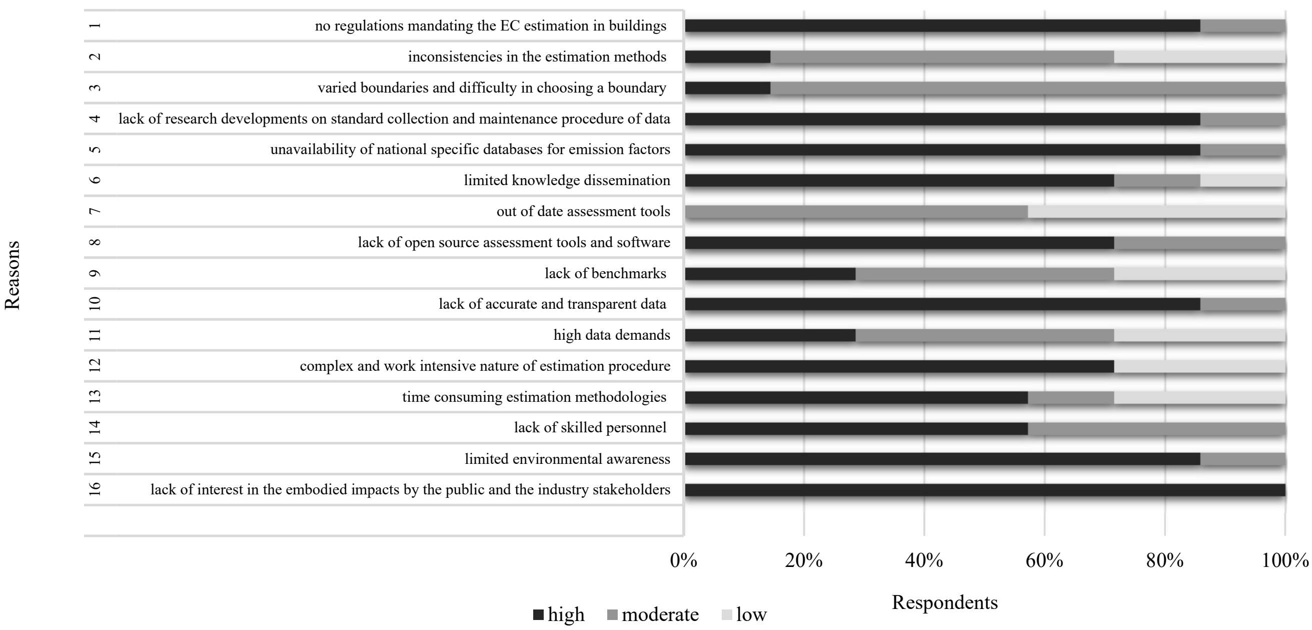

Fig. 1 Reasons for slow uptake in estimating EC and the respondents ranking

TABLE III
CLASSIFICATION OF REASONS

No	Reasons	Respondent Scores			Mode Score	Classification
		High Relevance 3	Moderate Relevance 2	Low Relevance 1		
1	no regulations mandating the EC estimation in buildings	6	1	0	3	**high**
2	inconsistencies in the EC estimation methods	1	4	2	2	**moderate**
3	difficulty in choosing an estimation boundary	1	6	0	2	**moderate**
4	unavailability of a standard data collection, estimation and maintenance procedure	6	2	0	3	**high**
5	unavailability of national database for carbon emission factors	6	1	0	3	**high**
6	limited knowledge dissemination	5	1	1	3	**high**
7	out of date assessment tools	0	4	3	2	**moderate**
8	lack of open source assessment tools and software	5	2	0	3	**high**
9	lack of benchmarks	2	3	2	2	**moderate**
10	lack of accurate and transparent data	6	1	0	3	**high**
11	high data demands	2	3	2	2	**moderate**
12	complex and work intensive nature of estimation procedure	5	0	2	3	**high**
13	time consuming nature of EC estimation	4	1	2	3	**high**
14	lack of skilled personnel	4	3	0	3	**high**
15	limited environmental awareness	6	1	0	3	**high**
16	Lack of interest in the embodied impacts by the public and the industry stakeholders	7	0	0	3	**high**

REFERENCES

[1] United Nations Environment Programme. *Sustainable building and climate initiative: promoting policies and practices for sustainability.* June 2010. (Online). Available from: https://business.un.org/en/assets/9500be08-37e8-4367-842d-2801f01c6586.pdf (Accessed 25 July 2017).

[2] UN-Habitat, *Green Buildings - Interventions for Social Housing, 2015.* Nairobi, Kenya: United Nations Human Settlements Programme.

[3] Royal Institute of Chartered Surveyors, *Methodology to calculate embodied carbon of materials,* 2012. 1st ed, Coventry: RICS.

[4] J. Heinonen, A. Säynäjoki, and S. Junnila. A longitudinal study on the carbon emissions of a new residential development, *Sustainability*, 2011, 3, pp.1170-1189.

[5] R. Crawford, Life Cycle Assessment in the Built Environment, 2011. Oxford: Routledge.

[6] T. Ibn-Mohammed et al. Operational vs. embodied emissions in buildings-A review of current trends, *Energy and Buildings*. 2013. 66 (2013), pp. 232–245.

[7] M. K. Dixit, et al., Identification of parameters for embodied energy measurement: a literature review. *Energy and Buildings*, 2010. 42 (2010), pp.1238–1247.

[8] C. De Wolf, F. Pomponi, and A. Moncaster. Measuring embodied carbon dioxide equivalent of buildings: A review and critique of current industry practice. *Energy and Buildings*, 2017. 140 (2017), pp. 68–80.

[9] Green Building Council Sri Lanka (GBCSL), *Green SL® rating system for built environment,* 2015. GBCSL (online) Available from: http://srilankagbc.org/Rating%20System%20for%20Built%20Environment.html (Accessed 13 May 2017).

[10] S.P. Pooliyadda. *Energy content and carbon emission audit of building materials*, MPhil Thesis (unpublished), 2000. Sri Lanka: Department of Civil Engineering, University of Moratwua.

[11] F. Pomponi, and A. M. Moncaster. Embodied carbon in the built environment: management, mitigation, and reduction – what does the evidence say? *Journal of Environmental Management.* 2016. 181(2016). pp.687-700.

[12] WRAP. *Information sheet for construction clients and designers: Cutting embodied carbon in construction projects.* 2011. WRAP (online) available from: www.wrap.org.uk/.../FINAL%20PRO095-009%20Embodied%20Carbon%20Annex.pdf (Accessed 13 May 2017).

[13] I. Sartori, and A.G. Hestnes. Energy use in the life cycle of conventional and low-energy buildings: a review article, *Energy Building*. 2007. 39 (2007) pp. 249–257.

[14] T. Ramesh, R. Prakash, and K. K. Shukla. Life cycle energy analysis of buildings: an overview, *Energy and Buildings*, (2010). 42 (10), 1592–1600.

[15] M. Victoria, S. Perera and A. Davies. A pragmatic approach for embodied carbon estimating in buildings. In proceedings of *SBE16 Torino*, Torino, Italy, 2016.

[16] Athena Sustainable Materials Institute. *Athena eco calculator*. n.d (online). Available from: http://www.athenasmi.org/our-software-data/ecocalculator/ (Accessed 28 May 2017).

[17] National Institute of Standards and Technology. *Building for Environmental and Economic Sustainability (BEES)*, n.d. (online) Available from: https://www.nist.gov/services-resources/software/bees (Accessed 20 May 2017).

[18] Environment Agency. *Environment agency carbon calculator*, 2012 (online) Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/571707/LIT_7067.pdf. (Accessed 20 May 2017).

[19] International Institute for Sustainability Analysis and Strategy. *Global Emissions Model for integrated Systems (GEMIS)*. 1989. Available from: http://iinas.org/gemis.html. (Accessed 20 May 2017).

[20] Centre Energy Efficiency of Systems, *EQUER*. n.d. (online) Available from:http://www.dep.minesparistech.fr/Valorisation/Ressources/EQUER/ (Accessed on 20 May 2017).

[21] SimaPro, SimaPro LCA software. n.d. (online) Available from: www.simapro.co.uk. (Accessed 20 May 2017).

[22] G. P. Hammond, C. I. Jones, Embodied carbon. The inventory of carbon and energy (ICE), 2011. eds. Fiona Lowrie and Peter Tse, BSRIA.

[23] Athena Sustainable Materials Institute, *Athena Life Cycle Inventory Product Databases.* n.d.. (online) Available from: http://www.athenasmi.org/our-software-data/lca-databases/ (Accessed 20 May 2017).

[24] A. Andrew, *Embodied Energy and CO Coefficients for New Zealand Building Materials*. 2001. Centre for Building Performance Research, Victoria University of Wellington.

[25] Franklin and Andrews Limited, *UK building black book: The cost and carbon guide*. 2011 ed. Croydon: Franklin and Andrews Limited.

[26] European Commission, *European Life Cycle Database (ELCD).* 2006. (online) Available from: http://eplca.jrc.ec.europa.eu/ELCD3/ (Accessed 20th May 2017).

[27] EcoInvent Association, *EcoInvent 3.3*. 2016. (online) Available from: http://www.ecoinvent.org/database/ecoinvent-33/ecoinvent-33.html. (Accessed 20 May 2017).

[28] Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, *ÖKOBAUDAT (German National Database).* 2013. (online) Available from: http://www.nachhaltigesbauen.de/baustoff-und-gebaeudedaten/oekobaudat.html (Accessed 20th May 2017).

[29] Australian Life Cycle Assessment Society, *AusLCI.* n.d. (online) Available from http://auslci.com.au/index.php/Home (Accessed on 20 May 2017).

[30] A. M. Moncaster & J.Y. Song. A comparative review of existing data and methodologies for calculating embodied energy and carbon of

buildings, *International Journal of Sustainable Building Technology and Urban Development*.2012, 3(1), 26-36.

[31] G. Ding. The development of a multi-criteria approach for the measurement of sustainable performance for built projects and facilities, 2004Ph.D. thesis, University of Technology, Sydney, Australia.

[32] Zhang et al. (2016).

[33] A. M. Moncaster and K.E. Symons A method and tool for 'cradle to grave' embodied carbon and energy impacts of UK buildings in compliance with the new TC350standards, *Energy and Buildings. 2013.* 66 (2013), pp. 514–523.

[34] M. Sansom and R. J. Pope. A comparative embodied carbon assessment of commercial buildings, *The Structural Engineer.* 2012. (online). Available from: https://www.istructe.org/getattachment/7eb7ebd4-d56c-4bc6-b4e3-932ad44e3a0a/EmbodCarbon.pdf (Accessed 15 June 2017).

[35] Sheng et al. Study and estimation of embodied carbon based on input output analysis. *Journal of Scientific and Industrial Research*. 2016.75. pp. 529-533.

[36] J. Nässén et al. Direct and indirect energy use and carbon emissions in the production phase of buildings: An input–output analysis. *Energy* 2007. 32, pp. 1593–1602.

[37] R. H. Crawford, and G. J. Treloar. Validation of the use of Australian input output data for building embodied energy simulation, In proceedings of *Building Simulation 2003*, Eindhoven, August 2003, pp. 11-14.

[38] R. H. Crawford. Validation of the Use of Input-Output Data for Embodied Energy Analysis of the Australian Construction Industry, *Journal of Construction Research*. 2004.

[39] E. Gavotsis. And A. Moncaster, Improved embodied energy and carbon accounting: recommendations for industry and policy, *Athens Journal of Technological Engineering*. 2015. 2 (1). pp. 9–23.

[40] M. Fouché and R. Crawford, The Australian construction industry's approach to embodied carbon assessment: a scoping study, in proceedings of *Living and Learning: Research for a Better Built Environment: 49thInternational Conference of the Architectural Science Association*, University of Melbourne, 2015, pp. 578–587.

[41] UK Green Building Council, *Embodied Carbon Week – Seeing the whole picture, Key findings from Embodied Carbon Week* 2014. UKGBC.

[42] C. K. Anand. and B. Amor. Recent developments, future challenges and new research directions in LCA of buildings: a critical review, *Renewable and Sustainable Energy Reviews*. 2017. 67 (2017). pp. 408–416.

[43] J. Giesekam, J. R. Barrett, P. Taylor, Construction sector views on low carbon building materials, *Building Research and Information*. 2016. 44 (4). pp.423–444.

[44] R. Giordano et al. Embodied energy and operational energy assessment in the framework of nearly zero energy building and building energy rating, *Energy Proceedia*. 2015. 78 (2015). pp. 3204–3209.

[45] M. K. Dixit et al. Need for an embodied energy measurement protocol for buildings: a review paper, *Renewable and Sustainable Energy Reviews*. 2012.16 (6). pp.3730–3743.

[46] P. J. Davies, S. Emmitt. And S.K. Firth, Challenges for capturing and assessing initial embodied energy: a contractor's perspective, *Construction Management and Economics*. 2014. 32 (3). pp.290–308.

[47] T. L¨utzkendorf et al. Net-zero buildings: incorporating embodied impacts, *Building Research and Information*. 2015. 43 (1). pp.62–81.

[48] S.T. Ng, J. Wong. And M. Skitmore. Challenges facing carbon dioxide labelling of construction materials, *Proceedings of the Institution of Civil Engineers: Engineering Sustainability*. 166 (ES1) (2013)20–31.

[49] T. Malmqvist et al. Life cycle assessment in buildings: The ENSLIC simplified method and guidelines. *Energy*, 2011. 36(4).

[50] M. Saunders. P. Lewis and A. Thornhill. *Research Methods for business students*. 7th edition. Essex: Pearson Education Ltd, 2016.

[51] A. Bryman, *Social Research Methods*.5th edition. Oxford: Oxford university press, 2016.