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ENVIRONMENTAL IMPACTS OF BUILDINGS ACROSS THEIR LIFE CYCLE STAGES

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The aim of this study was to investigate the environmental impacts of building activities in South Africa (SA). To achieve the objectives of the study, a critical review of literature was done which was followed by the use of a questionnaire to collect primary data on the possible barriers to the adoption of LCA methodology for buildings. Five major environmental impacts were identified from literature, which were subsequently explored with the use of the questionnaire survey. The questionnaires were distributed to the construction professional team (i.e., Quantity Surveyors, Architects, Facilities Managers, Construction Managers, Civil Engineers, and Site Engineers) in the South African construction industry. Findings from the study revealed that all the stages of a building cause environmental impacts. Although, for some of the identified environmental impacts caused by building activities participants where neutral for example, that building activities lead to "Loss of Marine Life". A comparison was done between the years of experience and the view on what the environmental impacts are and it was found that participants with more years of experience agree more that building activities causes environmental impacts as compared to participants with less years of experience, in the construction industry. The factor that was highly agreed upon by participants with more years of experience is Building Materials. The study contributes to the body of knowledge on the environmental impacts of buildings across their life cycle in the South African construction industry. The study therefore is valuable to the SA construction industry, built environment, infrastructure development, and/or sustainable urban development.

Keywords: Building activities, Construction industry, Life cycle assessment, South Africa.

1 INTRODUCTION

Life cycle assessment (LCA) also known as life cycle analysis is defined in many ways but however what the definitions have in common is that it has to do with the environmental impacts during the life of a given product or process from cradle to grave i.e., from the extraction of raw materials to the disposal of such a product or process etc. This, according to ISO 14040 (Striebig *et al.* 2014) is the definition of the life cycle of a product. However, Simonen (2014) and Muigai *et al.* (2013) informs that LCA is not simply a cradle-to-grave methodology, but that it is a cradle-to-cradle methodology. This is because cradle-to-cradle includes all the stages covered by an LCA project. The phases that constitute the "well-known" cradle-to-grave which is supposedly cradle-to-cradle therefore are: cradle-to-gate; gate-to-grave; and grave-to-cradle. Cradle-to-gate includes the extraction of raw materials, processing and manufacturing stages, transportation of the produced by-products. In light of the building sector for example; the cradle-to-gate is the whole process prior to the delivery of materials to the construction site. Gate-to-grave is the use of the delivered materials, (the construction of a building in this instance) as well as its maintenance and repair processes. The last phase is the grave-to-cradle which comprises the demolition, disposal, re-use or recycling of the product, (demolition of a building, and re-use or recycling of certain material where applicable).

LCA is also referred to as a scientific measurement tool that measures the environmental performance of a product or process (Schenck 2005). It is a process of estimating environmental burdens for energy and materials used and wastes released into the environment, often including impacts not considered in more traditional analyses (e.g., transportation of materials) and identifying opportunities for environmental improvements, (EPA 1993, Sadiq and Khan 2006). In addition, LCA methodology provides a quantitative basis for assessing potential improvements in environmental performance of a system throughout the cycle (Koronoes and Dompros 2005). Moreover, the systems perspective of LCA avoids problem shifting from one life cycle stage to another, from one type of problem to another and from one location to another (UNEP 1996). Instead, according to (EPA 1993) LCA evaluates all stages of a product's life from the perspective that they are interdependent, meaning that one operation leads to the next. This tool allows decision makers the opportunity to study the entire system of a product hence avoiding sup-optimization that could result when just one process were the focus of the study (Crawford 2011).

The built environment is one of the largest sectors in any community and thereby greatly contributes towards the environmental impacts. The built environment contributes to the environmental impacts for example; through the emissions of greenhouse gases by burning fossil fuels during transportation of materials during the construction activities; or incineration of waste that is generated from construction as well demolition activities. Buildings are one of the major products of the built environment and they comprise of six life cycle stages, i.e., extraction of raw materials, manufacturing, construction, operation and maintenance, demolition, and disposal. The six life cycle stages of a building makes the undertaking of LCA for the buildings almost impossible because it involves a great number of stakeholders; companies, personnel, legislations, etc. Buildings are developed to provide for human need such as shelter but however are found to be great contributors to the environmental impacts. Buildings are a significant component of the human environment and, accordingly, contribute to the economy and environmental impacts, including global climate change (Horne *et al.* 2009). One of the ways building developments affect the environment is through the use of non-renewable natural resources such as land and minerals. In addition, the quality of many people's lives is in a critical condition because land and other resources are being depleted at a rate which is not sustainable (Carpenter 2001). According to Crawford (2011) once non-renewable resources have been completely exploited, or at a point where they become considered too costly or difficult to extract from the Earth, we will have no choice but to look for or develop alternative solutions to meet our needs. Aglionby *et al.* (2001) argues that each project is built and operates in a different socio-economic, political and physical environment and therefore it may improve some lives whilst diminishing the quality of others. As one of the ways to help reduce the environmental impacts of buildings, philosophies such as sustainable design, lean design where invented into the industry. Generally, buildings impact the environment across six life cycle stages namely: raw material extraction, manufacturing, construction, operation and maintenance, demolition and disposal, reuse or recycling. According to Horne *et al.* (2009) buildings consume considerable amounts of materials and energy and therefore create impacts during at least two major life cycle phases: construction and operation.

2 RESEARCH METHODOLOGY

This research followed a quantitative design. Unlike a qualitative approach, a quantitative approach is deductive in nature, and it attempts to adopt an objective, detached approach to observing phenomena and conducting experiments (SACQSP, Module 18). A questionnaire survey research design was used to collect primary data. Unlike qualitative research designs such as interviews, questionnaire surveys are highly structured and place an emphasis on the careful random selection of samples, so that results can be generalized to other situations or contexts (Gray 2009). Structured questionnaires are those in which there are definite, concrete and pre-determined questions, (Kothari 2004). Questions should be clear, straightforward, and appear nonthreatening, and to accomplish this, a researcher must word items simply, objectively, and in as non-offensive of a manner as possible (Picardi and Masick 2014). Closed questions were used for the purposes of this research. The use of close-ended questions provided participants with a multiple of options to choose from without allowing them to put their opinions in their own words. The main advantage of using close-ended questions is their simplicity for data collection and analysis, thus they are less time consuming.

A questionnaire survey was carried out in the Gauteng Province, South Africa. Research was conducted with respect to the SA building construction sector and therefore the targeted respondents were construction professionals' i.e., architects, engineers, quantity surveyors and construction project managers. Overall, 116 questionnaires were counted and after a careful examination of the received questionnaires only 98 were usable. These formed the basis of the analysis for the study. Respondents had the leisure of completing questionnaires on their own time and space, and they were well informed of the purposes of the study, the importance of their participation in the study and were they can find the results if they are interested in knowing the outcomes of the study. The secondary data for the study is derived from the review of literatures, published and unpublished.

Survey research can yield data that is versatile and can be analyzed from a multitude of different perspectives, depending on the actual data collected and the sources (Picardi and Masick 2014). Data was analyzed using descriptive statistics. Descriptive statistics are used to describe or summarize a set of data. Factor analysis was also used in this study. This is because this study is of a quantitative nature and data was collected using questionnaires. A number of factors or variables were selected and/or formulated based on the literature that was reviewed and then analyzed to find out if whether they make up a structure; by assessing the correlation between them. For the purposes of this study, exploratory factor analysis is going to was followed to analyze data. Exploratory factor analysis is the older methodology and it focuses on the exploratory of the possible underlying structure on the outcome. Child (1990), informs that in exploratory factor analysis; variables are selected with no thought because they happen to be reasonably numerous as with questionnaire or attitude scale items, they are then submitted for analysis in a 'let's see what happens' spirit.

2.1 Mean Item Score

However, for the purposes of this study; a Mean Item Score and the Standard Deviation were used to analyze data. Mean Item score indicate the average level of agreement with an item. Three different Likert scales (2, 3, and 5-point) were used to record the responses. The Likert scales were transformed to a Mean Item Score (MIS) for each of the research objectives as applicable. The indices were then used to determine the rank of each item. These rankings made it possible to cross compare the relative importance of the items as perceived by the respondents. The MIS was based on previous studies as conducted by Mukuka *et al*. (2013)

where the ‘MIS’ rating was used. Following the mathematical computations, the criteria were then ranked in descending order of their relative importance.

3 FINDINGS AND DISCUSSIONS

3.1 Background Information of Participants

Findings on this aspect of the study revealed that a majority of the participants are Quantity Surveyor accounting for a little over half of the participants (51.02%). The 51.02% represents a total of 50 out of 98 participants. The least frequency was 4% i.e., 4 out of 98 participants, which represents Architects, which was in the same range as the frequency for Facilities Manager with 5%. Along the same range of frequency are the occupations: Construction Manager with 8%, Civil Engineer 9.18%, Site Engineer with 12%. The average number of working experiences of the participants was 7.35. This is supported by the huge gap between the lowest (min) and highest (max) number of years worked, i.e., 1 and 30, respectively.

3.2 The Extent to which Building Construction Activities Causes Environmental Impacts

This section of the questionnaire explored the benefits of making use of the LCA for buildings. A 5-point Likert scale: 1 = Strongly Disagree (SD) 2 = Disagree (D) 3 = Neutral (N) 4 = Agree (A) 5 = Strongly Agree (SA) was used to record the respondent’s level of agreement with the identified factors as the uses of LCA for buildings across their life cycle stages. For question C11 descriptive statistics as well as factor analysis was used to analyze data. As of the results from factor analysis no item needed to be reverse scored. Prior to performing PCA, the suitability of data for factory analysis was assessed. Inspection of the correlations matrix revealed the presence of all coefficients of above 0.3. The Kaiser-Meyer-Oklin value was 0.884, exceeding the recommended value of 0.6 and Bartlett’s Test of Sphericity reached statistical significance supporting the factorability of the correlation matrix. All factors have MSA values higher than 0.6, and therefore no factors were omitted. Lastly for the Communalities; all factors have Extraction values of more than 0.3 which makes them all appropriate for factor analysis.

Table 1. Total variance explained.

Factor	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**		
	Total	% of Variance	Cum. %	Total	% of Variance	Cum. %	Total	% of Variance	Cum. %
1	10.556	65.974	65.974	10.266	64.162	64.162	6.834	42.713	42.713
2	1.217	7.608	73.582	0.940	5.875	70.037	4.372	27.324	70.037
3	0.894	5.585	79.166						
4	0.762	4.762	83.928						
5	0.460	2.875	86.804						
6	0.367	2.294	89.097						
7	0.331	2.072	91.169						
8	0.321	2.006	93.175						
9	0.250	1.564	94.739						
10	0.210	1.315	96.055						
11	0.168	1.051	97.106						
12	0.159	0.997	98.103						
13	0.122	0.763	98.866						

Table 1. Total variance explained (continued).

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cum. %	Total	% of Variance	Cum. %	Total	% of Variance	Cum. %
14	0.076	0.472	99.338						
15	0.062	0.386	99.724						
16	0.044	0.276	100.000						

Note: Extraction Method: Principal Axis Factoring.

4 CONCLUSION

Most participants agreed that all the stages of a building cause environmental impacts. Although, for some of the identified environmental impacts caused by building activities participants where neutral for example, that building activities lead to "Loss of Marine Life". A comparison was done between the years of experience and the view on what the environmental impacts are and it was found that participants with more years of experience agree more that building activities causes environmental impacts as compared to participants with less years of experience. The factor that was highly agreed upon by participants with more years of experience is Building Materials.

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References

Aglionby, J. C. W, Carpenter, T. G, Hepper, E. J. M, Emglish, C, and Carpenter, D. D. Quality of Human Life, In: Environment, Construction and Sustainable Development, Vol. 1: The Environmental Impact of Construction, (ed. T.G. Carpenter), John Wiley and Sons, Ltd, Chisester, New York, Weinheim, Brisbane, Singapore and Toronto, 2001.

Carpenter, T. G., Construction in a Fragile World. In: Environment, Construction and Sustainable Development: Volume 1: The Environmental Impact of Construction, (ed. T.G. Carpenter), John Wiley and Sons, Ltd, Chisester, New York, Weinheim, Brisbane, Singapore and Toronto, 2001.

Child, D., 'The essentials of factor analysis', Cassell Educational, 1990.

Crawford, R. H., 'Life Cycle Assessment in the Built Environment', Spon Press, London and New York, 2011.

Environmental Protection Agency (EPA) United States, 'An Evaluation of Environmental Life Cycle Assessment', Economic Analysis and Innovations Division, Environmental Law Institute pp. 1-32, 1993.

Gray, D. E., Doing Research in the Real World, 2nd Ed, Sage Ltd, California, 2009.

Horne, R. , Grant, T. and Verghese K. , Life Cycle Assessment: Principle Practice and Prospects. CSIRO, Australia, 2009.

Kothari, C. R., Research Methodology: Methods and Techniques, 2nd Rev. Ed, New Age International, Delhi, India, 2004.

Muigai, R., Alexander, M. G., and Moyo, P., Cradle-to-gate environmental impacts of the concrete industry in South Africa. Journal of the South African Institution of Civil Engineering, 55(2), pp. 2–7, 2013.

Mukuka, M. J, Aigbavboa, C. O., and Thwala, W. D., 'Construction Professionals' Perception on the Causes and Effects of Project Delay in Lusaka, Zambia', In FA Emuze, Proceedings of the SB13 Southern Africa Conference, Central University of Technology, Free State, Bloemfontein,. Cape Town International Convention Centre, Cape Town, South Africa, 2013.

Picardi, C. A. and Masick, K. D., Research Method: Designing and Conducting Research with a Real-World Focus, Sage Inc., California, 2014.

Sadiq, R. and Khan, F. I., An integrated approach for risk-based life cycle assessment and multi-criteria decision-making: Selection, design and evaluation of cleaner and greener processes. Journal of Business Process Management, 12(6), pp. 770–792, 2006.

Schenck, A., 'Why LCA?' Journal of Life Cycle Assessment and Sustainability: A supplement to Building Design and Construction 3rd in a Series of Annual Reports on the Green Building Movement, (ed. R. Cassidy), pp1-64, 2005.

Simonen, K., Pocket Architecture: Technical Design Series: Life Cycle Assessment. Routledge, 2014.

Striebig, B. A., Ogundipe, A. A., and Papadakis, M., 'Engineering Applications in Sustainable Design and Development', S1 Edition, Cengage Learning, Canada, 2014.

United Nations Environment Programme (UNEP), Greenhouse Gas Emission Baselines and reduction Potentials from Buildings in South Africa, pp. 1–68, 1996.