Awareness and usage of life cycle assessment methodology in the building sector

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Abstract— Life Cycle Assessment (LCA) was developed to determine the holistic environmental impact of a product or service or activity or process to inform useful alternatives with fewer environmental impacts. The built environment is one of the largest sectors in any community, and buildings are one of the primary products of the built environment. Since buildings comprise of six life cycle stages; these phases significantly contribute to the environmental impacts of building construction and when in use. The objective of this paper is to determine the level of awareness and usage of LCA in the building sector and how LCA methodology can assist to achieve sustainable building practices in the built environment. The study was conducted with reference to existing theoretical literature, published and unpublished research. The study is mainly a literature review on LCA, its features, applications benefits and barriers regarding the building sector. Literature studied, revealed that LCA is not significantly utilized in the construction industry, particularly in the construction stage because most contracting companies are not aware of it, and where they are aware, there is resist to adopt the methodology. Also, the significant barriers to building experts who are aware of the method are that the method is termed complicated, time-consuming and costly. However, LCA when adopted in the construction environment, will assist to achieve sustainable building practices because its systems perspective avoids problem shifting from one life cycle stage to another. Also, since LCA procedure investigates a broad range of environmental impacts associated with industrial products such as Climate Change, Acidification, Ozone Depletion and Human toxicity. LCA, therefore, informs producer decisions about alternative processes in their attempt to improve industrial environmental performance.

Keywords— Built environment, building industry, environmental impacts, Life cycle assessment

I. INTRODUCTION

The increase in the awareness of natural resource depletion and environmental impacts has led to the development and establishment of tools designed to reduce the effects of human activities on the environment. Humans have long been concerned with the energy efficiency of technologies and the services they provide [1]. According to Environmental Protection Agency (EPA) report of 2006, many businesses have responded to the reduction of environmental awareness by providing greener products and using greener processes. For an increasing number of organizations, business drivers, public environmental and social concerns had reached a level where a more strategic and systematic approach to environmental challenges was necessary [1]. Life cycle assessment (LCA) is one of such tools, and it was developed to determine the holistic environmental impact of a product or service or activity or process. LCA evaluates the life of a product from - cradle to grave, that is, from the extraction of raw materials all the way to the disposal of the product.

The built environment is one of the largest sectors in any National State that greatly contributes towards the environmental impacts. The built environment contributes to the environmental effects through the following ways: through the emissions of Greenhouse gases by burning fossil fuels during transportation of materials during the construction activities and the incineration of waste that is generated from construction as well demolition activities. Buildings are the major products of the built environment, and they comprise of six life cycle stages. These include extraction of raw materials, manufacturing, construction, operation and maintenance, demolition, and disposal. These six life cycle stages of a building make the undertaking of LCA for the buildings almost impossible because it involves a significant number of stakeholders; companies, personnel, legislations, amongst others. LCA is a tool that is originally developed in order to encourage organizations to be environmentally friendly when embarking on production processes or activities. Society has become concerned about issues of natural resource depletion and environmental degradation [2]. In light of the built environment sector, Cassidy et al. [3] argues that architects, engineers, contractors, building owners, environmentalists, and government officials want assurance that the products and materials they are using to design and construct buildings are the most beneficial to the environment-“from cradle to grave”.

Therefore, the purpose of this study is to assess the level of awareness and usage of LCA in the building construction sector and how LCA methodology can assist to achieve sustainable building practices in the built environment. This is with the aim on how LCA can be used as a tool to reduce the environmental impacts of buildings and thereby achieving sustainable building practices. Besides, Amofo-Anti [4], argues that to place a construction on a real sustainable path of green building movement, it will need a method that goes beyond a subjective checklist of green features. Amofo-Anti [4] further informs that such methods must provide an objective guideline for a comprehensive assessment of the environmental impacts of a product or process. Hence, this study contributes to the body of knowledge of LCA methodology, and it value for the construction industry, infrastructure development, and sustainable urban development.

II. METHODOLOGY

The research was conducted with reference to existing theoretical literature, published and unpublished literature with a deep exploration of their context to meet the research objectives. The study is mainly a literature review and looks at the level of awareness and usage of LCA in the building construction sector and how LCA methodology can assist to achieve sustainable building practices in the built environment. This is with the aim on how LCA can be used as a tool to reduce the environmental impacts of buildings and thereby achieving sustainable building practices.

III. THEORETICAL OVERVIEW OF LIFE CYCLE ASSESSMENT

Life cycle assessment (LCA) also known as life cycle analysis is defined in many ways, however, what the various definitions have in common is that the environmental impacts of the life of a given product or process from cradle to grave, (from extraction of raw materials to the disposal of such a product or process) impacts negatively on the environment when there is no methodology to manage the cradle to grave process. Hence, Simonen [5] and Muigai et al. [6], informs that LCA is not merely 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 correctly cradle-to-cradle, are: cradle-to-gate; gate-to-grave; and grave-to-cradle. The cradle-to-gate process includes the extraction of raw materials, processing and manufacturing stages, transportation of the produced by-products. In light of the building sector; the cradle-to-gate is the whole process prior to the delivery of materials to the construction site. While the gate-to-grave is the use of the delivered materials, (the construction of a building using the delivered materials), as well as its maintenance and repair processes. The last phase is the grave-to-cradle, which comprises the disposal, reuse, or recycling of the product, (demolition a building, and re-use or recycling of certain materials where applicable).

Likewise, the International Standard 14040 of 2006, and Khasreen et al. [7] defined LCA as a technique for assessing the environmental aspects and potential impacts associated with a product, by: compiling an inventory of relevant inputs and outputs of a product system: evaluating the potential environmental impacts: and interpreting the results of the support tool. It is a tool that is used to identify, determine, quantify and evaluate the total environmental loadings and impacts (inputs and outputs) of a particular service, product, process or activity, from cradle to grave, i.e. the environmental impacts of all phases of the product's life are assessed, from the time materials are extracted through manufacture, transportation, storage, use, recovery, reuse/recycle and disposal, [8] [9]. LCA is also referred to as a measurement tool that measures the environmental performance of a product or process. It is a process of estimating environmental burdens for energy and materials used and wastes released into the environment, and identifying opportunities for environmental improvements [10]. Also, LCA methodology provides a quantitative basis for assessing potential improvements in environmental performance of a system throughout the cycle [11]. Furthermore, LCA enables the estimation of the cumulative environmental impacts resulting from all stages in the product life cycle, often including impacts not considered in more traditional analyses (e.g. transportation of materials [2].

Life cycle assessment is further an industrial environmental management approach that takes a holistically and comprehensively study of products, processes, and activities. In addition, LCA is the only science-based and credible tool that is actually designed to measure the environmental impacts of product, [12] and this is due to its holistic approach on products, services, or activities. Furthermore, United Nations Environmental Programme [13] informs that 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. Instead, according to EPA [2], 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. Basically what LCA does, for example when comparing two products in order to choose the one with less environmental impacts, it informs about the underlying impacts that are not easily thought of other than just choosing a product based on what we see. For example between option one and two, one might involve the use of less quantity of natural resources and secondly a greater quantity; thereby looking at that we might assume that option one is environmentally friendly than the second. However, when an LCA study is performed on both the options we might find out that option one is actually affecting the environment more through the use of more energy which will increase the release of more greenhouse gas emissions as it might probably take more time to extract the materials necessary to produce such a product.

LCA can be looked at together with other factors such as time, cost, and performance. Time is not talked about in the LCA research studies, and the researcher assumes that time has not been effected as part of the tool thus developed to date. However, the consideration of time into an LCA study may inform even more practicable results. For example; how long does it take to produce the product in comparison with the other and during such time what is the rate of releases to the three media; air, water and land (release may be in the form of waste, greenhouse gas emissions, amongst others). Comparison based on time may inform the issue of performance as part of the LCA. Results may inform if whether a product that takes more time to produce has more effect on the environment or not, because maybe a product that is produced faster actually releases more GHG into the environment than the other that is slowly produced.

Although, previous LCA have informed that LCA solves many environmental problems associated with the product. Also, Ampofo-Anti [4] informs that LCA procedure investigates a broad range of environmental impacts related to industrial products such as Climate Change, Acidification, Ozone Depletion and Human toxicity. LCA is also used to assist producer decisions about alternative processes in an attempt to improve industrial environmental performance [13]. Furthermore, LCA guides regulatory agencies and other stakeholders on decision-making relating to design, selection and evaluation of process [10]. Also, Grant and Hes (2002) inform that LCA can be seen as a way of thinking because it broadens our understanding of the environmental impacts of products, to include upstream and downstream effects of decisions. Khasreen et al. [7] further argues that LCA has become a widely used methodology, because of its integrated way of treating the framework, impact assessment and data quality. LCA also assist the identification of problems through tracing through all environmental media, namely, air, water, and soil, (Ampofo-Anti, 2009). Another benefit of LCA is that it is based on a chosen functional unit and can factor in many geographic, technological and temporal variations in its assessment [9]. By performing LCA, EPA [13] informs that analysts can; i) develop a systematic evaluation of the environmental consequences associated with a given product; ii) analyse the environmental trade-offs associated with one or more specific products/processes to help gain stakeholder acceptance for a planned action; iii) quantify environmental releases to air, water, and land in relation to each life stage and/or major contributing process; iv) assist in identifying significant shifts in environmental impacts between life cycle stages and environmental media; v) assess human and ecological effects of material consumption and environmental releases to the local community, region, and world; vi) compare health and ecological impacts between two or more products/process or identify the impacts of a particular product/process; and vii) identify impacts to one or more specific environmental areas of concern. This approach is what is advocated on sustainable construction concept [8].

The central motivation of LCA is the belief that products, processes, and other economic activities causes environmental harms that are not adequately controlled and use natural resources that are not properly priced [13]. Hence, LCA is one of the tools or solutions developed in order to increase environmental awareness. It is a tool that is originally developed in order to encourage organizations to be environmentally friendly when embarking on production processes or activities. Society has become concerned about issues of natural resource depletion and environmental degradation [2]. In light of the built environment sector, Cassidy et al. [3] argues that architects, engineers, contractors, building owners, environmentalists, and government officials want assurance that the products and materials they are using to design and construct buildings are the most beneficial to the environment- from cradle to grave.

A. *Phases of a Life cycle assessment project*

LCA methodology is based on ISO 14040 and consists of four distinct analytical steps: i) goal and scope definition, ii) the creation life cycle inventory, iii) impact assessment and iv) finally interpretation of the result, as shown in Figure 3. The outcome of LCA study is called the “ecoprofile” [12].

The following is informed by [9] and EPA [2]:

1. Goal and scope definition: This is the phase of the LCA process that defines the purpose and method of including life cycle environmental impacts into the decision-making process.

2. Creation of life cycle inventory (LCI): The process of collecting data and undertaking relevant calculations in order to quantify the inputs and outputs to the product system over its entire life.

3. Life cycle impact assessment (LCIA): The process of translating the results of LCIA into indicators for specific categories of the environmental impacts or loadings of the product system.

4. Interpretation: The process of combining the results from LCI and LCIA in order to determine the most important inputs, outputs nd potential environmental impacts of any product system.

IV. LCA IN THE BUILDING CONSTRUCTION SECTOR

The importance of obtaining environment-related product information by LCA is broadly recognised, although applying LCA in the construction sector has become a distinct working area within its practice [7]. Although LCA is becoming accessible for use by building designers and other non-scientists; building professionals are still unlikely to be in a position to carry out their LCA studies. This is due to that the science behind it is very new and is still evolving. Hence, Khasreen et al. [7] argues that the use of LCA in the building sector is less developed than in other industries, including the engineering and infrastructure sector. However, Cassidy et al. [3] argues that LCA is arguably today’s most talked about topic in the green building movement as it is said to be one of the tools that will assist to achieve sustainable building practices.

The built environment is one of the largest sectors in any community and greatly contributes to the environmental impacts. The built environment contributes to the environmental impacts in the following ways: through the emissions of Greenhouse gases by burning fossil fuels through 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, as already highlighted above; that include: extraction of raw materials, manufacturing, construction, operation and maintenance, demolition, and disposal. In each operation, there are numerous environmental impacts associated with each and every life cycle stage of a building. One of the many reasons why buildings greatly contribute to the total environmental impacts is that all their involved life cycle stages take a considerable amount of time, for instance; buildings operation stage is mostly over 10 years and with heritage buildings, they are even more than that, with an average of over 50 years. Reducing the impacts associated with design, construction, operation and management of the built environment will take a concerted effort on the part of the many stakeholders involved across all of the stages of the built environment life cycle [9].

Although, undertaking an LCA for buildings will be fairly difficult but according to Crawford [9], in order to alleviate many of the environmental issues that humans are currently facing, the built environment must be the central to any environmental efforts where the LCA methodology need to be applied.

LCA methodology is one of the tools currently talked about in the current world green movement, and it is already being used in many sectors. In addition, LCA is the only science-based and credible tool that is designed to measure the environmental impacts of product [12], that is due to the holistic approach LCA takes on products, services, or activities amongst others. Furthermore, 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, [14] [2]. Moreover, LCA procedure investigates a broad range of environmental impacts associated with industrial products. With the adoption of LCA to reduce environmental building impacts, producers' decisions about alternative processes in their attempt to improve industrial environmental performance will be greatly enhanced to reduce the impacts of buildings to the environment.

The use of LCA in the built environment, with a particular use in the building sector can help achieve the sustainable building practices as advocated. LCA can be useful in the design stage of the building to assess the potential environmental impacts that may result from particular design decisions or choices. If LCA is used in or during the design phase it will allow comparison of materials before deciding (such as: comparing two types of skirting; timber and aluminum, or ceramic flooring). Being able to compare different materials before making specification will mean that the product with less environmental impacts will be chosen. This means that the materials being compared against each other should or will be assessed across their entire life cycle. In this instance, natural resources; such as timber amongst others will be taken into consideration in the selection of materials. The manufacturing or processing or raw materials used in the production of building materials will also be considered; the impact of the materials while they are part of the buildings and the maintenance that will be require within the lifespan of the building. Lastly, LCA will assist to determine if building materials can be reused, or be recycled after demolition and how they will impact the environment. For example; if timber skirting is to be part of the waste that is going to be incinerated how much does timber contribute to greenhouse gas emissions? However, it may be fairly difficult to assess -if none at all- all the environmental impacts associated with a material and then only realise them after the building has been built.

However, the awareness and use of LCA in the construction sector is fairly low; a study by Khasreen et al. [7] found that there is lack of an internationally comparable and agreed data inventory and assessment methodology that is a major obstacle to the application of LCA within the building industry. Overall, LCA of buildings is less advanced than in other industries. The currently available datasets for building products are typically not transparent, and most of them are based on local and simple materials but not components or composites. While Kohler and Mofatt [8], inform that LCA of the built environment is difficult to apply as the focus of the current LCA exposure in the building industry is increasingly on carrying out a more general analysis of the built environment. Kohler and Mofatt [8] further inform that a complete LCA is not affordable in most project unless it is integrated with other tools such as quantity surveying or energy simulation.

A. LCA tools and systems in the building sector

According to Khasreen et al. [7] LCA has been widely used in the building sector since 1990. However, a majority of the LCA analysis systems are only developed for assessing the environmental burdens of individual building materials and not a holistic assessment of the impact of buildings. Such systems include Athena, BeCost, BEES, Eco-Quantum, and Envest 2. Athena, for instance, is an American life cycle assessment tool for buildings and building assemblies. This tool complies with ISO 140140. Also, BeCost was developed by VTT Technical Research Centre of Finland. It is used to assess and present environmental impact data and maintenance costs. While, BEES (Building for Environmental and Economic Sustainability) was developed by the National Institute of Standards and Technology in the USA. It is used to measure the environmental performance of building products using a life cycle approach aligned with ISO 14040. Eco-Quantum is an Australian life-cycle assessment method based on ISO 14040. It is used to assess environmental impacts and greenhouse gas emissions of products over their whole life cycle. Envest 2 was developed by the British Research Establishment to evaluate and present environmental and life cycle costs of different materials and building assembly options. In this system, twelve criteria's, ranging from climate change to toxicity, are used to measure environmental impacts, and these are agglomerated into a single Ecopoint score. However, Zhang et al. [15], informs of eight systems or tools that were as a result of the increased awareness of the environmental impacts of buildings. The tools are; i) Building Research Establishment's Environmental Assessment Method (BREEAM), by the United Kingdom. Leadership in Energy and Environmental Design (LEED), by the United States. Green Star, by Australia, Hong Kong Building Environmental Assessment Method (HKBEAM), Japanese Comprehensive Assessment Schemes for Building Environmental Efficiency (CASBEE), South African Sustainable Building Assessment Tool (SBAT), Arup's Sustainable Project Appraisal Routine (Spear), and Hong Kong Comprehensive Environmental Assessment Scheme (CEPAS). However, the increase in the awareness of natural resource depletion and environmental impacts has led to a great number of tools that were specifically established and developed to reduce the incidence of human activities on the environment. Life cycle assessment (LCA) is one of these instruments, and it was drawn up to determine the holistic environmental impact of a product or service or activity or process.

V. LESSON LEARNT

This study assesses the level of awareness and usage of LCA in the building construction sector and how the LCA methodology can assist to achieve sustainable building practices in the built environment. The lesson learned from the review of literature were:

1. The level of awareness of LCA in the building construction industry is still at its infant stage and not totally embraced by the entire construction sector;
2. Also, the literature review revealed that there is lack of an internationally comparable and agreed data inventory and assessment methodology that is a major obstacle to the application of LCA within the building industry;
3. Also, it was discovered that LCA of buildings is less advanced than in other industries and that
4. The currently available datasets for building products are typically not transparent, and most of them are based on local and simple materials but not components or composites.
5. LCA of the built environment is difficult to apply as the focus of the current LCA exposure in the building industry is increasingly on carrying out a more general analysis of the built environment than on specific parts which will improve the industry;
6. Also, a complete LCA is not affordable in construction projects unless it is integrated with other tools such as quantity surveying or energy simulation.

It was also learned from the study that the use of LCA in the built environment, with particular use in the building sector can help achieve the sustainable building practices as advocated through the following processes:

1. LCA can be useful in the design stage of the building to assess the potential environmental impacts that may result from particular design decisions or choices.
2. LCA application at the design phase will allow comparison of materials before deciding
3. Being able to compare different materials before making specification will mean that the product with less environmental impacts will be chosen.
4. Also, the manufacturing or processing of raw materials used in the production of building materials will also be considered;
5. The impact of the materials, while they are part of the buildings and the maintenance that will be require within the life span of the building, will be informed through LCA.
6. Lastly, LCA will assist to determine if building materials can be reused, or be recycled after demolition and how they will impact the environment.

VI. CONCLUSION

This study set out to determine the awareness level of the usage of LCA in the building construction sector and how the LCA methodology can assist to achieve sustainable building practices in the built environment. It was found from the extant review of literature that LCA evaluates the total life cycle of a product, from -cradle to grave- i.e. from the extraction of raw materials to the disposal of the product. Also, it was established that the concept –cradle to grave- is referred to as life cycle assessment, which is developed as one of the tools to help reduce the impact of a product on the environment by looking holistically at the life of such a product and thereby encouraging and informing better alternative ways and materials to reach the product with fewer amounts of environmental impacts.

Furthermore, the study found that the level of awareness of the usage of LCA in the building construction industry is still at its infant stage and not totally embraced by the entire construction sector. Also, the study found that the use of LCA in the building sector will ensure a great reduction in the environmental impacts of buildings and thereby less harm from building construction activities to human and habitat life, thereby ensuring the sustainability of buildings. This is as a result of the fact that sustainable development is now closely studied and implemented as a tool to reduce environmental impacts. Hence, one such tool is LCA, which enables sustainability of buildings to be seen in each and every its stages.

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