ON THE EFFECTS OF BUILDING LIFE CYCLE ON SUSTAINABLE DEVELOPMENT: A CASE FOR THE ADOPTION OF A BIM BASED LIFE CYCLE ASSESSMENT TOOL

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ABSTRACT

This paper appraises the need for proper planning of the building life cycle via a Building Information Modeling (BIM) based building life cycle assessment (LCA) tool in order to ameliorate adverse impacts of the various stages on sustainable development, specifically the environmental dimension. The study was based on anecdotal evidence/the researcher's firsthand experience/observation and a literature survey of building life cycle stages and sustainable development/environmental impacts as well as the building life cycle assessment as the key issues. Findings revealed that all stages of a building life cycle consumes energy and impacts on the environment via emission of greenhouse gases, waste generation and pollution, thereby affecting sustainable development. A life cycle assessment planning tool is also in existence, which is essentially aBIM software that enables users or built environment professionals to predict the impact of building materials such as the carbon footprints and processes on the environment. It can evaluate the life of building production from -cradle to grave, hence looking holistically at the life of such a building, thereby encouraging and informing better alternative ways and materials to reach such a product with fewer amounts of environmental impacts. This study expects not only to serve as a reminder or new knowledge to built environment stakeholders of how their activities cost the environment, it may also prove valuable to protecting Nigeria's built environment, construction industry, infrastructure development and/or sustainable urban development. However, challenges still abound that there is the lack of political will of the government to implement sustainability/environmental protection initiatives like promoting the mandatory adoption of LCAs as a construction planning tool, encouraging research into eco-friendly building materials and punitive measures on erring clients, designers and contractors on use of non-environmental friendly building materials and practices. Though, LCA tool is still very much at its infancy especially in the developing parts of the world like Nigeria, there is the urgent need for construction/built environment professionals and stakeholders to embrace it during project planning in order to ensure environmental protection and ultimately sustainable development.

Keywords: Building life cycle, Life cycle assessment, Sustainable development, Planning, Environmental impacts

INTRODUCTION

Sustainable development has been defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs (United Nations General Assembly, 1987, p. 43). The overall goal of sustainable development (SD) is the long-term stability of the economy and environment; which is only

achievable through the integration and acknowledgement of economic, environmental, and social concerns throughout the decision making process. While the economic and social pillars deal with supporting business and corporations to adhere to sustainability laws and creating awareness of legislation protection to protect the health and well-being of people, The third pillar which is environmental protection is concerned with the protection of ecosystems, air quality, integrity and sustainability of natural resources that place huge demands on the environment. It deals with the potential impacts or damage of technological advances on the environment (Stoddart, 2011).

Buildings not only mirror the infrastructural development or advancement of any nation, they are also products of careful decision making which compels the need for owners or clients and other stakeholders in the built environment to carefully think about the activities required to erect these facilities within available resources in such a manner that is not detrimental to future generations.

A building, just like a human being has a life cycle. The existence of a human being begins right from conception, to birth, normal growth/development and death. The existence of buildings on the other hand begins from conceptualization of the idea by the owner to planning and design, construction, usage and finally, possible demolition which marks the end of the building life span. However, Ngwepe and Aigbavboa (n.d) submit that there six life cycle stages of buildings are: raw material extraction; manufacturing; construction; operation and maintenance; demolition; and disposal, reuse or recycling. Department of Environmental Affairs and Tourism (DEAT) (2009) classify building in three stages, namely construction, operations and deconstruction. Though research is still ongoing on exploring methods of incorporating a whole life cycle view of buildings, rather than just focusing on the impact of the construction phase as is the current situation. This paper attempts to contribute to the body or scope of knowledge in this respect.

The life cycle stages of a building are all intensively involved, in that they consume a huge chunk of natural resources, energy and water are consumed in each of them, which impacts on the environment.. This paper thus discusses the imperatives of adequate planning of all stages for sustainable urban development, specifically the environmental dimension via a life cycle assessment as a veritable planning tool. This is done in order to encourage and to inform ways which can be incorporated into the building sector in order to reduce their impact on the environment and ultimately promote sustainable development.

Methodology

The study was conducted with the aid of primary and secondary sources. The primary sources were drawn from anecdotal evidence or the authors firsthand experience/observation, while the secondary sources constitutes existing literature, published and unpublished works of authorities in the field. Building life cycle and sustainable development (environmental impacts) as well as the life cycle assessment tools of buildings constitute the key issues extrapolated from the various sources.

The Building Life Cycle

According to Bengt (2013), the building life cycle begins with obtaining and transporting raw materials to factories for manufacturing. This is the ‘product phase’. Secondly, all construction products (including admixtures, formwork etc.) are transported or distributed and end up at the building site. All installing and other on-site work is then undertaken. This is the ‘construction phase’. Thirdly, maintenance, repair, replacement and refurbishment involve periodic site activities and replacements of components (instigating more extracting, transporting and manufacturing). This is the ‘use phase’. Fourthly, there are the on-site activities to demolish the building, process all waste, and transport it to where it will be reused, incinerated or disposed of in landfill. This is the ‘end of life’ phase. In the

view of Crawford (2011), a building has six life cycle stages, namely: raw material extraction, manufacturing, construction, operation and maintenance, demolition and disposal/reuse/recycling. In the view of DEAT (2009) building can be classified in three stages, namely construction, operations and deconstruction. Figure 1 synthesizes the aforementioned stages.

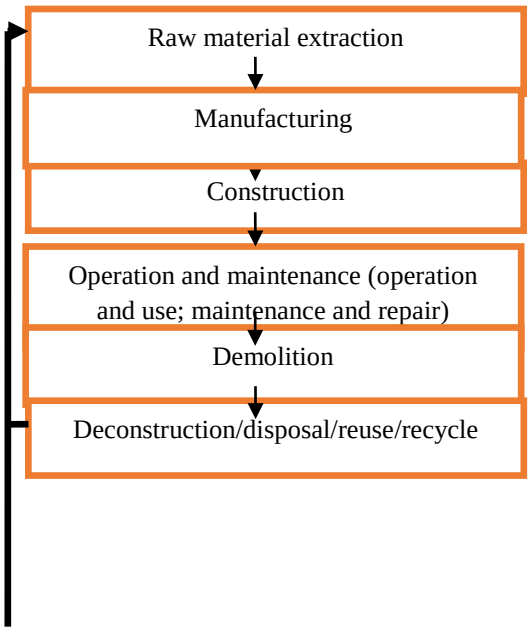


Figure 1. Building life cycle stages (Adapted from Bengt, 2013; Crawford, 2011; DEAT, 2009)

Building Life Cycle Cost Assessment

An important consideration in building life cycle is the life cycle cost (LCC). The life cycle cost of any building development embraces all cost components over the entire life of the building development. Ashworth and Hogg (2007) define LCC as the total relevant costs over the life of a system, including cost of acquisition, operation, maintenance, modification and disposal for the purpose of decision making. LCC can help in determining how the owner's money is distributed during the life period of the facility (Ngwu, 2011). It is used to determine the most economical way of meeting the entire life needs of a building. The earlier LCC is applied, the greater the possibility of saving and lowering the committed cost. In the view of Stephen and Alphonse (1995); Douglas, Peter & Jonathan (1999), LCC is also used to identify the design feature, components and finishing that have lowest total cost. It also provides a means of identifying high cost areas and evaluating changes that will reduce these costs. LCC takes into account the initial/capital costs and other running costs (cost of operation and maintenance of the building) over the life of the building. The initial/capital costs consists of items like land costs, construction costs, professional fees, while maintenance/operating costs are made up of items like repairs, replacements, cleaning administration and managing costs(Ashworth & Hogg, 2007).

Building life cycle costing is often calculated alongside building life cycle assessment. The earliest in the design process you calculate Building Life Cycle Costing analysis, the most savings you can achieve. Moreover, in both cases, you can compare design alternatives to find out which is better over the whole life cycle of the building. For example, if you perform LCC calculations you might find out that a product that has a cheaper initial cost might end up being much more expansive in the long run because it will need to be replaced more times during the building use phase, which is usually around 60 years. In short, the business case for Building Life Cycle Costing is a strong one. What Building LCC does is to provide reliable metrics on costs and savings over the whole lifetime of the building, and when paired with LCA, it can help design buildings that are more sustainable both from an environmental and financial perspective (Building Life Cycle Assessment, n.d).

Overview of Sustainable Development

Although many definitions abound, the most often used definition of sustainable development is that proposed by the Brundtland Commission. In 1987, the Bruntland Commission published its report, *Our Common Future,* in an effort to link the issues of economic development and environmental stability. In doing so, this report provided the oft-cited definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN General Assembly, 1987, p. 43). Albeit somewhat vague, this concept of sustainable development aims to maintain economic advancement and progress while protecting the long-term value of the environment; it "provides a framework for the integration of environment policies and development strategies" (UN General Assembly, 1987).
Thus, sustainable development recognizes that growth must be both inclusive and environmentally sound to reduce poverty and build shared prosperity for today's population and to continue to meet the needs of future generations. It is efficient with resources and carefully planned to deliver both immediate and long-term benefits for people, the planet, and prosperity (https://en.unesco.org/themes/education-sustainable-development/what-is-esd/sd). The concept is thus geared towards thinking about the future in which environmental, societal and economic considerations are balanced in the pursuit of an improved quality of life. For example, a prosperous society relies on a healthy environment to provide food and resources, safe drinking water and clean air for its citizens.

UN General Assembly (1987); Cerin (2006); Dernbach (2003) & Stoddart (2011) explain that the key principle of sustainable development underlying all others is the integration of environmental protection or stewardship, social inclusion, and economic growth into all aspects of decision making or sectors of development. These are often termed the three pillars of sustainable development (*see figure 2*). Culture has also been regarded as a fourth pillar (Concept of sustainable development, n.d).

The economic dimension entails providing incentives for businesses and other organizations to adhere to sustainability guidelines beyond their normal legislative requirements. The supply and demand market is consumerist in nature, and modern life requires a lot of resources every single day; economic development is about giving people what they want without compromising quality of life, especially in the developing world.

The social development is about awareness of and legislation protection of the health of people from pollution and other harmful activities of business. It deals with encouraging people to participate in environmental sustainability and teaching them about the effects of environmental protection as well as warning of the potential dangers.

Environmental protection is the third pillar and, to many, the primary concern of the future of humanity. It defines how to protect ecosystems, air quality, integrity, and sustainability of our resources and focuses on the elements that place stress on the environment. It also concerns how technology will drive our greener future; and that

developing technology is key to this sustainability and protecting the environment of the future from potential damage that technological advances could potentially bring.



Figure 2. Pillars of sustainable development (UN, 1987)

BUILDING LIFE CYCLE PLANNING AND SUSTAINABLE DEVELOPMENT: THE NEED FOR LIFE CYCLE ASSESSMENT (LCA) TOOL

Building life cycle and environmental sustainability

Sustainability or sustainable development is now closely looked in relation to the reduced environmental impacts. It is no longer just about developing the lives of the people but however developing these lives while also taking care of the environment (Concept of Sustainable Development, n.d). Sustainable development in this instance must meet the required sustainable building practices according to applicable legislation/s, etc. For example; building a house that ensures good quality of life for the people whilst contributing less to the environmental impacts and that is during the whole life cycle of that building; from cradle to grave.

Findings from a literature survey carried out by Ngwepe and Aigbavboa (n.d) surmised that that energy is consumed across all the stages of a building project. Environmental impact such as greenhouse gas emissions, waste generation and pollution etc. associated with a building are declared to be of a great quantity due to many and relatively long life cycle stages of building. Table 1 summarises and describes how the various life cycle stages of building can impact on environment and ultimately sustainable development.

Table 1. Building life cycle stages and impacts on environmental sustainability

S/N	Building life cycle stage	Nature	Impact on environmental sustainability
1.	**Raw material extraction**	Involves mining of building raw materials like limestone, copper, timber, petroleum which are naturally embedded in the earth.	• Scarcity of non-renewable resources • Dumping of waste, chemicals and other dangerous minerals in the water, soil and air • Resource depletion, release of emissions into the

			atmosphere (which may cause acid rains) and pollutants due to mining operations, fossil fuel burning, operation of transportation equipment for raw materials to the factory • Land erosion, loss of biodiversity due to indiscriminate harvesting and forced animal migration
2.	**Manufacturing**	Here, natural resources are converted to basic building or construction materials such as steel, plastic, cement, aluminum. Material production factories have been considered to be one of the largest fuel consumption industries globally.	• Air pollution due to emissions of green house gases(GHG) like CO_2 and methane from factories • Pollution of water bodies and soil due to dumping of factory wastes
3	**Construction**	Involves fitting parts or materials together to form the building structure. They are the basis of development geared towards bettering the lives of people. It involves considerable form of skills and consumes large quantities of materials. This stage accounts for one-third and one-half of commodity flow worldwide and consumes 40% of materials entering the global economy and generates 40% of GHGs (OECD, 2003).	• Depletion of natural resources • Release of solid and liquid wastes and toxic emissions into the air as a result of transportation of materials, operation of construction plant and equipment like trucks, mixers etc. • On-site construction requires energy in form of electricity or fuel to power electric tools and machinery hence the production of waste and emissions (Beaumont, 2001).
4.	**Operation and maintenance** **(a) Operation and use**	Regarded as the longest stage of a building life cycle. Some buildings have a span of over 50 years. Here, water, energy are required for heating, ventilation and air conditioning (HVAC), lighting, telecommunications etc.	• Involves burning of fossil fuels especially in developed countries where coal is required for heating. • Liquid fuels like crude oil and gas, hydro, nuclear, petroleum products are used for power, heating and lighting which in turn produces harmful emissions • Fresh water consumption depletes water resources while disposal of sewage waste can pollute water bodies and soil and affect biodiversity (OECD,2003).
	(b) Maintenance and	Takes place during refurbishments or when the	• Generation of solid waste and dumping into water, soil causing pollution

	repair	building is demolished	• Consumption of large quantities of natural resources for producing new materials • Harmful emissions from demolition equipment and transformation of demolished materials
5.	**Demolition**	Involves dismantling the structure, separating the components for the purpose of removing the whole building from existing. It is necessary due to safety, health concerns and infrastructural developments and technological advancements	• Generates large quantities of solid waste which could find their way into the water and soil, hence affecting biodiversity and soil/water quality • Waste going for incineration emits GHG affects air quality • Emissions from demolition machinery and transportation of waste to landfills • Disposed materials may decompose and leach into the ground, resulting in eutrophication (the process by which a body of water becomes enriched in dissolved nutrients like phosphates that stimulate growth of aquatic plant life, resulting in depletion of dissolved oxygen) of the surrounding environment • Decomposing materials like timber can release CO_2 and CH4(methane) into the atmosphere and soil
6	**Recycling and re-use**	Building materials or components can be reused after being dismantled (e.g windows, doors, roofing sheets, blocks).	• Materials that require re-processing will entail fuelling for transportation, energy and other resources to make up the new products, resulting in emissions into the atmosphere

Source: Adapted from Ngwepe and Aigbavboa (n.d)

The case for Building Life Cycle Assessment (LCA) as a planning tool for sustainable development

The life of a building and the lives of its components are easy to confuse. In fact, understanding exactly how they overlap is important to clearly define the scope of building life cycle analysis or assessment and identify the processes that we need to understand better to reduce the environmental impacts of buildings. All wastes generated during transporting, manufacturing, constructing and replacing components of buildings must be planned and managed effectively. These processes apply to all of the main building

components (the envelope, finishes, services and structure). The next logical step of appropriate planning is to identify the variables or 'factors' associated with each process to clarify what designers can do to influence the effective and efficient use of resources with minimal environmental impact. According to Horne, Grant & Verghese (2009), buildings present a classic life cycle assessment problem, since they consume considerable amounts of materials and energy and therefore create impacts during at least two major life cycle phases: construction and operation.

Since buildings are complex systems, the use of a Building LCA software is usually required. A Building Life Cycle Assessment tool can automate the calculations, making it easier and faster to calculate LCA, and, therefore, economically feasible to integrate LCA in the design phase. According to Building Life Cycle Assessment (n.d); Ngwepe and Aigbavboa (n.d), LCA evaluates the life of a product, etc. from -cradle to grave- i.e. from the extraction of raw materials all the way to the disposal of such a product, etc. 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 such a product with fewer amounts of environmental impacts.

Ngwepe and Aigbavboa (n.d) further argue that the six life cycle stages of a building makes the undertaking of LCA for the buildings almost impossible or more than LCA may be required to really understand the environmental impacts of a building; because a it involves a great number of stakeholders; companies, personnel, legislations, etc. The use of LCA in the building sector may ensure a great reduction in the environmental impacts of buildings and thereby less harm or prone to harm of human and habitat life. LCA thus ensures sustainable development via sustainable building construction/practices.

In recent times, Building Life Cycle Assessment (LCA) has been linked with Green Buildings where the focus has been executing buildings with minimal emissions or impact on the environment. According to Building Life Cycle Assessment (n.d), **there are three main reasons why Building LCA is important:**

i. Building Life Cycle Assessment is a scientific methodology that can support the efforts of Green Building professionals to build more sustainable buildings.
ii. Construction professionals need to be aware of how buildings affect climate change. Buildings cause 40% of global carbon emissions, which have a proven effect on global warming
iii. Healthy and affordable living is one of our sustainable development goals. As more people around the world access better housing, we have to make sure the buildings we all build won't bring Planet Earth to the brink of destruction

LCA can be carried out via a software tool which is essentially a Building Information Modeling (BIM) tool. Construction/built environment professionals are especially encouraged to purchase and embrace this LCA software called **'One Click LCA'** which will aid them in proper LCA of their projects (https://www.oneclicklca.com/trial-access/)
Building Life Cycle Assessment (n.d) further itemize the following salient and recent facts about Building LCA planning tool that is worth noting:

(**a) Building Life Cycle Assessment is a scientific methodology:** Calculating the Life Cycle Assessment of a building is a scientific methodology used to calculate the environmental impacts, including carbon footprint, of a product, service, or process**. It** is possible to calculate the LCA of a building to find out how it will affect the environment through its whole existence, from extraction of raw materials to construction phase, use, and finally demolition and disposal.

(b) **Whole Building Life Cycle Assessment and Carbon Footprint:** With building LCA it is possible to calculate the carbon footprint on a building and learn how much C02 it will release through its whole lifecycle. However, Building Life Cycle Assessment does not evaluate only carbon footprint, but many more impact categories, in order to fully understand the effects of a building on the ecosystem. For example, Global warming potential, which is one of the official impact categories measured in Whole Building LCA according to European standards, measures the impact of all greenhouses gases emissions, including but not limited to carbon.

Impact categories help us evaluate how different actions of the building life can affect the environment: for example, ozone depletion potential measures the potential of specific substances to erode the ozone layer, and acidification potential measures the potential of pollutants to cause the acidification of soil and water. To solve this, a solution can be adjusting results according to local conditions, something that 'One Click LCA' does with a data regionalization methodology.

(c) Building Life Cycle Assessment helps fight Climate Change: Performing a Building Life Cycle Analysis is currently the most reliable way to evaluate the sustainability of a building. The adoption of LCA by building professionals followed can help and increase awareness of how buildings affect global warming.

(d) LCA of Building materials can assess the environmental impacts of specific materials or products: Materials are a very important part of Building LCA. By performing building materials LCA, one can assess the environmental impacts of a specific material or product**.** This often takes the form of Environmental Product Declarations, or EPDs and it basically means calculating the LCA of a product, from cradle to cradle, or from extraction of the material to disposal and recycling.

In fact, building materials already embodies impacts when they are purchased and brought to the building site: their production has caused certain gases to be released in the atmosphere, the transportation of the materials to the manufacturing facilities has caused other impacts, and so on. If an EPD of that material is available, it means that the impacts of the material through its whole life cycle are known, and that makes it easier to calculate the environmental impacts of the building. This is why many developed countries are pushing towards creating EPD databases of materials produced by local manufacturers.

(e) Building LCA can be used for achieving green building certification/Building CLA Credits: There are numerous LCA applications in construction. Not only can a whole Building LCA be conducted, it can also measure the impacts of the building site and use it for land sales competition, refurbishments, or city planning, performing the LCA of an Infrastructure project, or achieving assessment or impact credits on Green Building certification schemes around the world (https://www.oneclicklca.com/lca-credits-green-building-certifications/); like Leadership in energy and environmental design(LEED)**(**https://new.usgbc.org/leed); Building Research Establishment Environmental Assessment Method (BREEAM) (https://www.bregroup.com/products/breeam/) and the German sustainable building council (DGNB) **(**https://www.dgnb-system.de/en/system/certification_system/index.php).

(g) Building LCA can be automated: To calculate Building LCA, the user will **need the bill of materials for the project.** This information can be stored in BIM, a Revit model, a gbXML file, or even an Excel spreadsheet. The user will also need the calculated energy performance of the building. As the construction industry moves towards a wider adoption of Building Information Modeling and the use of modeling software, the possibilities of

automation for Building LCA have increased dramatically with the development of plugins and integrations.

(h) An LCA database is needed for effective use: Most Building LCA tools come with an LCA database of building materials. This allows users to map material choices from their model to the software. Assessing the impacts of building materials is a necessary part of calculating Building LCA and an LCA database helps to achieve exactly that goal. There are two types of Life Cycle Inventory Databases**:** LCA databases can use generic materials, (Environmental Product Declaration) EPDs, or both. An EPD database incorporates which allows you to choose a specific material produced by a specific manufacturer and access all the Life Cycle Assessment data of that material. On the other hand, a generic database is based on industry averages, which means that highly performing materials are put in the same basket as materials that emit a lot of CO2. For more transparent and reliable results, use of an EPD database is strongly advised.

(i) Building LCA is growing, but not fast enough: There are some challenges to the wider adoption of Building LCA. First of all**,** its use can be costly and time-consuming**,** requiring weeks and even months to be completed. This has been solved by the development of dedicated tools that can automate the calculations and cut down the time required for an LCA by 85%. Secondly, the lack of a database can be an obstacle for Green Building professionals working in countries without their own EPD database. To solve this, a solution can be adjusting results according to local conditions, something that 'One Click LCA' does with a data regionalization methodology. Thirdly, while there is more awareness surrounding the impact of the built environment on climate change, there is a need for stronger incentives and legislative initiatives by international organizations and governments to make the business case for building life cycle assessment even stronger.

(j) Any built environment stakeholder can be a Building LCA expert: Building production needs to be sustainable and impact positively on the environment, hence it has to be easy to understand for everybody, even children. At the same time, Building LCA is a complex topic that cannot be fully summarized in this paper. Interested stakeholders or professionals can begin to develop their expertise in Building LCA by downloading the Building Life cycle assessment white paper, joining the Linkedin group: LCA Made Easy, following the twitter handle, reading more articles, case studies and watching videos on LCA, downloading studies, and signing up for the newsletters to receive the best LCA content twice a year (https://www.oneclicklca.com/trial-access/).

CONCLUSION

The process of building production comprise of six life cycle stages, i.e. extraction of raw materials, manufacturing, construction, operation and maintenance, demolition, and disposal. They produce considerable amount of environmental impacts across each and every stage and impacting negatively on sustainable development, hence the need for adequate planning to ameliorate these impacts. Emissions of Greenhouse gases by burning fossil fuels during transportation of materials during the construction activities; or incineration of solid waste that is generated from construction as well demolition activities are just a few of these effects.

With the ever increasing natural resource depletion, a number of planning tools have been developed to predict and reduce the impact of building life cycle on the environment. One of such tools is Life cycle assessment (LCA) which was developed to determine the holistic environmental impact of a product or service or activity or process.

While there is increasing awareness surrounding the impact of the built environment/building production on climate change, propelled by the annual climate change summits held around the globe, there is a need for stronger incentives and legislative initiatives. LCA tool is still at its infancy especially in the developing parts of the world like Nigeria, however it is hoped that construction/built environment professionals and stakeholders will embrace this tool for proper planning of projects in order to promote sustainable development. While the European Union and countries, like Finland, France, and Norway, are pushing for zero carbon buildings throughout the life cycle, there is a still a lot of work to be done to make the business case for adoption of building LCA tool even stronger in developing countries. Given the lack of political will characterizing a country like Nigeria as well as the dearth of research in eco-friendly building materials, the adoption of LCA to plan for our sustainable development may take longer than we may expect.

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