American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)

ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Sustainable Development: The Life Cycle Design Approach

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Abstract

This paper reviewed the concept of sustainable development and that of Life Cycle Design. The influence of the latter in achieving the former was explained. In particular, a diagram of their interconnection has been developed; thus, illustrating the very important interdependence and justification of one on the other to exist and function as concepts. Moreover, a quantitative Life Cycle Design equation was propounded as a means of analyzing in numerical terms the attributes of Life Cycle Design (LCD) that distinguishes it from the Traditional Design Method (TDM) for any product of interest. Design for Environment (DfE) was also reviewed; highlighting it's origin, justification, challenges and proffering solutions on means of improving the effectiveness and wide acceptance of the concept. A new basis for classifying life cycle design; Holistic, Non Holistic, Adhoc, Strategic and Classic were discussed along the line of this application.

Keywords: Sustainable development; Life Cycle Design; Design for Environment and Traditional Design Method.

1. Introduction

Growing environmental concerns led to the birth of environmental policies and the development of environmental assessment methodologies in order to lower the environmental footprints of product manufacturing.

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Consequently and for sustainable development, the manufacturing industry became proactive in the design of new products and improvement in the existing products. Alongside this phenomenon, various concepts including the “Life Cycle Design” emerged [1]. Until recently, the life cycle framework has been associated with environmental assessment than design. Gregory and Dan (1994); explained further that the principle of life cycle design (LCD) originates from concurrent design programs [2]. Unlike it’s evaluation tools (i.e. LCA etc), the life cycle design (LCD) seeks to integrate product and process design in a single function to more effectively reduce aggregate environmental impacts associated with product systems [1-3]. In adopting the option of LCD, it is important to note that it is a comprehensive approach towards evaluating the entire processes involved in the manufacture of goods or provision of services [2-4]. LCD evaluates the totality of products’ effects from the cradle of raw materials extraction through the various production processes to the consumption and eventual disposal of all possible waste and their impacts on the environment. Hence, the name Life Cycle Design. (LCD)[2,4,5].

It is therefore imperative to distinguish a product design concept emanating from the traditional concept of the efficiency and economics of the product design from a design concept focused on LCD in relation to sustainability approaches [2-6]. Whereas the primary aim of a product manufacture is for it to meet certain objectives of functionality, factoring it’s economics of production, especially for commercial goals, the LCD sustainability principle can be incorporated or infused in the design process to ensure that the products impacts on the socio-economic, health, physico-chemical and biotic environmental spheres of relevance are highly minimized, if not possible to be completely eradicated [2,6,7,8].

This paper reviews the concepts of sustainable development and Life Cycle Design. It thus proposes the LCD equation. Other key concepts; Design for Environment (DfE) and Traditional Design Method (TDM) are also explained as ingredients in achieving sustainability through the LCD. Finally, a developed diagram that explained the interactive stages between LCD approaches and sustainable development concludes the paper..

2. Sustainable Development

Sustainable development is a fairly recent concept that arose out of the need to responsibly exploit, process and utilize the earth resources in such a way that the continued availability of such resources are not in any way jeopardized for both the current or future generations [3-8]. Consequently, the World Commission for Environment and Development report (WCED, 1987) defines Sustainable Development; as that model of economic and social development that meets the need of the present generation without compromising or jeopardizing the ability of future generations to meet their needs [9]. Sustainable development is therefore a concept that has very clear principles or elements, objectives and goals. It is obvious from the meaning and concept of sustainable development that one of the most fundamental objectives/goals of sustainable development is the conservation and sometimes by extension preservation of the Earth resources, such that it shall continue to adequately service the needs of mankind inter and intra generationally. The definition of conservation rendered by Brown (1981), clearly situates the concept of conservation within the central domain of being a cardinal objective/goal of sustainable development; “conservation is the sound preservation, management and rational use of available renewable natural resources” [10]. Thus, the various ways of conserving biodiversity, have been outlined in the following key strategies as basic systems for conservation of bio-resources [10]:

- The rapid decline of certain species can be protected by banning extensive hunting, fishing, trapping etc.
- The rare species having small populations should be allowed to live under protected environment.
- Through habitat management as well as by ensuring food, water and shelter, we can conserve the threatened species. For optimum survival of wildlife, reserves and sanctuaries should be created.
- Strict enforcement of laws can curb the extensive killings and safeguard wildlife from its dwindling position.
- Sanitation measures in a habitat can protect the threatened species that have been affected by disease.

From the preceding, it can be inferred that conservation is a critical aspect of any project or development that is focused on sustainability principles. Conservation can therefore be said to constitute some form of intrinsic tool in approaching and realizing sustainable development objectives.

Another aspect of the sustainability objective/goal is preservation. Whereas it is a word that can be interchangeably used with conservation in relation to sustainable development, preservation can be said to constitute an aspect of the overall objective/goal of preservation within the context of the subject matter of sustainable development [1,6,11]. This is because the need to preserve could be for future use or an effort to ensure continued existence of an earth asset in this regard either in it's pristine or near pristine condition [11]. Weiss, (1989) justified this assertion as he amplified one of the four cardinal principles of sustainable development thus; "The principle of inter-generational equity advocates the necessity to preserve natural resources for the benefit of future generations". In order words, preservation would entail actions or inactions intentionally deployed in order to protect and not in any way exploit a resource so that it can be available for future generations. However, it is vital to point out that preservation within the concept of sustainable development is more relevant to the issues of protecting the environment that bears the resources that man has continued to exploit for his survival [6,11].

The key challenge in this "school of thought" however, is how, where and when to draw a line between what should be conserved or preserved considering the conflict of resource interest globally [6-11]. Suffice to say for

now, that this of course is the basic problem that sustainable development vis-à-vis Life Cycle Design is targeted to achieve.

3. The relevance of life cycle design to sustainable development

Reference [12] in a review explained the dependence of a clear understanding of the impacts and benefits of a product or service throughout the whole life cycle to successful and sustainable innovation. Furthermore, the long tradition in the chemicals and the chemistry-using sectors of not worrying about the raw material and its impact(s) to both the product and the environment, result in the evolution of policies and demand of societies for a more responsible product stewardship; thinking beyond the factory gate and understanding the full life cycle of a product or an activity [12]. In a similar analysis, Karthik et al (2010) in their review, explained that carbon dioxide emission from the industrial sector in the United States is expected to increase to over sixteen million metric tons by 2030 as against the over twelve million metric tons in 2007. Hence, the imperative of design products and processes that is environmentally sustainable [13].

Life cycle design applies sustainable development principles with the goal to minimize the aggregate life cycle environmental burden associated with meeting societal demands for goods and services [2-3]. The major compelling justification that has propelled sustainable development is related to the problem that "World resources are not infinite and in juxtaposing the present level of consumption of these resources against projections of increasing populations, it should tolerate or support such ways of living" [2,6,7,14,15].

Several diverging approaches with respect to system boundaries and allocation methods, risk based LCA and environmental input-output based that may have a tense relation with some of the basic principles of the ISO (sustainable development) standards, led to the commissioning of the CALCAS (Co-ordination Action for innovation in Life Cycle Analysis for Sustainability) project by the European Commission. Thus, the establishment of a framework for Life Cycle Sustainability Analysis (LCSA) which links life cycle sustainability questions to knowledge needed for addressing them [16,17]. It identifies available knowledge and related models, knowledge gaps and defining research to fill the gaps [16,17]. Hence addressing the full sustainability scope (people, planet and prosperity) and to a more complete set of mechanisms [16,17].

The elements of sustainable development are encapsulated in four principles. Accordingly, Weiss, (1989) expatiated on the four principles of sustainable development as follows [11]:

- The principle of inter-generational equity advocates the necessity to preserve natural resources for the benefit of future generations.

- The principle of sustainable use implies that natural resources should be exploited in a "sustainable" or "prudent" or rational or "wise' or "appropriate manner".

- The principle of intra-generational equity acknowledges that the use by one state must take account of the needs of other states.

- The principle of integration suggests that the environmental considerations be integrated with socio-economic or other development plans, programmes, projects and the functionality of developmental project needs should equally be taken into account in applying environmental objectives.

It is therefore very obvious that there is a strong relationship between Sustainable development and LCD. This is more so that life cycle design has implications for the entire value chain (Figure 1) of a product from cradle to grave [2,8,18].

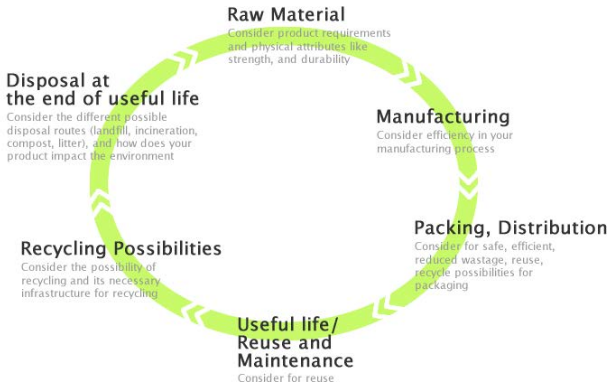


Figure 1: Stages of a products life cycle **–** http://d2w.com.sg/uploads/Life-Cycle-Stages.png

Thus, the challenges posed by the duo of the product impact on the environment cum it's utilization becomes fundamental in the design approach towards the utilization of such products for sustainability. Consideration to the most common Design for Environment (DfE) practices; Design for recycling, Design for manufacture; Design for disassembly; Design for energy efficiency and hazardous material minimisation, or elimination are given in LCD [19]. It is only through the careful and planned application of the principles of LCD at all stages of the product development and utilization that maximum sustainable development objectives and goals achievable from it can be realized [8,19,20].

4. Design for Environment

Although, LCD and DfE are difficult to distinguish, the genesis of Design for the Environment (DfE) is from the design for X approach (DfX); where X can represent manufacturability, testability, reliability, or other downstream design considerations [2,8,19,20]. It is a concept that arose out of concern by researchers that most of the designers' products to meet the developmental needs of man were largely concerned with the aesthetics and customer satisfaction of their products [8,20]. They were not necessarily taking into cognizance the social and environmental consequences of their finished products on the environment. Hence, the non-consciousness for the pre-designed for environment era, was described thus; "this pre scenario developmental product probably had its origins in 1974 with Victor Papanek's critique of designers' obligations to society and the environment in his book Design for the Real World: Human Ecology and Social Change [18,21]. On this basis, designers were observed to be preoccupied with a few aspects of the product, rather than the whole product; its function, maintainability, affordability and its social and environmental impact" [18,21].

Hart in his research [15] was of the view that designing for environment had been a slowly progressing concept initially, but had recorded tremendous progress following the several reviews of the publication of the work; "Beyond Greening: Strategies for a Sustainable World. According to Lee and Xu "ranging from food to chemicals to machine tools, there was no consensus of opinion on what constituted good DfE practice" [18]. The authors further asserted that Companies used guidelines and checklists more than analytical tools which were mainly developed in-house. The implication of this is that there was no uniformity of standards that could be applied in developing the practice of DfE for productive ventures globally [18,20,21]. Every organizations application of in house developed standards meant the outcome of such analysis could be quite subjective and disputable, depending on who is doing the evaluation [18,20,21].

In order to move the concept of DfE forward, it therefore became expedient to sensitize the productive enterprise machineries of the world to shift their design approach towards designing for the environment (DfE). Indeed the concept of DfE would no longer be an option to be ignored. Rather, it should be a mandatory requirement for the globe to continue existentially at optimal levels of sustenance, using standardized approaches. The push to Design for the environment was further justified and energized by some surveys carried out among various global brands [18-22]. The findings of the surveys clearly showed that manufacturers of such brands either deliberately avoided designing for the environment or could not help designing for the environment due to certain obstacles [18-22].

A good example is the report by [23] of four major electronics firm in the United States on the application of DfE in their product development. The result showed that most firms were only dragging along in applying DfE in their product development designs. Further, it was revealed that there is greater chance of more widespread diffusion of DfE if there were technical competency centres containing company-wide information relevant to environmental design and if these centres coordinated with product design teams. Access then, to environmental costs and benefits by product managers were also implicated as serious stumbling huddles for the application of DfE practices in industry [23].

With these findings the poor status of applying DfE principles in product development in industry as that period and some of the major obstacles preventing industry from applying the principle of DfE became very glaring to researchers and policy makers globally. This therefore provided the basis for a more justified and more purposeful push for industry to incorporate the principle of DfE in their product development design concept [19,24].

Furthermore, one of the most compelling reasons that contributed to producers embracing the need to design with environmental consequences in mind is certainly connected with the various environmental turbulence and disasters of the late 20th century [1,3,6,20]. These occurrences occasioned global environment summits that were held particularly from the second half of the twentieth century. Notable in this regard is the Stockhlom conference on human environment of 1972 and the Rio Earth summit of 1992. The 1972 Stockholm Conference on the Human Environment laid the foundation for the Rio Earth Summit of 1992. One of the major issues of the Stockhlom summit is that it set out some fundamental principles and declarations that engendered the global need to preserve and enhance the human environment [25].

The Rio Earths was the next large scale global environment summit; the Summit hosted an overwhelming 172,108 governmental officials, 2,400 representatives of non-governmental organizations, and 17,000 attendees at a parallel NGO forum. With an estimated 10,000 journalists on site, the widely reported Summit was heard by millions of people around the world. The Rio Summit focused on developing a global framework for addressing environmental degradation through sustainable development [25].

Among many approaches which focus on environmental impacts and conserving resources through design is the life cycle design (LCD) [2]. It focusses on the life extension (i.e. durability, adaptability, reuse and remanufacture) which is on top of the LCD strategies. Moreover, the design for recyclability is another single strategy (of LCD) effort aimed at closing the material life cycle loop [2].

5. Life Cycle Design Approaches: classifications and applications

The recognition of how choices influence what happens at each stage of product manufacture in order to balance trade-offs and positively impact the economy, the environment and the society is what is termed Life cycle approach [6,26,32]. It is a way of thinking which helps us recognize how our selections are one part of a whole system [32].

Life cycle approaches can be splitted along the lines of analytical and practical approaches; The analytical part, containing analytical tools, checklists, models and techniques, are used to assess the effects of planned decisions in a scientifically sound way [28-30]. Also, life Cycle Assessment (LCA), is used to assess the environmental consequences of products or services over their whole life cycle ("from cradle to crave") [28-30]. It is one of the most fundamental tools for application in Life Cycle Designs towards achieving sustainable development in productive ventures. A producer, for instance aiming at developing a product that is easy to recycle, can use this tool to calculate the environmental impact of the re-designed product by comparing the environmental impact of the old and new design. The practical life cycle approaches are meant to translate the results from the analytical approaches, and help to achieve a life cycle economy [26,27]. Governmental and corporate programs, for instance, are programs that aim to reach (a part of) a life cycle economy. Both governments and organizations can enact a Green Procurement policy, which is used to encourage the purchase/consumption of products or services with a reduced environmental impact. Policy instruments help governments and organizations to execute these programs. In the case of the Green Procurement policy, governments can use a financial instrument (taxes) to stimulate the purchase of sustainable products [28-30].

Understanding the basis for classifying and applying Life Cycle Design approaches to sustainable development is critical towards the standardization of the practice of Life Cycle Design (LCD). Most importantly it is a needed knowledge in achieving sustainable development objectives and goals. These have been developed to assist in decision-making at all levels regarding product development, production, procurement, and final disposal. They can be used in all sectors, and offer the possibility to examine a range of key impact categories and indicators, assessing the environmental and social impacts (e.g. Environmental LCA and Social LCA, carbon footprint, water footprint, etc.), as well as the ultimate effects of these on all three key sustainability pillars (e.g. life cycle sustainability assessment) (web; Life cycle initiative). Thus, a life cycle approach is relevant to our choices of goods or services purchases for consumption. It aids us as consumers to understand that whatever goods we consume are one part of a whole system of events."

The various advantages or benefits that Life Cycle Approach Promotes as given by UNEP (2004) are outlined as follows [32]; (i)Awareness that our selections are not isolated (ii) Improving entire systems, not single parts of systems, by avoiding decisions that fix one environmental problem but cause another unexpected or costly environmental problem, (iii) Informed selections, but not necessarily 'right 'or 'wrong' ones. (iv) Life cycle thinking simply helps us put our decisions in context with facts from all parts of the system or life cycle and (vi) Making choices for the longer term and considering all environmental and social issues associated with those.

Whereas Life Cycle Assessment (LCA), constitutes an integral approach to Life Cycle Designs geared towards sustainable development, this study generally considers five major or broad classifications of Life Cycle Designs approaches applicable to sustainable development. These approaches are thus deduced as (a). Non-Holistic, (b). Holistic, (c). Strategic, (d). Ad-hoc, and (e). Classic. Depending on the objective of the design, one or a combination of some or all of these Life Cycle Designs approaches could be applied in developing a product sustainably.

1. Non-Holistic:When a single factor is considered or a combination of factors that are non-exhaustive of all known processes and sub-processes of a product life cycle, then that design approach can be said to be Non-Holistic. For example if the Life Cycle Assessment for the design of a product is restricted to issues of reducing energy consumption during the manufacturing processes and quantity of raw materials used to produce a specified unit of the product, the approach is restrictive and therefore non-holistic. This is because other sub-processes of the products life cycle such as logistics for product distribution and sales, repairs and maintenance, recovery, reuse, recycling, and eventual disposal, which are critical part of the product life cycle as well are not factored in the Life Cycle Assessment leading to it's Life Cycle Design. Similarly, if the design approach for a product is essentially focused on Design for Environment (DfE), it is essentially a non-holistic design approach. Ishii (1991), justified this assertion by reporting that; "Design for X' or DfX is a design methodology to specifically incorporate issues in sub process X of the product life cycle at early design stages [33] For instance, the interest of the Life Cycle Design in a product could be to infuse characteristics that should encourage a buy back of the packaging material for re-use or recycling by the manufacturer. Take for example the metal cans used to can fish products; it's LCD design concept should be such that makes it easy and convenient for the consumers of the product to easily store the containers within their home. The product package also have qualities that makes it easy to evacuate to designated retrieval centres, having attained a minimum required weight that should attract some form of financial compensation to the consumer. Specifically, designing the containers to be amenable to easy domestic simple hand tool compaction equipment would be a key factor in this example. This singular factor of interest is considered the X factor in this Non-Holistic approach. There could be several Xs' factors under this approach, but as far as it is not encompassing of all other possible and foreseeable factors that could influence the product life cycle, then it falls within the realm of non-holistic approach.

2. Holistic approach: It essentially involves the design that considers all possible factors that could be involved in the entire life cycle of the product from cradle to disposal. Within such an approach issues such as raw material options, production technology options, energy requirements and alternatives for the production processes, product sales, maintenance during use, recovery for re-use or recycling and all disposal issues are taken into consideration. Under this approach all the X factors are considered across the entire product life cycle. This should imply that the DfX should transcend from $DfX_1 \ldots X_n$. The value of X_n will be a function of

the product type and the result of it's Life Cycle Assessment outcome.

3. Strategic approach*:* In this approach, a wide range of interests are taken into consideration. These interests' cuts across issues of laws/regulations governing Life Cycle Design in a particular clime or geopolitical entity, policies of presiding administration or Designated Authority, Industry peculiarities and consumer preferences. This approach although quite similar to the Holistic approach, but it differs in terms of prioritizing the factors of interest and therefore applying the ones considered more critical or advantageous in achieving the set objectives/ goals of the Life Cycle Design. A good example in this regard, could be that of a developing nation shaping her Life Cycle Design policy in order to encourage export of raw materials from that nation. This could be with the sole objective of boosting her solid mineral sector in order to create employment locally for citizens. Such a country may necessarily have to down play the issue of recycling scrap metals for either export or local industry consumption in choosing her approach to Life Cycle Design policies. This approach is purely to serve strategic interest of the concerned nation; hence it is considered a strategic approach. Chinese manufacturing sector, utilizing coal for a considerable portion of her energy needs, leads to enormous greenhouse gas emissions in about the last two decades ranging from the terminal years of the 20^{th} to the present year of the 21^{st} century. China tops the list of the ten top energy consumers country in the world with 3,013 MT units and U.S. is second to China with 2,0187 Mts. unit as at 2013. Out of the entire energy consumption of China as of 2013, 3,588 MT comes from coal and lignite China accounted for as much as 80% of global consumption of coal as at 2013 [34]. China is quite conscious of the impacts of her energy basket options on global warming. However, due to her strategic interest of sustaining her productivity levels as the current world factory, her policies for Life Cycle Designs might be deliberately undermining impacts of emissions into the atmosphere from factories, due to her energy complex basket.

4. Ad-hoc approach: As the name implies, this method of Life Cycle Design can be said to be either remedial or intervention approach. This is because this approach reviews an existing design that has most probably been deployed, up and running, in order to correct undesired effects of the products life cycle on the environment. This could be as a result of an unforeseen factor in the products initial life cycle design. It could also be that the factor was considered at the initial stages of the Life Cycle design of the product. However, due to the dynamics of improving technologies in enhancing detection of hitherto undetectable impacts across the various segments of the products life cycle, the considered factor(s) becomes irrelevant over time. Consequently, an ad-hoc Life Cycle Design precisely targeting the identified defects in the initial Life cycle assessment becomes applicable. Thus, it is rightly a remedial or intervention approach to solve a current challenge diagnosed from the actual running of the products life cycle. A good example in contemporary times is the conventional means of distributing telecommunications lines through a wired network. In the first half of the 20th century and even through the terminal decade of the 21^{st} century, wired networks abound globally. However, with the advent of Global System for Mobile (GSM) Networks, it has become imperative for earlier wired communication based networks to be redesigned at some point. The main purpose of such re-design is to enhance efficiency, ease of access and reduced cost among other considerations. Most importantly within the contest of this paper reviewing approaches of Life Cycle design applications to sustainable development; is to reduce the various environmental externalities associated with wired networks.

5. Classic approach: In this [13] explained this approach under the Eco-Design tools classified under three categories; tools based on life cycle assessment (LCA), tools based on checklist and tools based on quality

function deployment (QFD). It is so classified in that it involves the use of precise, standardized and advanced decision making tools in conducting the Life Cycle Assessment (LCA) of a product. Given that all conditions of application of this classic approach are equal, irrespective of the environment, the result produced from it should be essentially and consistently similar. Example of such classic approach may include Life Cycle Assessment for determining the appropriate packaging materials for different products. Lee and Xu are of the opinion that the issues of biodegradability, weight, ease of compaction, re-use, recyclability and of course the extent of protection it renders to the products consistently applies to different products. Thus, when a particular formula is applied in arriving at an acceptable Life Cycle Design standard for packaging a particular product X, same standard is most likely to give similar result for product Y. Take for example the issue of protective integrity of the packaging material. Irrespective of the product involved, once it's protective integrity is compromised in place of weight reduction for example, the likelihood of high incident of damaged products during transportation exists. Invariably, this leads to higher reproduction to replace the damaged items. Ultimately, this leads to an unnecessary consumption of raw materials. Thereby negating the principles of sustainable development based on Life cycle designs [18].

Reference [35] demonstrated the versatility of a Classic Life Cycle Design Approach within the concept described as Design Problem Modeling in the Distributed Design Environment (DDE); "In the DDE, objects can interact by invoking services of other objects over computer networks using a standard communication protocol. Therefore, design participants associated with objects can exchange design information through these objects. We refer to the objects in the design problem modeling domain as Modules. A module is distributed if it can be executed as a stand-alone unit and is capable of providing its services to other modules, objects, or applications using a standard communication protocol. Thus, an integrated model of a complete product design problem can be built using modules (and embedded design resources) that are physically distributed over the Internet" [29].

Advances in computer networks and information technology have enabled product designers to more effectively communicate, collaborate, obtain and exchange a wide range of design resources during product development [36]. This is an approach that has helped to bridge the spatial divide between different design teams that must necessarily synergize in order to achieve a common product LCD objectives and goals [36-38].

Overall, the various applications of ionic liquids (ILs) green solvents makes a good example in summarising the LCD approaches. Accordingly, ILs tunability provided for the design of hydrophobic, hydrophilic, biodegradable, non-biodegradable, recyclable, task specific and general purpose ILs. Hence, used for synthesis, corrosion inhibition and for various other analytical applications [39-72].

6. The Life Cycle Equation

Life Cycle Design seeks to integrate environmental requirements with traditional performance [2,13,20,73]. The challenge of understanding the issues with Traditional Design Method (TDM) concept that makes products arising from it unsustainable (where little attention is paid on environmental issues) as against sustainable development biased designs has been considered in the proposed equation.Product design for flexibility and cost effectiveness for possible recovery, conversion, reuse, recycling and ease of disposal of unused portions of every product having met it's original intent of manufacture, becomes critical in the equation of it's Life Cycle Design. As part of this paper's contribution to expansion of the tools for LCD design knowledge base, we therefore develop a quantitative analysis of Life Cycle Design as stated and expressed in the following equation:

$$LCD_v = (RM_{x1} + WP_{x1} + C_{x1} + R_{x1} + R_{x2} + D_{x1})/TDM_v \quad (1)$$

Where;

LCD_v = Life Cycle Design value of product X.

RM_{x1} = Residue and Effluent wastes values (Weight in kg/ton) from raw materials extraction (Weight in kg/ton)

WP_{x1} = Residue and Effluents wastevalues (Weight in kg/ton) arising from processing raw materials to finished products

C_{x1} = Conversion values (Weight in kg/ton) ofthe products residue + packaging material after use

R_{x1} =Reusable value (weight in kg/ton) ofthe products residue + packaging material after use

R_{x2} = Recyclable value (weight in kg/ton) of the products residue + packaging material after use

D_{x1} =Disposal value (weight in kg/ton) of the products residue + packaging material after use

TDM_v = Traditional Design Method values of Product X as defined in $RM_{x1,}$ $WP_{x1,}$ R_{x1}, R_{x2} and $D_{x1.}$

Theoretically, the LCD_v value can be said to be in the range of sustainable design if it is >1 and non-sustainable design range if < 1. When the result of this quantitative analysis = 1, it simply indicatesthat there is no quantitative difference between the the LCD_v andTDM_v values. This means that whatever innovations have been introduced in the product design has a nullity effect in terms of advantages associated with LCD as against the TDM. With this quantitative analysis equation, a certain range of value >1 can therefore constitute the acceptance level for the design to be $LCD_{v.}$ compliant. Values outside this range are therefore considered otherwise. For this range it can be subjective depending on the peculiarities of the product, the prevailing environment and what the design team considers it's threshold in order to achieve the set objective. It is important to point out that the preceding equation does not in any way factor the qualitative elements of LCD. However, it is logical to conclude that the quantity of a material or product in terms of weight as considered in the equation is generally correlated to certain quality factors. A good example is shown by the fact that the higher the quantity of a material by weight or chemicals by concentration, the higher their energy outputs from that material. Also in terms of adverse impacts, the higher the quantity either in terms of volume or by weight, the higher it's impacts on the environment and biota.

A key component of considerations in evaluating life Cycle Assessment (LCA) for LCD analysis of a product is the quantum of energy input and output for both the extraction of the raw material, processes of production, packaging, distribution, consumption, recovery for recycle, reuse, conversion into other useful products and disposal [30]. This is because the energy equation has a direct correlation on the carbon foot print of the product. This in turn proportionally impacts the ozone layer adversely through the production of greenhouse gases such as methane, carbon dioxide and CFC etc. It has been established for instance "that far more energy and chemicals than previously suspected go into the manufacture of semiconductors, according to the first comprehensive life cycle assessment of the tiny silicon chip [37].Bras and McIntosh (1999) equally reported that the Life Cycle Assessment for many consumer products show that the use stage is the most polluting [38]. Good examples of such include automobiles and hydrocarbon or coal powered machineries. Therefore their remanufacturing processes should not add to the environmental burden, otherwise their benefits can be easily negated.

7. Interactions between Life Cycle Design and Sustainable Development

The analysis of LCD quantitative equation clearly shows the importance of LCD_v in terms of re-engineering product manufacturing process design, such that sustainability approaches are applied to specific areas of product life cycles that will yield the desired result. Just like living organisms, products have a life cycle as well. Where living organisms originate, reproduce, and eventually die, products are produced from raw materials, used by consumers, and eventually disposed of. A product's life cycle is generally broken down into five stages (Figure 1); 1. Raw materials; 2. Production, 3. Distribution, 4. Use, 5. End of life. These stages are illustrated in Figure 2 [12,31,74].

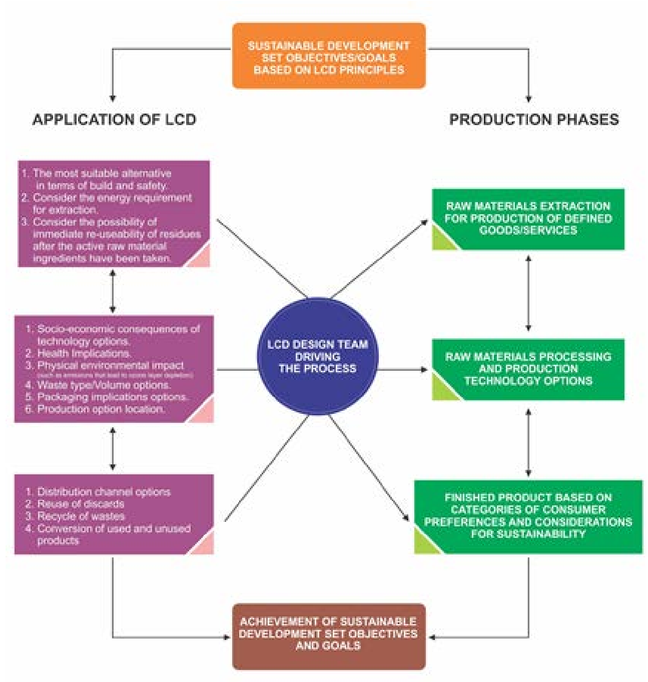
Whereas the product design phase is not shown in the figure 1.7a, it is equally as important as any other phase of the life cycle of any product. For each product type the life cycle phases are fundamentally what have been illustrated in figure 1.7a. However, the peculiarities of the products production requirements and functionality accounts for variations or differences in each phase of it's life cycle. An illustration of the various interactive links between Lifecycle designs and the various phases of sustainability thinking is considered necessary. This constitutes a further contribution to knowledge of this paper.

Having reviewed the relationship between life cycle and sustainability thinking therefore, we further develop an illustrative diagram of the link phases between the two as shown in Figure 1.7b. It links the conventional developmental phases for product X and the LCD design options that guides decision making.

8. Conclusion

The present study identifies the key interactive stages between life cycle approach and sustainable development. It further reports the classification of life cycle development approaches and hence proposed a novel equation for the quantitative analysis of life cycle design of a product. In order to achieve sustainable development without recourse to first mitigating impacts and subsequently re-designing the causative products to prevent future incidents, then Life Cycle Design becomes a necessary option. Furthermore, the compelling need to conserve the world resources and maintain the environment at levels that they are optimal to human habitation has made the issue of LCD critical. With the ever geometric increasing global population estimated to be about

7 billion in recent times, LCD for products geared towards sustainable development becomes the only panacea to meeting the human needs on earth. However, LCD concept has it's conflict points with the TDM concept. The managers of resource should therefore find a way of continuously balancing these points of conflict, so that the productive machinery of the globe is not jeopardized on the altar of LCD. This will require multilevel and multilateral collaborations between different interest groups, in order to carefully balance the divergence of interest. In order words, product design decisions should entail harmonizing and surrendering differing interests in order to reach a design goal that meats the socio-economic quest of one and yet serves the sustainable development interest of all.



Conventional development phases LCD design options

Figure 1.6b: Interactive stages between Life Cycle Design Approaches and Sustainable Development

Acknowledgements

The authors thank Dr. Idris M. Jega and Abubakar Sodangi for comments on earlier drafts.

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