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Sustainable Engineering in Developing Countries: A World of Limitless Opportunities

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Abstract— Many developing economies are making concerted effort at achieving development that would fulfill the aspiration of its populace for comfortable living. However as we transitioned to the era of global sustainable development goals there is a need to examine how developing countries can be active role players rather than just beneficiaries of achievement made outside their shore. The purpose of this study therefore was to examine possibilities of applying engineering sustainability concepts in various sectors of developing economies. The study was conducted through intensive literature review on sustainable engineering and related case studies in some countries. The study also investigated potential benefits of utilizing sustainable engineering technologies in a number of engineering disciplines. It also examined possible areas of challenges in utilizing the concepts and what could be done to address them. Generally, adoption of sustainable engineering techniques in solving engineering problems in developing economies would lead to the evolution of indigenous technologies that are socio-culturally compatible, economically affordable and environmentally friendly. Moreover, the participative nature of recommended sustainable engineering concept would lead to capacity building for local technicians and progressive improvement in the standard of living in developing countries.

Index Terms — Capacity building, Engineering, Lifecycle assessment, Renewable resources,Sustainable engineering, Technology adoption, Technology development.

1 INTRODUCTION

The general focus of professionals and the political class in many developing economies is on how to meet the needs of the populace for food, clothing, shelter and good health. Various techniques and technologies are often developed or acquired to satisfy these needs. However, many of these technologies have been found to have serious defects on the long term. A number of such technologies require importation of raw materials for their operations; acquisition of spare parts from abroad for repair and maintenance, and recruitment of foreign experts to service the system.In addition, the design of some of the technologies are incompatible with the sociocultural and geographical situation of end users. Furthermore, many of the technologies cause surface and ground water contamination, and negatively impact human health and ecosystem welfare. Such defects have left many consumers a worse condition than they were prior to the technology adoption. There is therefore a need for reapproachment on how to meet the socio-economic needs of the populace without the attendant negative consequences. There is a need to develop technologies that are locally serviceable, economically affordable, socio-culturally compatible and ecologically friendly. Sustainable engineering is an interdisciplinary and multifaceted approach that facilitates achievement of that goal [1 - 8].

1.1 Sustainable Engineering

A number of definitions have emerged on what sustainabele engineering is. It is referred to as "the integration of social, environmental, and economic considerations into product, process, and energy system design methods" [9]. It is also referred to as "the creative process of utilizing science and technology, making use of energy and resources at a rate which does not compromise the integrity of the natural environment, or the ability of future generations to meet their own needs [10]. While each of these two definitions seemed to have captured most aspects of what is done in sustainable engineering, they appeared incomplete to me because their definitions placed the entire responsibility on the manufacturers. Therefore, according to Dunmade [11], sustainable engineering is "an interdisciplinary/ multifaceted approach to adaptive integration of supply side and consumer side of an engineered system over its lifecycle stages by utilizing various methods in a technically sound, socio-economically sensible and environmentally friendly manner."

2 MATERIALS AND METHODS

This study was conducted through intensive literature review and sustainable engineering case studies in some developing countries of similar standing as Nigeria. The study investigated potential areas of apllication of sustainable engineering concepts in various sectors of our economy especially where agricultural, civil, mechanical and electrical engineering disciplines have significant roles. This was done by examining what engineers in these discipline do, how they do it, where sustainable engineering principles can be incorporated and potential benefits of doing so. Futhermore, the study examined possible areas of challenges in utilizing the sustainability approach and what could be done to address them.

3 RESULTS AND DISCUSSION

According to Dunmade [11], Sustainable Engineering approach to solving engineering problems can be divided into four pathways, namely: Design, Process, Management, and Assessment pathways. Each of the pathways consists of a number of paradigms that are targeted at achieving specific goals at one or more stages of the system's lifecycle. The four pathways and the constituent paradigms are illustrated with Table 1.

3.1 Areas of Sustainable Engineering Opportunities

Our study revealed that there are several areas of sustainable engineering concepts application in various sectors of the economy, whether in a developed or a developing country. Opportunities for sustainable engineering concepts' application in developing economies are particularly limitless. Looking at Agricultural and food industry, sustainable engineering can be applied in the design of facilities, in the choice of materials, in the management of resources used. Similarly, manufacturing sector stands to gain from sustainable engineering in the area of resource utilization, waste reduction, and an overall system optimization. Our infrastructure will benefit a lot from sustainable design and lifecycle management which are aspects of sustainable engineering. This would be achieved as sustainable engineering concepts' application would enable us develop infrastructure that are technically suitable, environmentally friendly, economically affordable, and socio-culturally compatible. Consequently, there would be complete elimination/reduction in abandoned projects, unserviceable facilities and economically burdensome infrastructural systems.

3.2 Potential Areas of Sustainable Engineering Concept Application in some Engineering Disciplines

The following are specific examples of where and how sustainable engineering concept pathways and paradigms can be applied in agricultural, civil, mechanical and petrochemical engineering projects that directly affect various sectors of our economy and infrastructural development.

All agricultural, chemical, civil, electrical and mechanical hardware can be designed for sustainability. In the agricultural engineering areas we can design facilities such as livestock housing, food processing facilities, milking machines, sprinkler systems, tillage implements, tractors and harvesters, seed planters, drills, fertilizer applicators, sprayers, transplanters, harvesters, imaging devices, and other technologies associated with agricultural and agri-industrial activities by using a number of sustainable design concepts [12].

We can use sustainable engineering concepts, particularly the design paradigms such as design for X where X is materials, manufacturing, assembly, disassembly, remanufacturing, durability, ease of installation & use, reusability, maintainability, upgradability and so on in a number of civil and building engineering structures and devices. For example, design for materials would find significant applications in the building industry where component parts and sub-assemblies can be designed such that locally abundant and durable materials could be utilized. The same thing would be applicable in road and bridges construction, weirs, foundations and structures

Design for manufacturing would be essential for easy and cost effective production of bricks, roofing sheets, and fasteners used in agri-industrial, mechanical, electrical, electronic, petrochemical and civil engineering systems.

Sustainable design concepts can be used in the design of buildings, roads, airports, waterways, railways, bridges, tunnels, docks, offshore structure, dams, water supply, drainage and irrigation systems/schemes, treatment and water distribution systems, including storage, pumping and piping. Others include traffic control devices and design of traffic signals, railway, harbour and river works, pipelines; airport plan, layout and location; aircraft data and runway design. The permanent ways, turnouts and sidetracks; locomotives, motive power, train resistance and velocity profile, ports and harbours; channel regulation; coaster structures, pipeline transportation, tramways and belt conveyors

Furthermore, sustainable engineering paradigms such as design for material, design for assembly and disassembly, design for manufacturing, design for modularity as well as sustainable manufacturing would find useful applications in the design and development of air-conditioning, refrigeration systems, transformers, relays, other household and industrial electrical/electronic gadgets.

Some of the sustainable design concepts that could be utilized when designing these facilities and devices are shown in table 1 below.

Design for assembly is aimed at improving the system for easy and low-cost assembly. This design concept involves focusing on functionality and assemblability concurrently. This is achieved by simplifying the product configuration and minimizing part count. It also involves analyzing both the part design and the whole product for any assembly problems early in the design process. In addition to reducing the cost of assembly, design for assembly also improves the product quality and reliability [5, 13-15].

Furthermore, the facilities and devices can also be designed for disassembly. According to Dunmade [11], design for disassembly involves "considering the ease with which a product can be economically taken apart at the end of the service life or for maintenance." Designing a product for disassembly enables its parts to be easily reused, re-manufactured or recycled at the end of its life. Design for disassembly is achieved by:

- Minimizing the part count ;
- Utilizing "push and pull" mating parts except it is not functionally possible to do so;
- Using fasteners that does not require the use of tools or setup wherever possible;
- Designing joints that makes mis-matching parts almost impossible; and
- Employing fasteners that facilitate component reuse or material recycling at the end of life".

Similarly, the concept of design for materials have to be applied when designing these facilities and devices to assure their sustainability. Design for materials "involves evaluating the suitability of a set of candidate materials for a given engineering system development and selecting the "best" option at the design stage. Some of the evaluation criteria are availability, toxicity, durability, recyclability, and biodegradability. According to Dunmade [5], design for material guidelines says:

- utilize renewable materials except it is not possible;
- use minimum possible amount of material;
- utilize locally available materials except it is not possible;
- incorporate highest possible recycled content;
- use recyclable materials;
- employ lowest possible varieties of materials;
- use of homogenous materials rather than composite materials;
- utilize biodegradable materials wherever possible;
- choose non-hazardous materials; and
- consider using materials that require least amount of energy to process.

Design for Modularity is a design principle in which an attempt is made to ensure that each function that a product performs is made independent of all other functions that the product performs [16 - 17]. It is a means to incorporate life cycle considerations into product architecture design [18 - 22]. To achieve this goal, there would have to be similarity in the physical and functional architecture of product subassemblies' design. Consideration would also have to be given to the coupling of subassemblies in a way that the effectiveness of the whole product system will not be hampered. This design principle would make it easy to locate the faulty parts of a product, and thereby eliminate unnecessary disassembly of unessential parts. That would result in shorter labour time and consequent reduction in the cost of recycling the product. It would also make it possible to upgrade the product by simply replacing outdated modules with new technology-based modules instead of having to buy a whole new product [21]. This anticipation of the future need to upgrade functional units is very essential for a product that will be remanufactured and used for multi-lifecycle. Incorporation of this design principle will facilitate product disassembly, component reuse and material recycling. Outcomes of such design features and the facilitated operations are reduction in resource exploitation and waste generation, as well as lower cost of ownership when compared with production and utilization of replacement products [11].

Furthermore, sustainable manufacturing and cleaner production processes can be utilized in manufacturing the devices. As each of the sustainable design and manufacturing concepts are utilized in developing these products, consequences of their utilization on the environment and socio-economic issues are also assessed by using the lifecycle assessment methods. These methods enable us to evaluate the environmental burden associated with material, energy, water, and other resource consumption; as well as the emissions generated by the products/devices at various stages of their life cycle. This identification of consumptions and emissions impacts can use in help identifying, articulating, and implementation of possible improvement opportunities for these equipments at various stages of their life cycle, as shown in Figure 1. Other added advantages of this tool are the possibility of using it for product development, improvement, and comparison.

3.3 Potential Challenges in Applying Sustainable Engineering Principles

Despite the numerous opportunities in applying sustainable engineering concepts in various sectors of our economy, there are a number of huddles that would have to be overcome to harness the aforementioned benefits.
Some of these challenges include:

- leadership foresight to create a common vision for a sustainable future,
- tenacity to implement practical strategies for creating/ achieve change,
- promotion of inclusion and social justice,
- belief in/acceptance of our (individuals and groups') abilities to accomplish great achievements,
- building the grass-root skills and enhancing community decision making and problem solving processes,
- developing and consistently enforcing suitable/enabling governmental and corporate policies/support,
- government demonstration of leadership by example through the policy of buying local and patronage of local expertise by their agencies and contractors, and
- citizens' show of solidarity and understanding/patience until the desired goal is achieved

All these will take time to accomplish, a number of them will result in some inconveniences, and some of them would require enforcement to see them through. However, patience, consistency and focus would be necessary in order to accomplish them. This will consequently enable developing countries that imbibe sustainable practices to contribute to the achievement of global sustainable development goals. It will also facilitate their developing technologically and appropriately. All the pitfalls of the industrial revolution era would be avoided. The citizens will achieve a far better standard of living, long life and prosperity [1, 23-24].

4 Conclusion

Our world is changing rapidly. It is changing socio-culturally, economically, ecologically, and technologically. Engineers need to be proactive in order to be able to adapt to these changes, to maintain relevance, and to facilitate provision of basic necessities of life. The role of engineers is widening to include newer areas such as bionanotechnology; biofuels, the environment, and the next industrial revolution still depend largely on engineers. Sustainable engineering concepts will foster the development of novel products, processes and systems. Engineers have to imbibe sustainability approach in their activities by incorporating life cycle thinking and sustainable design principles in various fields of engineering. Doing these will facilitate achievement of the much desired technological development in those economies. It will help in reducing the environmental impacts of manufacturing and services. It will also help organizations using engineering services to be more competitive. Finally, adoption of sustainable engineering techniques in solving engineering problems in developing countries would lead to the evolution of technologies that are socio-culturally compatible, economically affordable and environmentally friendly. The next step in this study will be focusing on case studies in relation to the application of sustainable engineering paradigms in infrastructure and agri-industrial development sectors.

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Table 1 Sustainable Engineering Pathways [11]

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Pathways	Lifecycle stage(s)	Approaches/Paradigms
Design	All	Design for Modularity Design for Materials Design for Assembly Design for Disassembly Design for Manufacturing Design for Remanufacturing Design for Use Design for Reuse Design for Maintenance/Service Design for Safety Design for Simplicity Design to Cost Design for Packaging Design for Recycling Design for Minimum Residue Design for Multilifecycle Design for Sustainable Behaviour
Process(es)	Manufacturing	Cleaner Production Green Manufacturing Sustainable Manufacturing
Management	End-of-Life/ Retirement	Disassembly Reuse Eco-Industrial Development Refurbishing Remanufacturing Reverse Logistics Recycling Pyrolysis Product Stewardship Hydrolysis Lifecycle Extension Certifications e.g. Ecolabel
Assessment	All	Lifecycle assesment Social lifecycle assessment Lifecycle costing Lifecycle sustainability assessment Cost benefit analysis Material flow analysis Enabling Resources and Infrastructural Analysis

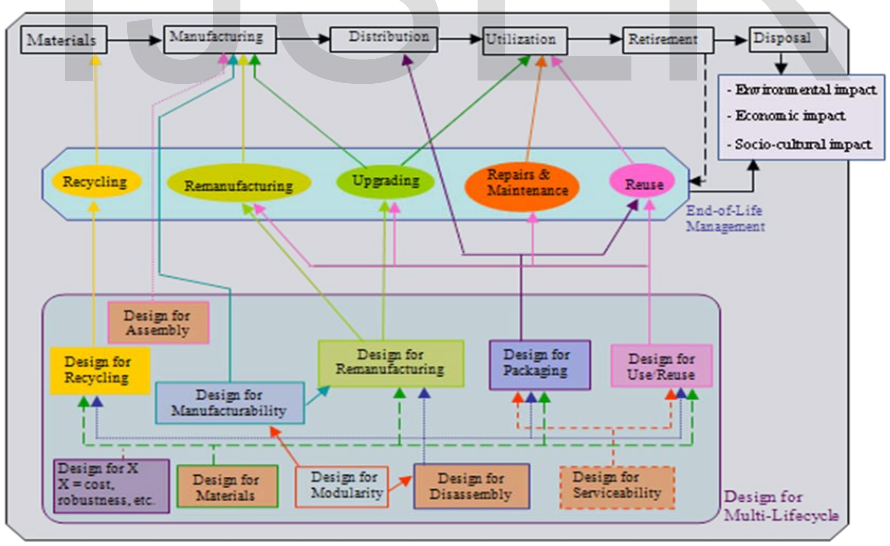

Figure 1 Various Design Paradigms, their interrelationships and stage of lifecycle focused [5]