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Design for Multi-Lifecycle: A Sustainability Design Concept

Israel Dunmade
Department of Environmental Science, Mount Royal University, Calgary, Canada

ABSTRACT

The purpose of this paper is to discuss the concept of design for multi-lifecycle (DFML) and how DFML helps to improve sustainability of systems designed on the basis of that concept. Design for multi-lifecycle is a sustainable design approach that seeks to maximize the utility of resources used in developing a product by incorporating features that enable the elongation of the techno-economic service life of that product at the design stage. The goal of DFML concept is an "indefinite" use of the resources invested/embodied in a product without compromising its economic reasonableness, technological soundness and social-cultural acceptability. The lifecycle engineering methodology is highlighted in the design of a threshing machine.

Keywords - Design for Multi-lifecycle, Sustainable Design, Sustainability, Lifecycle Engineering, Design for Modularity, Design for Recycling, Design for Reuse

I. INTRODUCTION

Sustainable development has been in the forefront of campaigns from governmental and non-governmental agencies at the local to international levels. The number and variety of persons and organizations working on how to address technology and products' related environmental problems have grown significantly since then. Corporate and non-profit organizations have devoted a lot of human and material resources to achieving sustainability in their operations. One of the focuses of attention has been on the sustainable design and development of products and processes that require fewer resources, which minimize emissions, compatible with our environment, affordable, and do not intrude our lifestyle [1-7]. In otherwords, the goals of sustainable design approaches to product design and development is the reduction of the overall negative impacts of a product throughout its life cycle. Sustainable design approaches can be divided into three classes [8], namely:

1. Those which are applied *within* a single product life-cycle and focus on *specific* life-cycle stages,
2. Those that focus on a *complete* product life-cycle and cover *all* life-cycle stages, and
3. Those that go *beyond* single product life-cycles.

II. PRODUCT DESIGN FOR A SINGLE LIFECYCLE

Most of the consumer electronic and mechanical products are designed for a single lifecycle. The service life of many of these products is about four years. Thereafter, they are expected to be disposed off in landfills. They were not expected to be repaired and maintained. This design philosophy has caused significant environmental problems and resulted in enormous economic wastes. According to University of Arkansas (2012)[9], about 20 and 50 million tonnes of electronic waste world-wide are generated each year. Many of these electronics contain some toxic substances such as mercury and lead which could negatively affect human health.

It is a known fact that such enormous waste of resources cannot continue indefinitely. The reason is not only because of the economic and future resource availability implications but also in view of the potential human health and ecosystem welfare consequences. As a result, there is a need for new design philosophies and paradigms that enable us to design products that minimize ecological footprints and improve systems durability. Design for multi-lifecycle is one of the sustainable design approaches that help us achieve these goals.

III. DESIGN FOR MULTI-LIFECYCLE

This is an integrated design approach that maximizes the utility of resources used in developing a technology by incorporating at the design stage, features that enable the elongation of the techno-economic service life of that technology [4]. The incorporated product features were to enable a product go beyond single lifecycle. This design concept includes design for assembly, design for disassembly, design for simplicity, design for modularity, design to cost, design for materials and design for use and reuse [5, 7, 10 - 12]. Others are design for manufacturability and design for packaging as illustrated in Figure 1.

The goal of design for multi-lifecycle is 'indefinite' use of the resources invested/ embodied in a product without compromising its economic value, technological soundness and social-cultural acceptability. In essence, one should be able to use and re-use a product or system designed for multi-lifecycle indefinitely.

3.1 Design features and service life operations that facilitates multiple lifecycle use

There are a number of product features and operations during a product service life that would be necessary to accomplish an indefinite cycling and re-cycling of a product or system through its lifecycle. These features and operations as well as their associated design paradigms are illustrated in Figure 1. The main features and principles of operations that are necessary for multi-lifecycle use are:

3.1.1 Assemblability and Disassemblability

Any product would have to be "assemblable" whether it is for single or multiple lifecycles. However, a product that would be taken through multiple lifecycles would be disassembled and assembled many times. Consequently, special consideration have to be given to the ease with which it can be disassembled and reassembled at a short time period, with minimum effort, and minimum deterioration over several cycles of disassembling and reassembling. In summary, the product has to be designed for assembly (DFA) and designed for disassembly (DFD). These design concepts are essential to make products friendlier for maintenance and remanufacturing practices. These design features make it economical to cycle and re-cycle the product through many lifecycles due to the resulting shortness of labour time which would culminate in lower cost of labour. In addition, such features will make it possible to reuse the component parts, thereby reducing the need for new resources to produce new component parts. It will also reduce the need for time and energy to produce new components. The reduction in resource needs will lead to reduction in environmental impacts that could arise from resource exploitation. In addition, elimination of the time and energy that would have been required to produce new component parts will reduce the reuse/recycling cost, thereby making the recycled products more economically sustainable. There are several scholarly works on design for assembly and design for disassembly. Among such works are [11, 13 – 18].

3.1.2 Durability and Accessibility

Component parts of products that will be re-cycled many times will have to sturdy, wear resistant and uneasily breakable. Durability of a component is directly dependent on structural material composition, properties and choice of size [19]. Durability is not only essential for product safety but it is also important for long lifespan of the components' integrity and reuse. The design configuration of the components, sub-assemblies and the whole product assembly would also have to be easy to access for cleaning and rework if it would be used for multi-lifecycle. This would be necessary for repair and maintenance of the product. Reusability of components and modules will result in resource conservation, make such resources available for future generation, and lead to reduction in cost of ownership. This would make product thus designed for multi-lifecycle more environmental friendly, economically profitable and socially justifiable in comparison to similar products that are designed for single lifecycle.

3.1.3 Modularity

This is a design principle in which attempt is made to ensure that each function that a product performs is made independent of all other functions that the product performs [20, 21]. It is a means to incorporate life cycle considerations into product architecture design [22 - 27]. 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 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 [26]. This anticipation of the future need to upgrade functional units is very essential for a product that will be used for multi-lifecycle. Incorporation of this design principle will facilitate product disassembly, component reuse and remanufacturing, and material recycling. Outcomes of such design feature 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. Consequently, products designed for multi-lifecycle would be more environmentally and economically sustainable compared to single lifecycle products.

3.1.4 Simplicity

Simplicity as a design consideration is very essential if the system would have to be used, repaired and maintained by rural populace where the level of conventional education is low. The simplicity would need to be in terms of product configuration as well as in relation to the language of instruction for assembling component parts. Simplicity of product configuration would make it easy to train intending users and local technicians on the use of the product and on the repair and maintenance of the product respectively. This design principle is enshrined in the concept of design for serviceability. A number of scholars such as Watson, Theis and Janek, and Karvonen have articulated the need for simplicity of design [28, 29].

Easy use facilitated by design for simplicity will make the product more socially sustainable than its more complicated peers. Long-time use of the same product encouraged by its simplicity would reduce the number of demands for new products. That would lead to resource conservation, reduction in waste, and reduction in expenses on consumer products or on machinery. That would consequently make such products that are designed for multi-lifecycle to be environmentally, economically and socially more sustainable than similar products that are not designed for multi-lifecycle.

3.1.5 Utilization of Standard Parts

Utilization of locally available standard parts in the product configuration would make it easy to find replacement parts for whatever component parts is faulty whenever such incidence arises. This would eliminate the need to wait for generally costlier imported components. This would reduce the maintenance cost and thereby improve the economic sustainability of the product [3].

3.1.6 Socio-cultural consideration

Ergonomic consideration, consumer taste and preference in product configuration as well as an understanding of other socio-cultural dynamics of target customers are essential to product acceptance by the consumers. Cultural background of consumers and the extent to which the use of a product reduce drudgery will affect psychological and behavioural responses of consumers to the product. Anticipation and consideration of possible psychological and behavioural responses of consumers to a product's design would therefore affect the value attached to the product and the quality of the usage experiences associated with it [29, 30]. Outright contradiction of the principles of operation of a technology with consumers' cultural tradition could result in rejection of a technology. Compatibility of the product's operational characteristics with the target users' way of performing an operation will affect the adoption of the technology for that purpose. It will also affect consumers' loyalty and adherence to the use of the product over a long period of time. Such compatibility will make the product to be socio-culturally sustainable.

IV. DESIGN OF A THRESHING MACHINE FOR MULTI-LIFECYCLE

Each of the design features for multi-lifecycle concept was highlighted in a peanut shelling machine shown in Figure 2 as follows:

4.1 Assemblability and Disassemblability

Design consideration for assemblability and disassemblability was incorporated into this threshing machine by ensuring that most component parts of the shelling machine were joined together by simple same sized easily removed fasteners. The shelling chamber was also made into two halves clamped together by using same size fasteners that can easily be removed without using any tool. This makes the internal component accessible and its faulty components replaceable. This shelling chamber design is a new design development that is at variance with previous models which were completely closed and internal parts were made inaccessible for repair.

4.2 Durability and Accessibility

2mm thick galvanized steel plate was used for the shelling chamber housing, separation unit housing, and other parts of the shelling machine to ensure durability. 40mm wear resistant carbon steel shaft was used to facilitate durability of the functional part. The galvanized steel housing, the carbon steel shaft, and the fasteners used in the design of the shelling machine were locally available. The choice of the shelling machine configuration, size of component parts, and component shapes facilitated easy cleaning and accessibility to various parts for repair.

4.3 Modularity

Components parts of the machine were organized into three functional modules, namely: the shelling unit, the separation unit and the grading unit. This makes it easy to know where to go if there is any fault and reduces repair time. It also make the repair and maintenance cost to be cheaper than what it would have been without incorporating such design concept.

4.4 Simplicity

The product architecture and component parts' design were made very simple to understand and to manufacture. It was also made easy to install, operate and repair. This was achieved by simplifying the product configuration, the shape of the component parts, and through the use of locally available materials and fasteners.

4.5 Utilization of Standard Parts

Both the galvanized steel and carbon steel shaft were purchased locally. Only two sizes of locally available standard fasteners (M10 and M12) were used for the machine construction. Utilization of locally available standard parts in the product configuration made it easy to find replacement parts for whatever component parts is faulty.

4.6 Socio-cultural consideration

Ergonomic consideration was incorporated into the design by carefully choosing the machine height, hopper size, and safety features that protect the user from any foreseeable harm.

V. CONCLUSION

A sustainable design concept was presented. Incorporation of the multi-lifecycle design features facilitate would repairs and maintenance of the machinery. It would also facilitate components reuse, remanufacturing and recycling. These features and operations will results in resource conservation, reduction in waste, and reduced lifecycle cost. Ultimately, these features and operations will foster ecological, economic and social sustainability.

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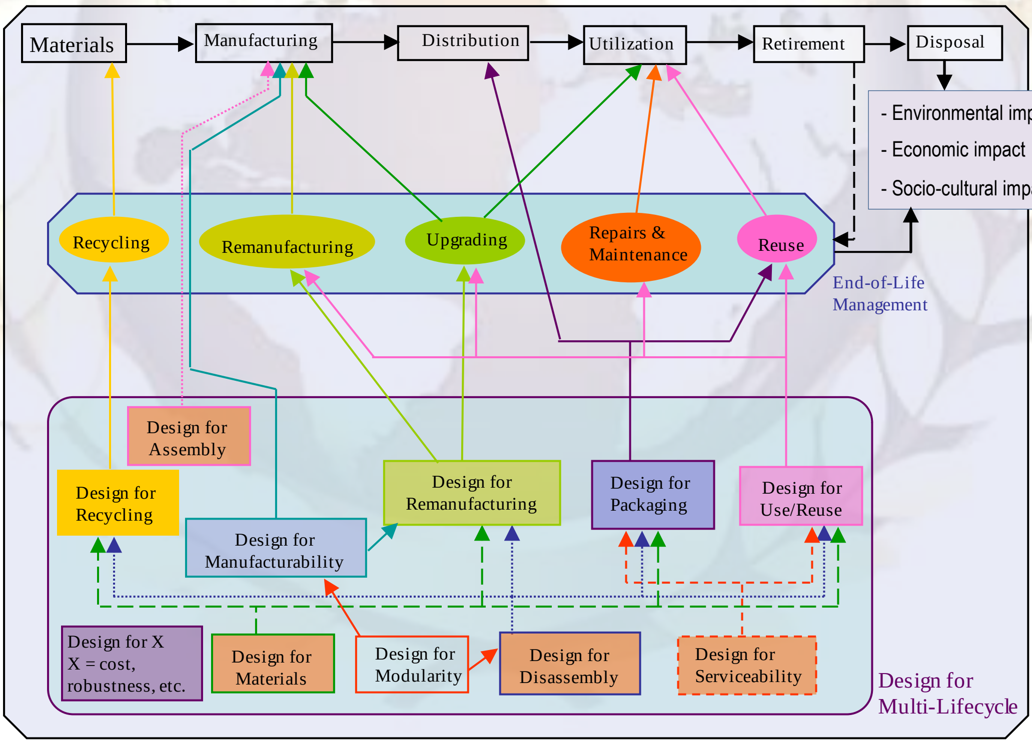

Figure 1 Correlation between Lifecycles stages, End-of-life Management, DFX Concepts, and Design for Multi-lifecycle (source: Dunmade, 2006)

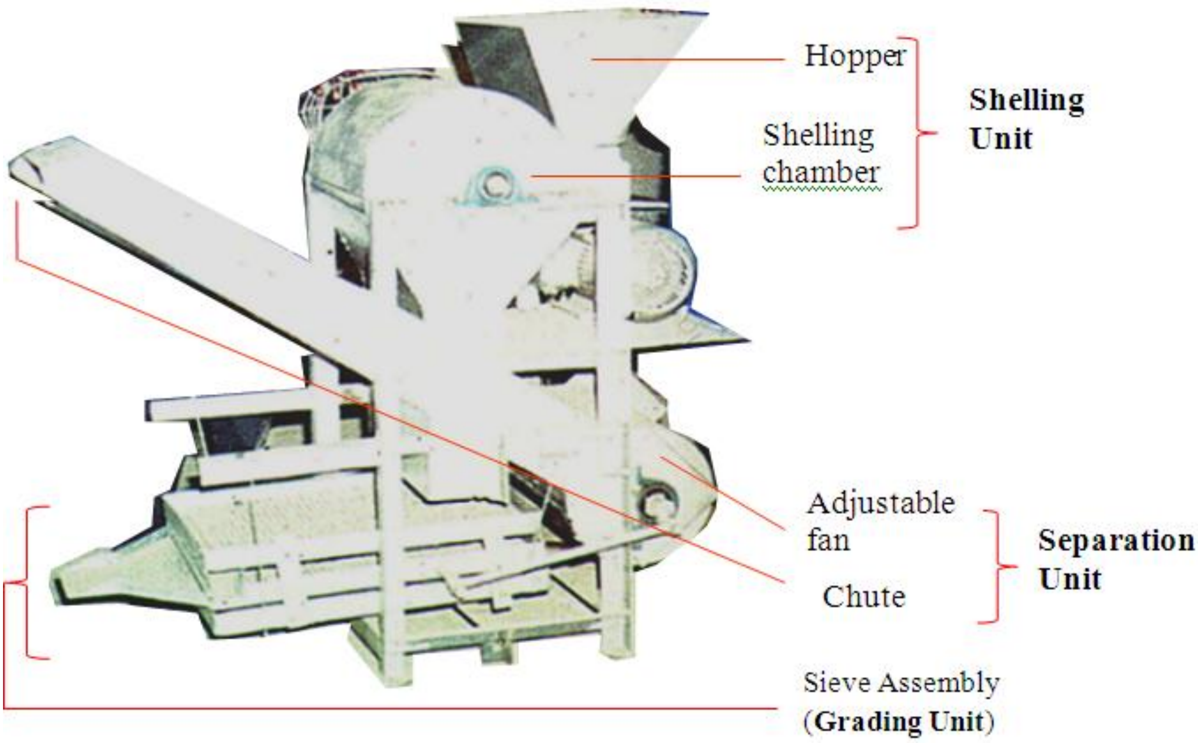

Figure 2 A Peanut Shelling Machine and its Modular Units