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***Research Paper***

# Issues in the sustainability of products designed for multi-lifecycle

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**Abstract**

Design for multi-lifecycle (DFML) 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 is "indefinite" use of the resources invested/embodied in a product without compromising its economic value, technological soundness and socio-cultural acceptability. However, there is a limit to how many times a product designed for multi-lifecycle can be cycled. The aim of this research is to identify issues affecting how many times products designed for multi-lifecycle could be cycled. Another goal of this study is to articulate how the understanding of these issues can be utilized in improving product design for multi-lifecycle. This study is based on intensive literature survey and on over twenty years' experience in conventional- and in sustainable design and development of agri-food machinery. From the study we learned that the sustainability of products and equipment designed for multi-lifecycle depends, among other things, on the durability of the core components, the required performance standard, resource consumption tipping point, economic advantage eradication point, changes in consumer taste, and regulatory changes. It means that the number of times that resources invested in a product designed for multi-lifecycles can be cycled is increasable by improving the durability of the structure and core components of the product. It also means that designers would be able to improve the sustainability of machinery designed for multi-lifecycles by incorporating features that facilitate easy reconfiguration and upgrading of the product at reasonable cost as consumer taste and regulations changes.

***Keywords**: Design for multi-lifecycle, design for environment, sustainable design, sustainability, Eco design.*

## 1. Introduction

In the last three decades, sustainable development has been in the forefront of campaigns from governmental and non-governmental agencies. The number and categories of persons and organizations working on how to address technology and products' related environmental problems have grown significantly since then. Many corporate and non-profit organizations have also devoted a lot of human and material resources to achieving sustainability in their operations. One of the focus 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], [4]. In other words, the goals of sustainable design approaches in 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 [5], namely: (a) those approaches that are applied within a single product life-cycle and focus on specific life-cycle stages, (b) those that focus on a complete product life-cycle and cover all life-cycle stages, and (c) those that go beyond single product life-cycles. Design for Multi-lifecycle is one of the sustainable design approaches whose focus covers all lifecycle stages and goes beyond single product lifecycles. The goal of design for multi-lifecycle is "indefinite" use of the resources invested/embodied in a product. However, the problem is that there is a limit to the number of times that resources embodied in the product could be sustainably cycled. Such limitations cause huge resource wastage, reduction in corporate profit, pose high risk to human health, and cause ecological damage. It is therefore necessary to identify those factors that limits how many times resources invested in the product can be cycled and how the bottlenecks can be removed. To achieve these goals, an intensive study of previous research works on sustainable design concepts, especially design for multi-lifecycle was conducted. Comparison was made between products designed for single lifecycle and those designed for multi-lifecycle. The place of design for multi-lifecycle within the spectrum of various sustainable concepts was also examined. Furthermore, the author's past experiences in sustainable design of agri-industrial facilities and in pilot plants' operations provided an impetus for adequate diagnosis of sustainability problems of facilities and products designed multi-lifecycle and potential solutions to the problems.

## 1.1. Conventional design: design for a single lifecycle

Most of the consumer electronics 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 of in landfills. This single life (design) philosophy has caused significant environmental problems and resulted in enormous economic wastes. According to university of Arkansas [6], about 20 to 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 [7]. 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 negative human health and ecosystem welfare consequences. There is therefore a need for new design philosophies and paradigms that foster design of products that minimize ecological footprints and improve systems durability. Design for multi-lifecycle (DFML) is one of the sustainable design approaches that facilitate the attainment of these goals.

## 1.2. Design for multi-lifecycle (DFML)

As earlier explained, DFML 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 [8]. The incorporated product features were to enable a product go beyond single lifecycle. The design concepts that facilitate incorporation of such features in a product 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 [2, 9-14]. Others are design for manufacturability, design for remanufacturing, and design for packaging [15] as illustrated in Figure 1.

So, the goal of design for multi-lifecycle is to enable the use and re-use of a product designed for multi-lifecycle forever. However, that has not been possible. What makes it impossible to be able to use a product forever? What are the issues that determine how many cycles of life a technology or product can go through? These are among the research questions that this study addressed. The focus of this design concept is on engineered products like electronics, machines, and physical infrastructures.

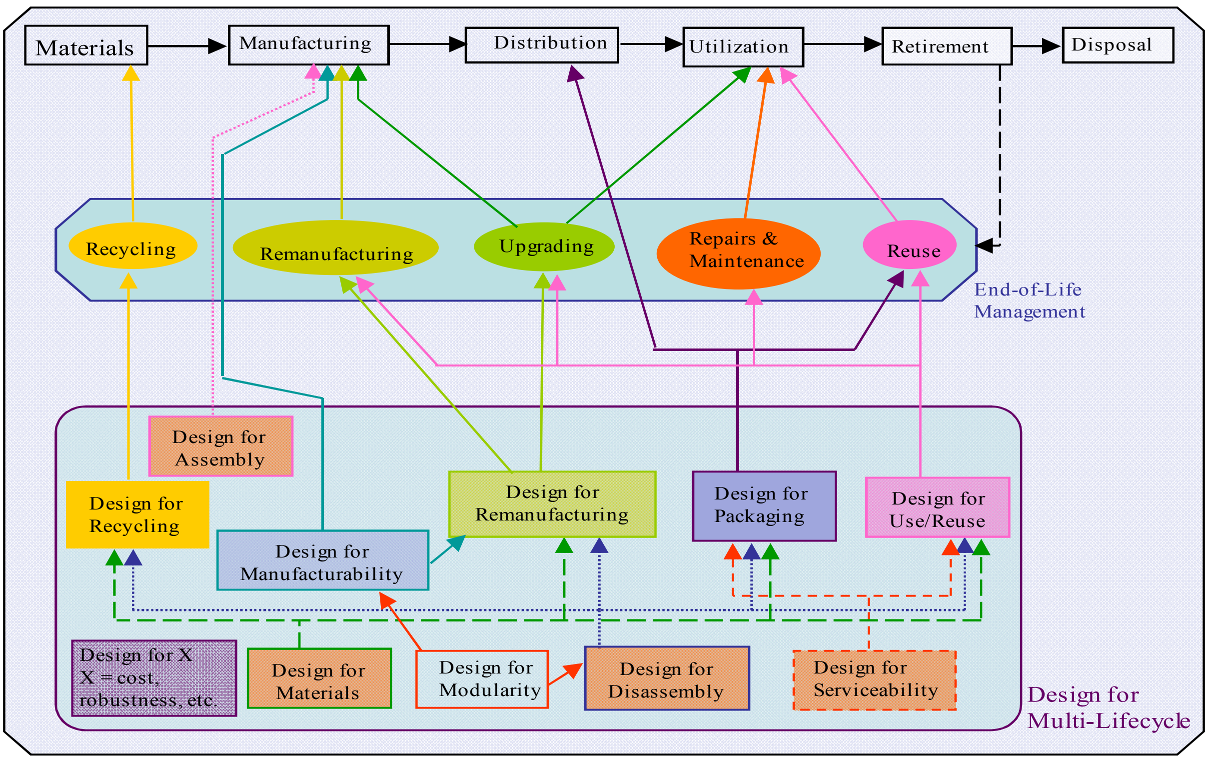

**Fig. 1:** Correlation between Lifecycles stages, End-of-life Management, DFX Concepts, and Design for Multi-lifecycle [8].

### 1.3. Literature review on design for multi-lifecycle

There are only few research reports on incorporation of multi-lifecycle concepts in products design and development, just as there is limited information on how incorporation of the concepts would result in product recovery optimization. Among the few available research works include: integrated PLM-process-approach for the development and management of telecommunications products in a multi-lifecycle environment [11]; design for multi-lifecycle: a sustainable design concept applied to an agro-industrial development project [8]; designing for multi-lifecycle to promote industrial ecology philosophy [10], and multi-lifecycle product recovery for electronic products [16]. However, none of these works have examined limits to sustainability of products designed for multi-lifecycle. An understanding of the fact that nothing engineered can last forever led to this research on determinants of how many times a product or technology designed for multi-lifecycle can be cycled in a sustainable manner. The points raised in this paper were based on intensive literature review. It was also based on over twenty years' experience in research and development of machinery for agri-industrial applications, and in working with various stakeholders on sustainable design and development concepts. In the next section we discussed the concept of design for multi-lifecycle. Sustainability issues affecting products designed for multi-lifecycle was discussed in section 3. Various aspects of sustainability limits are discussed in section 4. This was followed by section 5 where how the understanding of sustainability limits can be utilized to improve product design for multi-lifecycle was highlighted before the conclusion was drawn.

## 2. Methodology

This qualitative study was based on personal observation from sustainable design research experience and desktop research on previous works reported by others scholars in various areas of sustainable/lifecycle design of mechanical products. The author has several years of working with stakeholders in the areas of sustainability research, and in the design and development of agri-industrial machinery for small and medium scale industries in a developing country. Articulation of many issues highlighted below was among the challenges personally encountered by the author and solutions proffered to them that were found to be effective. The rest were based on other scholars' experiences and reports.

## 3. Factors affecting sustainability limit of products designed for multi-lifecycle.

Although the goal of design for multi-lifecycle is an indefinite use and re-use of a technology or a product that has been so designed, the following factors illustrated in Figure 2 were found to be among the factors that limit how many cycles of life that a technology or product designed for multi-lifecycle can sustainably go through:

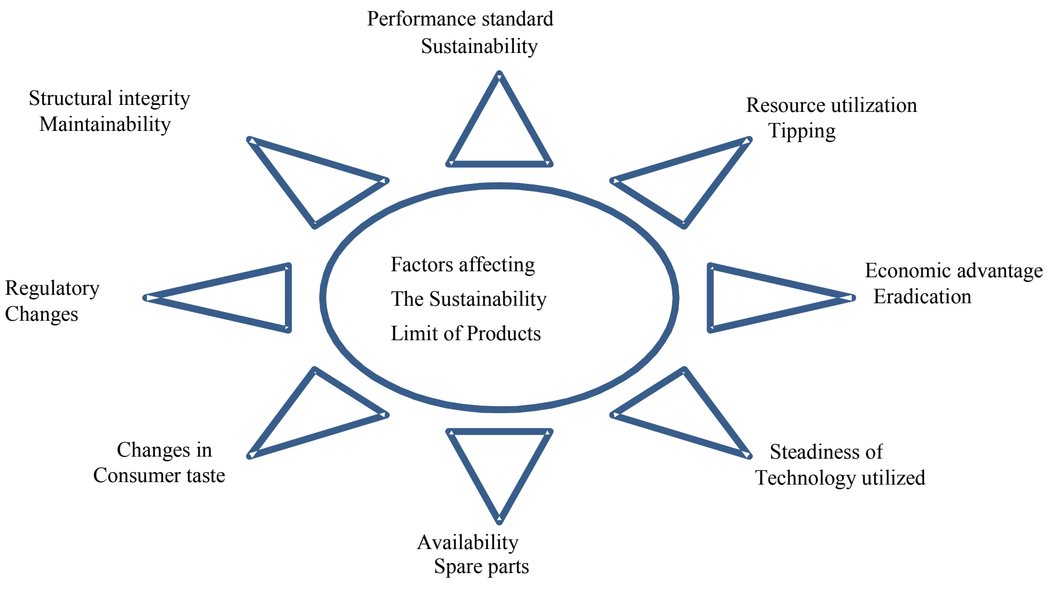


**Fig. 2:** Issues affecting sustainability of DFML products

### 3.1. Performance standard sustainability

Technology or product performance decreases with age. It also decreases with each subsequent cycle. Reasons for the degradation in performance may be due to wear and tear of functional units of the products which reduces the effectiveness of their functionality. It may also be due to weakness structural parts or slipping of meshing subassemblies in operation. The sustainability of a product in terms of its meeting acceptable minimum performance standard depends on the nature of the product and the industry standard. After a number of cycling, it may be difficult or impossible to meet the required minimum performance standard without replacing or upgrading vital parts of the product. Performance sustainability limit is reached when the attainable performance standard in the cycle falls below the minimum required performance standard. Sustainability limit is also reached when the resources required maintaining the performance standard equals or exceeds what is needed by a new single lifecycle designed product to attain the required performance standard.

### 3.2. Structural integrity maintainability

Environment in which products are used differ from one another. Sometimes products are exposed to corrosion, sometimes they are used in rough terrain, and at times they are exposed to ultraviolet radiation. These conditions may lead to a build-up of stresses in the product's components as the product is cycled over and over again. Exposure to ultraviolet radiation would weaken the material structure of the product. The build-up of stresses and weakening of the product structure could lead to the product's failure at some point. Thus, sustainability limit is reached when the structural integrity of the product can no longer be guaranteed.

### 3.3. Resource utilization tipping point

As a product is used and reused again and again, resources required to bring it to the required standard level for reuse will likely increase with each subsequent cycling. It will not be rational to continue the cycling when the resources requirement for the next cycling is the same or more than resource requirement for manufacturing a new product of the same quality.

### 3.4. Economic advantage eradication point

One of the hallmarks of multi-lifecycle designed product is reduced total lifecycle cost when compared to the lifecycle cost of single life products. However, as the number of cycles through which a product is taken increases the economic advantage may become eliminated at some point. Elimination of the economic advantage may be as a result of increased costs of resources required for subsequent lifecycle or due to increased liability. Consequently, the sustainability limit of the multi-lifecycle product is reached when it loses its economic advantage over an equivalent single life product.

### 3.5. Steadiness of technology utilized

The operating principle of some products is steady for a long period of time while for some products the technology changes frequently. Changes to some products are gradual while some other ones are drastic. For example, the operating principle of automobiles is relatively stable with only minor changes while communication systems have experienced complete revolution within a short period. Products that undergo frequent changes in operating principle will soon become obsolete because new facilities different from the previously used one may be required for each change. Such demand for facility changes may limit the economic viability of using the product over several lifecycles [3].

### 3.6. Availability of spare parts

Availability of spare parts needed for replacing faulty parts goes a long way in determining the sustainability of the product over a long period of time. The availability could be in terms of the parts being locally accessible or in terms of the cost not being prohibitive. Availability or non-availability of spare parts depends on technical know-how, import/export regulations in effect, demands for the product, and the nature of the economy at the place of use. Availability of spare will definitely affect the reparability and maintainability of the product. This will consequently limit the sustainability of the product [3].

### 3.7. Changes in consumer taste

Consumer taste changes with time. The changes may be triggered by available substitutes that are either cheaper or of higher quality. Changes in taste may also come as a result of consumers' exposure to different culture which may make them imbibe the foreign culture and taste. A product has reached its sustainability limit when consumers no longer have a taste for it or if their taste for it waned. This is because it will lead to reduced demand for the product thereby discouraging continued subjection to multi-lifecycle use.

### 3.8. Changes in regulations

The regulation regarding the technology, use, or management of a product may change either due to socio-political, techno-economic or environmental reason(s). If the regulatory changes cause the use of a new technology or the ban of old technology, then the product designed for multi-lifecycle based on the old technology has reached its sustainability limit.

## 4. Types of sustainability limit

These factors that affect how many cycles of life a product designed for multi-lifecycle could go through can be grouped into the following three types of sustainability limits (Figure 3):
1) Technical sustainability limit.
2) Economic sustainability limit.
3) Socio-political sustainability limit.

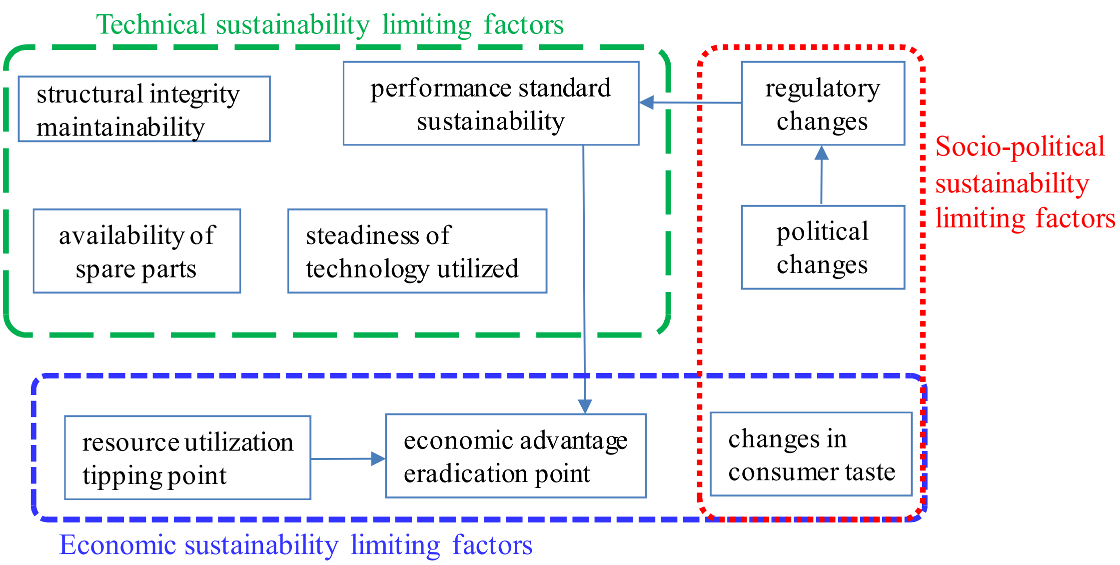


**Fig. 3:** Correlation between types of sustainability limits and sustainability limiting factors

### 4.1. Technical sustainability limit

This is the sustainability limit imposed by technical limitations to reusing the product in the next lifecycle. Among such limitations are changes in the technological principle/ mechanism on which the functioning of the product is based, availability of spare parts for repairs and maintenance, structural integrity of the product, and resource utilization tipping point.

### 4.2. Economic sustainability limit

Economic sustainability limit is imposed on a product when the reuse of the product in another cycle of life doesn't make economic sense. For example, economic sustainability of product Y is reached if the lifecycle cost of a newly manufactured product Y is equal or lower than the total cost of the next lifecycle of the multi-lifecycle designed product.

This could be due to increased resource consumption, the need for more spare parts, changes in regulations that affect availability of spare parts, increased utility billing rate, and other costs associated with multi-lifecycle designed liability [2]], [14], [17].

### 4.3. Socio-political sustainability limit

This is the limitation that could result from regulatory changes, political changes, and change in customer taste as it affects the product in question. At this point, one of the steps that could be taken is to take the utilizable components and used them in building other similar product(s) that are socio-political sustainable at the point in time. Alternatively, the material content of the multi-lifecycle product that has reached its socio-political sustainability limit may be recycled and used in a new product.
All the three types of sustainability limits are interrelated and socio-political factors can weigh heavily on the technical- and economic sustainability as shown in Figure 3.

## 5. How the understanding of these issues can be utilized in improving product design for multi-lifecycle

Figure 4 illustrates the link between issues affecting product sustainability and various design concepts embodied in design for multi-lifecycle. The understanding of possible changes in regulations regarding emissions, resource consumption and standardization at any given time will help product designers to be innovative in designing the product functions in modules. Being more innovative in designing for modularity will facilitate replacing and redesigning such module to satisfy the new regulation without necessarily having to redesign the entire product.

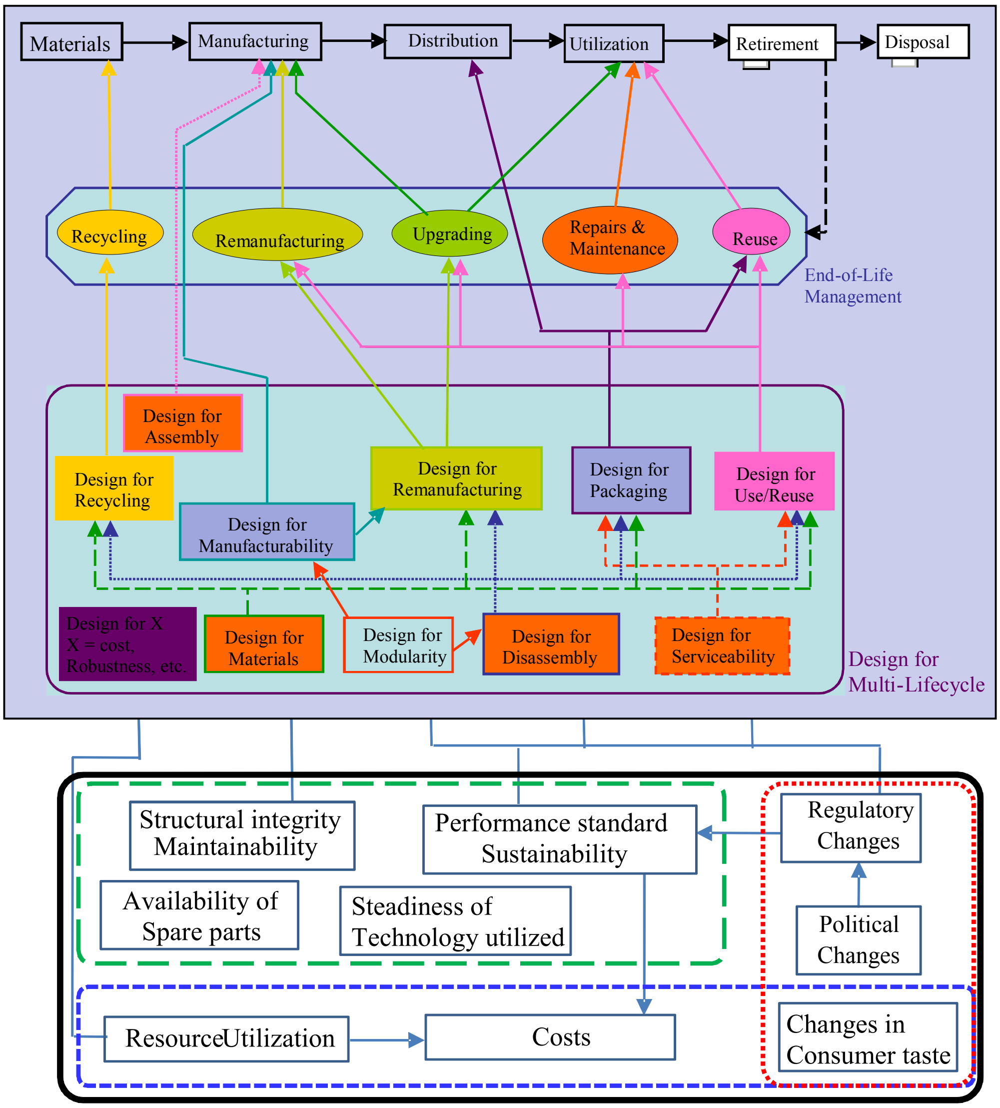


**Fig. 4:** Links between sustainability limiting factors and design for multi-lifecycle

Consequently, this will lead to cost savings by reducing resource consumption, reduced quantity of wastes to be discarded, reduction in facility required for product changes, and reduction in costs that would have accrued to implement the changes. The understanding of potential changes in consumer taste and preferences will help designers to be more articulate when designing for X where X is either design for use and reuse, design to cost, design for materials or design for recycling. This is particularly important in view of the upsurge in environmental awareness and the associated health implications. Furthermore, the knowledge of each of these issues will make eco-designers to be more sensitive when making a number of other design decisions.

# 6. Conclusion

Various issues that affect sustainability of products designed for multi-lifecycle were highlighted in this paper. They include technical issues like technological changes, availability of spare parts, and ability to maintain product structural integrity. Others issues include changes in consumer tastes and changes in regulations. However, if designers can bear in mind the probability of this changes happening, he/she would be more innovative in designing for modularity, designing for materials and in designing for use and reuse. Doing these will consequently increase the numbers of cycles of reuse that such product could go through before being retired and subjected to a different end-of-life management. This means that the number of times that resources invested in a product designed for multi-lifecycles can be cycled is increasable by improving the durability of the structure and core components of the product. It also means that designers would be able to improve the sustainability of products, technologies and/or machinery designed for multi-lifecycles by incorporating features that facilitate easy reconfiguration and upgrading of the product at reasonable cost as consumer taste and regulations changes. Further studies of the concept would involve developing metrics for quantification of sustainability limit of products designed for multi-lifecycle.

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