Measurement of design feasibility for sustainability

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ABSTRACT

The paper presents the feasibility measurement of design for sustainability. Major feasibility considerations for sustainable design have been enunciated. It is proposed that present day design must include the environmental considerations in design of part or systems.

Keywords: Feasibility, design phase, sustainability, reuse, recycling, design methodology

1. INTRODUCTION

The purpose of this paper is to present a methodology for measurement of feasibility of design in engineering and sciences. The paper states the generic synergic relationships among various design parameters which affects the feasibility of design for sustainability. There has been increasing concern for environmentally friendly product and system in the market. Government world-wide have been tightening environmental regulations for products and systems. The reasons for this development are many but specially running out of fossil fuel, global warming, depletions of natural resources, and such other related factors.

But we in academic engineering world have not taken notice of these factors in our design process and so the engineers graduating from engineering schools have no concern for these developments. It is an attempt to make this awareness felt among future engineers. It is advocated in this paper that technological requirements for green design be espoused at early stage of engineering education. Concerns for energy consumption, material selection, manufacturability, recycling, reusing, including packaging should be taught in engineering design. Green design basically is a multidisciplinary approach for reducing energy and material consumption. It is estimated that in USA about 25% is recycling and 15% is waste combustion and rest 60% goes to landfill. It is time to bring these problems to class rooms of future engineers. The objective of design should also be to restrict use of hazardous materials in design which have adverse effects on human health as well as on environment. No where we teach in design class end-of-life aspects of the product i.e. state of disposal. A paradigm shift in our approach to achieving sustainable design is needed by including life cycle thinking in design. We can call it Life Cycle Assessment (LCA), or Design for Environment (DFE), or Green Design but concept and approach should always be based on life-cycle aspect of the product [1, 2]. Later in the paper I have enunciated feasibility measurement for sustainable design.

It is generally known that any final design adopted started with several design hypothesis. However good and robust design shared a small numbers of common characteristics to make the design adoptable. This paper studies the impact of such multiple views and representations and how it could be accommodated. Large scale design project involve many different disciplines each with their own area of concern and expertise. At various stages of design designers from different disciplines will represent an abstraction (a model) of the current design according to their views. The different models will initially be incomplete and inconsistent but through collaboration they will undergo changes as inconstancies are removed and details are added and eventually a constituent representation emerges. Hence, it is proposed that the essence of feasible design could be captured. It is recognized by designers that no amount of parameter tuning can markedly improve the feasibility of design if it is not grounded with fundamental theories of natural sciences. It also discusses resources issues that are traditionally discovered so late in design process like materials, manufacturability, weight, functionability, cost, and sustainability. For a feasible and good design customer attributes should match with functional requirements. And then functional requirements must be incorporated in design parameters to make it feasible. Feasibility may be of the following types.

1) Short term feasibility: The ability to immediately satisfy the needs.
2) Medium term Feasibility: the ability of the system to work at the maximum levels of productivity when use of the systems is varied.
3) Long term feasibility: the possibility to adapt the system to new types of use other than intended purpose.

The sustainable design requires a holistic view, from designing products that use machines and processes that produce them to optimizing the layout of the facility itself.

2. DESIGN CRITERION

However, as we know in the engineering world the designers sometimes misses the process parameters and manufacturability requirements of the product. In particular good design must be theory grounded: Good and feasible design must reflect the theory which is being investigated. We know that sometimes the designer is not able to visualize the force or load or a combination of them acting on the part. This simple analytical process would start the designer on good footing. We should also be able to analyze if the load will cause fatigue or the load is dynamic in nature.

It should also be noted that good design should not be situational as it limits its universability in the days of global economy. We all well know that engineering parts and products are designed in country X and manufactured in country Y and assembled in country Z and shipped to country N. To make the part or product internationally acceptable it has to follow standards and codes acceptable globally not country specific.

However the most important feature of feasible design means it should be implementable, i.e. it should be manufacturable. The sequence and timing of manufacturing steps should carefully be thought about during design to weed out the potential problems during manufacturing process. Sometimes in the design of a system the redundancy should be built in as we can visualize its need in space shuttle, aircraft and such other systems. Often this flexibility results from duplication of essential design features. Good design strikes a balance between redundancy and tendency to over design. In engineering design sciences, it is called factor of safety. It is used to improve the safety of the part. However, as we try to improve safety by increasing FOS, it increases the material requirement of the part and the system. This in turn makes the part or system heavy and more costly and less profitable. The factor of safety is greater than 1 i.e. $1 < FOS \le n$, where n is any number greater than 1. As we notice making the system more safe means increasing the material consumption. So to make the product or system safer means increasing the weight of the part or system and it is not sustainable. We should reduce the weight of the system but it may become less safe. We can appreciate the dilemma of aircraft design engineers. Heavier system would affect the performance of the entire system. The figure 1 below shows the effect of factor of safety (FOS) on materials, cost of manufacturing and total cost of a system.

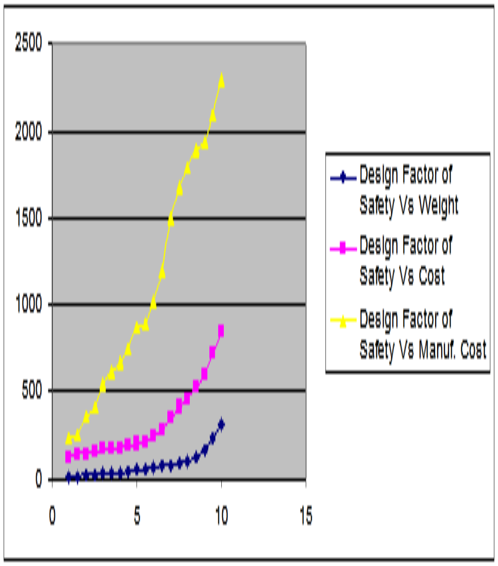

Figure 1: FOS VS Weight, Manufacturing Cost, Cost

As we consume more material it can affect the profit of the manufacturing company. We know

Profit/part = Sales Price/part - Cost/part

As we can see as FOS increases the profit will decrease and this situation is not sustainable. So the design engineers will have to account for all the consequences in the downstream of the design and manufacturing. Sometimes less FOS can affect the material selection and that in turn will affect the manufacturing process. For example, if you select cast iron to manufacture, say, flywheel you need foundry process, or if you select steel you need material removal process or sometimes with aluminum you may need forging press. All these downstream manufacturing processes are depended on the material selected and on FOS assigned in the design process. With less FOS sometimes you may be forced to select more expensive material. The quality control process would be entirely different for different manufacturing process and a good designer must bear this in mind while designing a part or system. With all the above contradictory factors described above, it is best to adopt an optimization technique to design the part. In optimal design process, an objective function needs to be formulated like minimization of cost, or minimization of weight, or maximization of profit. These objectives can also be combined together to make multi-objective function. Then we have to recognize the constraints on the objective function to make the solution more feasible and sustainable.

The paper tries to present a comprehensive methodology for a good, feasible and sustainable design. Developing new products involves ideation, which involves failure- not something that processes like to embrace. Many ideas are generated and discarded in the hope that the best idea will eventually be found [5]. History reveals that well-known ideas were often born when product functions were combined with new applications. The following adaptations are known the world over.

1) The gramophones was initially designed as a voice recorder, but then used to play music.
2) Adapting tea packages for easier preparation led to the innovation of tea bag.
3) Blotting paper in brass pot with drilled holes led to the coffee filter.

A conscious or not, using a product in a different way than its purpose is the seed of creating new applications, if not innovation. Adopting a product to a new need or situation relates to what is known by context awareness; human factors related context is structured into three categories.

a) The user’s tasks and needs (e.g.… spontaneous activity, engaged tasks, generate goals).

b) The user’s environment (e.g., location interaction with others).

The feasibility can be expressed in terms of capability and capacity of the part being measured. The capability can be measured as the number of different types of applications that a part can perform, while capacity is defined by cost and time required to configure a part for different types of operations. Therefore feasibility of a part can be expresses as a function of the set of operations, time and cost for reconfiguration. That is

Features=function of (capability, Capacity),
Capability=function of (Range of Operations)
Capacity=function of (Time, Cost)

Therefore, Feasibility=function of (Range of operation, Time, Cost)

3. DESIGN METHODOLOGY

Engineering Design Methodology (DM) is a formal approach to design, its aim is to provide a theory to the engineer with which he can systematically generate and evaluate solutions to a design problem in an objective and effective manner. DM tries to make design teach and learnable, and to ensure that engineer arrive at optimal solutions not by chance but by methods. DM provides methods and structure for design and divides the design process into the following phases [3]. Figure 2 shows the phases described here.

a) Task clarification: The design process starts out with the clarification of task. During this phase information about the requirements to be met are collected. Up to recent the design engineers used to think that requirement just means functioning of the component or system. With the onset of sustainability concept the factors like safe (non-hazardous) material for the entire life time of the product has become essential along with cost and quality. The detailed requirements must include safety, cost, and quality along with the functioning of the system/product. The requirements list is basically a description of the ideal object.

b) Conceptual design: From the description of the ideal object, functions that object has to realize are derived, and a function structure is generated for sustainability. The detailed description of these phases is shown in figure 2 below. By combining these solutions a vast amount of concept ideas are generated. In order to decide which one of these concept variants should be developed further a realistic evaluation has to be made. For this purpose the ideas that do not meet the requirements in terms of cost, quality, and long term safety requirements are eliminated and rest are examined further [4].

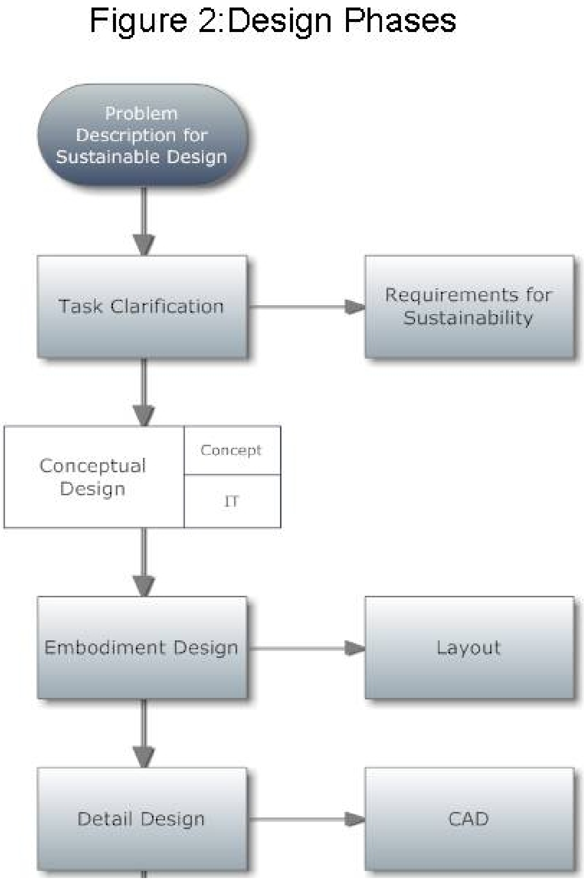

Figure 2: Design phases

c) Optimal design: In this phase the engineer refines the concept and determines the shape, size and geometry of the object in accordance with requirements for sustainability and real world constraints. The dimensions and surface properties of all parts and system are optimized, checked against constraints and fixed.

d) Detail design: In this phase the design is finalized and detail drawings, parts list, and 3-D models are generated by a CAD software. Although this engineering design methodology seems different but a similar variant of ideas are used by design engineers are used more regularly and are described in most of the design textbook. This is presented in Figure 3 below.

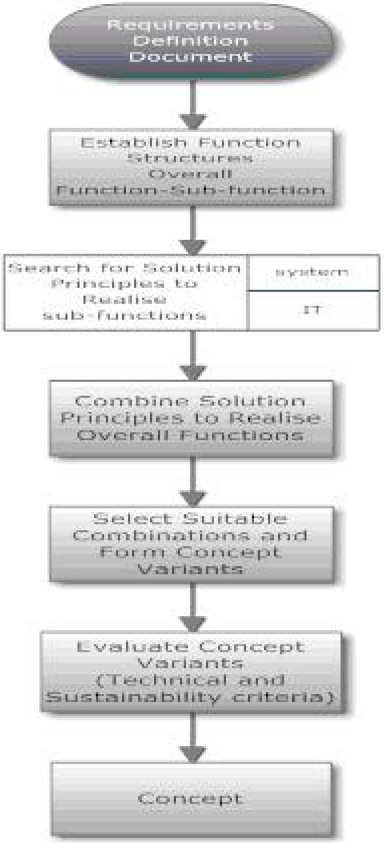

Figure 3: Phases of conceptual design

4. COGNITIVE CONCEPT NEEDED FOR DESIGN ENGINEER

Experience in engineering and design is important for designers. It is the knowledge a designer gained through seeing things and doing [6]. But it may not so literally. If for example a designer in space agencies has to design a vehicle for traveling on Mars, we can confidently say no designer has seen the vehicle on Mars. The ‘doing’ part is guided by design of vehicle on earth or some one may have some knowledge of designing moon vehicle. So we say some times when designing an object or system the experience is just inferential. The mental concept in human being is formed by the following models:

i) Classical model: In classical model a mental concept is defined by a set of necessary and, together, sufficient features. Mental concepts are organized hierarchically and all features are of structural nature.

ii) Probabilistic model: In the probabilistic model the mental concept is still defined by a set of features, but these need not be defining but only be typical. Each feature has a measure of typicality attached to it and classification of an object is done on a probabilistic basis.

iii) Exemplar model: Exemplar models do not have a set of defining features but instead a set of defining exemplars. An object is classified according to its similarity to the exemplars of the mental concept.

iv) Hybrid models: Hybrid models mix the defining-feature based and exemplar based models to form a system where both defining features and a set of exemplars exist.

v) Microtheory models: Microtheory models, on the other hand, use the rules governing the classification of the object as the core of the mental concept model.

The experience of design engineers plays a central role throughout the design process. Transferring the problem at hand into tasks to which solutions can be found is a process that is based on the ability of engineers to relate to the problem to his prior experiences and his domain of knowledge. It may not be out of place here to mention that in mechanical engineering, the designer store a description of what technical object does and its basic properties, along with some examples and counterexamples as concepts.

5. THE FRAMEWORK OF FEASIBILITY MEASUREMENT IN DESIGN FOR SUSTAINABILITY

The paper presents the following feasibility criterion for sustainable design [7].

1. Choose non-toxic, sustainably provided or recycled materials.
2. Energy Efficiency: Use manufacturing process and produce products which require less energy.
3. Quality and durability: Longer-lasting and better-functioning products will have to be replaced less frequently, reducing the materials requirements in future.
4. Design for reuse and recycling: Product processes and systems should be designed for performance in a commercial "after life".
5. Design impact measures for total carbon footprint and life cycle assessment for any resources used are necessary. Available measures are complex but some give quick and accurate whole-earth estimate of impacts. One measure estimates any spending as consuming an average share of global energy use of 8,000 BTU (8,400 kJ) per dollar and producing CO_2 at the average rate of 0.57 kg of CO_2 per dollar.
6. Biomimicry: Redesigning an industrial system on biological lines- enabling constant reuse of materials in continuous closed cycle. At this stage of engineering design, we don't see any biomimicry being used in design. However it is certainly a useful idea.
7 .Service substitution: Shifting the mode of consumption from personal ownership of products to provision of services which provides similar functions e.g. from a private automobiles to a sharing service. Such a system promotes minimal resources use per unit of consumption.
8. Renewability: Material should come from nearby, sustainably managed renewable service that can be composted when their usefulness has been exhausted.
9. Robust eco-design: Robust design principles are applied to the design of pollution sources.

6. CONCLUSION

The paper has tried to present the measurement of long term feasibility considerations for sustainability in artificial and natural sciences. It has been pointed out that present engineering education in particular doesn't emphasize on the environmental considerations. The long term feasibility considerations have been clearly enunciated to make the sustainable.

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