A modular product design approach for sustainable manufacturing in a fuzzy environment

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Abstract

Green modular product design is a very crucial technique for sustainable manufacturing. By making good choices of combinations of the available components and modules of a design, it is possible to build sustainability into the life cycle of a product. For effective modular design, it is critical to know the design factors and their potential impact on the ultimate economic, environmental, and the social performance of the product or process. Nevertheless, in a fuzzy environment, one or more factors are not precisely known at the design stage. First, we propose a set of multiple criteria for evaluating a modular product design. Second, a fuzzy grouping genetic algorithm (FGGA) is proposed for grouping components of a design in a modular fashion. The proposed modular product design approach is promising, especially when the design factors and the criteria for sustainability evaluation are not precisely known at the design stage.

1. Introduction

Given the ever-increasing environmental damage, passive approaches such as garbage classification and resource recycling, are no longer adequate. Environmental protection is important to every product design and manufacturing. Therefore, it is important to develop more proactive approaches. It is crucial to maximize resource, while
minimizing environment damage, right from product design stage [1]. This approach is known as green lifecycle engineering [1] [2] [3]. The notion of product life cycle points to the time from material usage, manufacturing, assembly, product use, and the final disposal or product recycle. In this case, green life cycle is centered on the last two stages: product use and disposal or recycle [1]. It is highly important for the designer to take a holistic look at the entire lifecycle of the product in order to maximize the usage of resources and, at the same time, minimize the damage to the environment. This should be considered as early as early as possible; at the design stage. While this is desirable, it is often difficult to precisely determine the relevant design information as early as the design stage.

Several researchers have explored green design from various viewpoints, for instance, design for environment, design for recycling, and design for ease of disassembly [4] [5]. Modular structures and the concept of modularity can play a very important role in the life cycle of a product, in terms of ease of upgrade and maintenance, ease of product diagnosis, improved efficiency in reuse and recycling, as well as ease of repair and disposal. Though it is crucial to build green design into products at the planning stage, the idea is practically difficult to implement. The challenge is that, at the design, the information to be used for design may not be known precisely. For example, factors relating to the costs, design, and green fitness may not be precisely known early enough. Therefore, developing efficient grouping techniques is imperative. Thus, this research proposes a modelling approach to green modular design based on a hybrid approach that incorporates fuzzy evaluation techniques [6] and grouping genetic algorithm [7] [8].

The rest of the paper is organized as follows: The next section gives a brief background to sustainable manufacturing, modular product design in Section 2. Section 3 presents a fuzzy dynamic grouping genetic algorithm approach to modular design. Section 4 concludes the paper.

**Nomenclature**

\[ m, n \] number of modules, number of components

\[ I_{lk} \] liaison intensity between pairs of components \( l \) and \( k \) in a module

\[ c_m \] the costs associated with the material to be used

\[ c_p \] the costs associated with the manufacturing process

\[ c_a \] the costs associated with the assembly process.

**1.1. Sustainable manufacturing**

Sustainable manufacturing is a critical concern for industry, governments and other stakeholders. It can be defined as the creation of products that minimize environmental damage, minimize energy and natural resources consumption, and are economically sound [9]. However, factors such as health and safety of employees, communities and consumers are also essential. It can be seen from this perspective that sustainable manufacturing should address the need for integrating all the three triple bottom line of sustainability, by simultaneously considering the environmental, social, and economic indicators.

Considering the diminishing nonrenewable resources, manufacturing sustainability is a very critical need. There is need for stricter regulations on the environment and occupational safety, as consumer preference for environmentally friendly products continues to grow. Sustainable manufacturing must address issues regarding (i) economic challenges, (ii) environmental challenges, and, (iii) social challenges. The green modular product design approach seeks to address these issues.

**1.2. Green modular product design**

Green modular design is a product design approach that splits a system into modules that can be built independently, so that a variety of different systems can be assembled from them [10] [11]. There are three fundamental types of modular design, that is: (1) function-based modular design, (2) modular manufacturing design, and (3) assembly-based modular design [1]. In the real world, where demand for product variety and customization keeps increasing, manufacturers need to keep abreast with multiple variations of product specifications and modules,
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