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An approach to analytically evaluate the product disassemblability during the design process

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Abstract

In order to favor the implementation of closed-loop scenarios at the product End of Life (EoL), it is essential to consider the disassembly phase during the design process. In this context, the paper presents a design for disassembly approach to quantitatively estimate the product disassemblability. The methodology is based on a knowledge database about liaisons, which have been classified and characterized with different properties, in order to take into account the liaison specificity and real conditions in the moment of the disassembly. Starting from the product structure and liaisons between components, the methodology allows to analytically calculate the disassembly time and cost of components/sub-assemblies. The case study (combination oven) demonstrates the usefulness of the proposed approach in identifying the product criticalities which is necessary to consider during the redesign phase in order to improve the product disassemblability performances.

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1. Introduction

The environmental problem is becoming extremely important in the modern society. In order to preserve the natural environment for future generations, it is essential to consider the variable "environment" during the development of new products, processes and services, as well as the other classical design drivers, such as costs, functional requirements or performances. To this aim, the design departments need to extend their view outside the company boundaries, considering not only the design and manufacturing phases but the whole life cycle, from material extraction to disposal.

In this context, the End of Life (EoL) is recognized as one of the most critical phases. This is essentially due to the fact that it is the most far away phase, in terms of time, from the moment of the product conception. But it is also well known that the EoL is the joining link to "close" the product life cycle. The accurate management of the EoL scenarios, in the early design stages, is emerging as a fundamental eco-design strategy for companies, in order to create closed-loop scenarios of materials (reuse of products or components, remanufacturing of components and recycling of materials).

Within the product EoL, the disassembly is a preliminary but fundamental phase. Only reducing a product into its individual components it will be possible, for example, to reuse or remanufacture components. The Design for Disassembly (DfD) concepts should be integrated within the design process, when designers have the necessary freedom to change different characteristics of the products, such as component materials or connection methods, with minimal impact on the manufacturing process or production costs.

The proposed paper provides a useful methodology which supports companies in the evaluation of the product disassemblability. It permits to analytically assess the disassembly phase, on the basis of the product architecture and liaisons between components, taking also into account the real condition of the product at the moment of the disassembly. And considering the disassembly processes and tools, as well as the labor cost, the disassembly cost of each component can be estimated. The integration of this methodology during the design process allows to

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quantitatively identify the most critical components/sub-assemblies from a disassembly point of view. This is an essential result to help designers to proceed in the right way during the improvement phase.

2. Literature Review

In the recent years international governments have issued directives, such as the disposal of electronic and electrical products and equipment, and the restrictions on the use of hazardous substances [1][2], which focus on the EoL phase, in order to force manufacturers to effectively participate to the waste treatment. The only possible way to facilitate the dismantling activities at the EoL, is the implementation of DfD or Design for EoL techniques.

Design for Disassembly is a well-known target design methodology which allows the easy separation of components in industrial products [3]. It involves the selection and use of appropriate materials, the design of components and product architecture and the selection and use of joints, connectors and fasteners which could be easily disassembled [4]. DfD makes the de-manufacturing plan of components simple and efficient, and must be considered, in particular, for components with a high quality/value [5].

In literature there are many works on issues about this important theme. Dewhurst [3] evaluates the depth of disassembly for particular components in a product to establish the effective cost convenience for disassembly operations. His index is one of the first examples of quantitative methodology to assess the feasibility of the disassembly process. Johansson [6] suggests the product properties that are essential for efficiency of the disassembly process: ease of identification, accessibility, ease of separation, and ease of handling of components and subassemblies. However, none of these works provide a method to estimate the disassembly time, which is one of the most important indicator of the ease of disassembly.

In the last decades, the most important works on disassembly methodologies have focused on extrapolating data from 3D CAD models. In particular, many researchers [7] have developed algorithms to find the transition matrix and the best disassembly sequence for components in an industrial product. Their topics are mainly oriented to the selective disassembly of components due to the high value. Kara et al. [8] propose an evaluation method to detect the possible paths for the disassembly of a specific component from the product. Kang et al. [9] propose an algorithm for the efficient derivation of a transition matrix based on a product's architectural information, which includes the product's physical connections and the relative geometric locations between individual parts. Several authors are focused on the disassembly scheduling. The identification of the optimal disassembly sequence is performed using linear programming and genetic algorithms [10][11]. Giudice and Fargione [12] propose an approach to disassembly process planning, based on genetic algorithms, that supports the search for the disassembly sequence best related to two aspects: service of the product and recovery at the end of its useful life. Srinivasan et al. [13] analyze the types of connections between components, the arrangement of components (product architecture), the directions of extraction and the first component to be disassembled in order to minimize time. A further step in this direction is the ability to recognize the type of mechanical liaisons between components, thus to generate an optimum disassembly sequence directly from the CAD product model. Different algorithms have been developed to solve Disassembly Sequence Planning, i.e. the determination of the sequence for disassembling component parts using combinatorial structure models [14]. Even if all these proposed methods are very interesting to solve the sequence planning problem, they do not provide quantitative outputs to measure the disassemblability of products.

Another method, called "virtual disassembly", use Virtual Reality systems to create a realistic multimodal interaction (visual/audio/haptic) experience with the CAD product model and can support collaborative de-manufacturing between manufacturer/de-manufacturer, disposer and designer [15]. Aleotti and Caselli [16] describe a method to use Virtual Reality to find all physical admissible subassemblies for the automatic disassembly planning. Chen et al. [17] propose a virtual disassembly system which enables operators to disassemble products interactively in a virtual environment. Also these methods are mainly focused on the sequence planning and do not consider disassembly time and cost to assess the feasibility of the disassembly process at the EoL or during the maintenance phases.

Only few literature works consider the disassembly time estimation to measure the degree of disassemblability of products [18][19]. Anyway, none of these considers also the disassembly costs.

In this sense, this paper aims to go beyond the state of the art about design for disassembly methods, presenting a methodology to analytically estimate the disassembly time and cost for each product component/sub-assembly. In particular, this latter could also represent a tangible and very useful metric for designers, in order to assess the cost related to the maintenance and EoL phases, in a life cycle perspective. Using this methodology, designers can rapidly identify the most critical components from a disassembly point of view, to the aim of conceiving the correct product architecture or choosing the most appropriate joint methods.

3. Methodology

The final goal of the proposed methodology is to help designers in the application of a Design for Disassembly approach. It is essential to support designers in evaluating the disassemblability of components and sub-assemblies. The analytical estimation of the disassembly time and cost, for the feasible disassembly sequences, represents the first step toward the optimization of products considering the EoL aspects. The classification and characterization of the possible liaisons between components is the starting point for the successive quantitative evaluation.