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Includes knowledge of dismantling centers in the early design phase: A knowledge-based design for disassembly approach

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Abstract

Nowadays, a large number of goods (e.g. appliances and electronic products) must be treated in dismantling centers after the conclusion of their lifecycle. Selective disassembly is necessary to accomplish environmental directives and to increase their sustainability. Dismantling centers developed internal non-standardized procedures to remove dangerous components and to minimize disassembly costs. The proposed approach aims to create a collection of the disassembly knowledge coming from dismantling centers as a repository for design actions oriented to End-of-Life. The final goal is to define a knowledge-based Design for Disassembly approach to support companies in designing products with improved disassemblability and maintainability.

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Keywords: Disassembly Knowledge; Design for disassembly; Dismantling center.

1. Introduction

The Circular Economy is considered as a global economic model that decouples economic growth and development from the consumption of finite resources. It is recognized as the best economic model to efficiently face the rapid growth of world population and raw material consumption. Beyond the theoretical benefits that, from a research point of view, this model guarantees, there are several pilot projects all over the world demonstrating the practical advantages. For instance, the Waste of Electric and Electronic Equipment (WEEE) recycling and the remanufacturing techniques applied to the automotive sectors are nowadays good examples.

In addition, an increasing number of enterprises are moving their business from products selling toward services selling. In this context, the take-back practice (used to close the loop) is one of the key elements of these business models, which need to be considered. The related economic advantages (from the industrial and consumer perspectives) are pushing forward research in this field. From one side, innovative recycling processes are becoming attractive for their economic potentialities to earn money from wastes, providing also new job opportunities. From the other side, the remanufacturing strategy is becoming even more attractive than recycling for its possibility to give a second life to used components, with an important cost saving compared with new products.

The above scenarios, with the related economic opportunities, are also driving the application of the environmental sustainability concepts, like a virtuous process. However, the connections between the product design and End-of-Life (EoL) phase have to be straighten.

Currently indeed, the design for Remanufacturing, Recycling and Disassembly are just theoretical concepts, with a limited application within a real industrial context. The academic and industrial state of art do not contain any virtuous approach where the knowledge of dismantlers and recycling centers are formalized and organized in order to be used by designers for the re-design of goods and products. Many case studies demonstrate the advantages of applying eco-design guidelines during the product development but an approach for the dismantlers and remanufacturers knowledge formalization is missing.

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This paper presents a method, based on four steps, to gather positive and negative knowledge and expertise from dismantler and remanufacturing centers with a focus on the disassembly processes in order to be used during the product design phase.

2. Related research works on product disassemblability and disassembly knowledge

In the recent years, international governments have issued directives (e.g. disposal of electronic and electrical equipment, vehicles and the restrictions on the use of hazardous substances [1][2][3]) focused on the EoL phase which force manufacturers to effectively participate to the industrial waste treatment.

The waste reduction is a key challenge for the modern society; hence, many researches are focused on this topic. Lederer et al. [4] present a method to gather knowledge from the stakeholders of the dismantling sector in order to optimize the waste management. However, the knowledge is not formalized in a way that can be used by designers; so that only marginal benefits can be achieved toward the waste reduction. Reyes et al. [5] present a theoretical framework of a tool to represent the knowledge of dismantling processes but, as the previous case, the knowledge is not collected for engineers use. Terazono [6] studied the advantages of sharing the recycling knowledge among stakeholders of the same sector, but none methods to formalize the knowledge have been proposed. According to a research lead by Li et al. [7] the designers' attitude and perceived behavioral control have the largest and most significant effects on the waste minimization so it is necessary to give them the required knowledge.

Another approach for the waste reduction is suggested by Das et al. [8], which present a standard coding structure for documenting and transmitting the disassembly knowledge to dismantlers. The authors expect that in the near future the product manufacturers will create and distribute the product Bill of Materials to potential collection and disassembly facilities through product labelling or a public access website. This is an attractive scenario with further potential advantages. These advantages can be achieved if recycling problems are faced during the design stage by adopting Design for End-of-Life and Design for Disassembly theories.

Concerning Design for EoL, Ma et al. [9] proposed quantitative indicators to assess the sustainability dimensions, economic (residual value), environmental (Eco-indicator) and social impact (job creation, human toxic potential and land use) for each EoL option. Movilla et al. [10] present a methodology consisting of two major steps: firstly, an evaluation of assemblability and disassemblability and secondly, three different recovery rates. This solution allows designers to explore different assembly alternatives in order to find the one that leads the highest percentage of components with a closed-loop lifecycle. Even if these scientific contributions help designers in finding the best design solution in terms of EoL options, they do not provide tangible suggestions for a product optimization.

The Design for Disassembly topic was historically characterized by several approaches aiming to find the disassembly sequences and the relative times [11]. Guo et al. [12] present a framework for the automatic disassembly of 3D CAD models and the illustration of the disassembly, generating an animated sequence. Germani et al. [13] have identified a method to calculate the disassembly time considering precedence among components and working on a database of standard disassembly times. Another method is presented in [14] but it does not contain knowledge of dismantlers and the approach cannot be used at the conceptual design stage. A step beyond to support designers in finding the best solution is given by Ghazilla et al. [15]. They developed a multi-criteria decision making model to assist designers in selecting fasteners for Design for Disassembly (DfD).

The above presented approaches describe, mainly, meaningful algorithms to assess disassemblability, but the knowledge of dismantlers is not considered. To bridge this gap, Soh et al. [16] propose a conceptual framework based on practical considerations to aid the product designer in prioritizing the relevant DfD guidelines that could be used to increase the efficiency of retrieving a high value core of a product for remanufacturing. Although the knowledge-based approach, it does not present a method to capitalize the knowledge and expertise of the stakeholders working at the dismantlers centers.

Another step beyond has been done by Vongbunyong et al. [17], which propose a method to learn and use the knowledge related to the automated disassembly process of particular product (e.g. LCD screen) using a cognitive robotic agent. This knowledge has been used for the definition of a disassembly sequence plan and disassembly process plan [18]. This is a very powerful approach for automated disassembly systems of a specific product family but do not consider selective manual disassembly for component subjected to remanufacturing and reuse as well as different product families. Furthermore, this knowledge collection is not used to formulate design guidelines for the product improvement and development.

In the context of building constructions, Godfrey et al. [19] present a study showing how experience has the that greatest influence on building waste knowledge, nearly twice that of data/information and three times that of theory. This is a widespread conclusion in the sector of e-wastes.

For all the above reasons, during the last years, several studies are aiming to develop conceptual frameworks for managing the EoL knowledge to support designers during the product concept and embodiment phases with better environmental performances from a system perspective. The purpose is the sharing of EoL information among product designers and EoL stakeholders. In particular, the target is the knowledge management during the design process [20]. Enterprises are so focusing more and more on knowledge issues for global product development. Xu et al. [21] propose a knowledge evolution process in product development activities and a knowledge evaluation method in product lifecycle design. Vareilles et al. [22] investigate how it is possible to support design decisions with two different tools relying on two kinds of knowledge: case-based reasoning operating with contextual knowledge embodied in past cases and constraint filtering that operates with general knowledge formalized using constraints.

In conclusion, the literature review highlights the following limitations. There is not any approach that can be used to gather