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A method for manual disassembly analysis to support the ecodesign of electronic displays

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ABSTRACT

Waste Electrical and Electronic Equipment (WEEE) is one of the fastest growing waste streams in contemporary societies. Proper treatment and recovery of WEEE is an important challenge not only because of its content on hazardous substances but also because it contains significant quantities of valuable materials. The pre-processing stage of WEEE recycling plays a major role in the recovery network, in particular when carried out through manual dismantling processes. Dismantling allows components to be separated prior to further treatment. However, recycling organisations usually find this particular stage considerably time-consuming, and hence expensive, since products are not designed to be easily dismantled. One particular waste stream that could reduce dismantling costs through an improved design is the stream of Flat Panel Displays (FPD). However, little detailed data is nowadays available on the dismantling processes, which prevent designing FPD according to the requirements of treatment operators.

The purpose of this paper is to propose a method for in-depth analysis of dismantling practices of electronic displays in order to obtain useful data for product design. The method is composed of three stages: (1) study definition, (2) data construction and (3) data analysis. The first stage allows setting out why, how and where the analysis will be performed. The second stage consists in describing dismantling operations in detail to construct a detailed and meaningful dataset. Finally, product indicators are developed and the best and worst design practices from a dismantling point of view are identified.

The approach is illustrated through a case study on the manual dismantling of 12 FPD. The sample was dismantled at one of the European recycling facility representatives. Data on the dismantling time spent on each component, operation and tool was obtained. Collected data can be used as empirical evidence to support the development of quantitative ecodesign strategies. Some examples of ecodesign strategies that can significantly reduce the dismantling time of the sample are given. This work opens perspectives on how the quantitative data from the recovery phase obtained within the study can be used in product design.

1. Introduction

Resource conservation is one of the great concerns of the 21th century. Waste prevention and management are seen as leverages since they help both developed and developing countries fight against pollution and make better use of natural resources. One of the most challenging types of waste to deal with is the one issued from consumer electronics, known as e-waste or Waste Electrical and Electronic Equipment (WEEE) (European Parliament and Council, 2012). E-waste generation and recovery present particular challenges due to three main key characteristics (McCann and Wittmann, 2015): (1) the continued increased volumes; (2) the content on hazardous substances; and (3) the recycling costs. Indeed, e-waste recovery is subjected to economic impacts that are mainly influenced by the prices of secondary materials, the availability of markets for output fractions, the development of treatment technologies and the treatment requirements for particular product streams (Goodship and Stevels, 2012).

Another important characteristic of WEEE is its content on valuable materials that would be wasted if not properly recovered. WEEE is composed by a high variety of recoverable components and materials, some of which are listed as critical raw materials by the European Commission (European Commission, 2014). One of the main driving forces for prompting recovery of WEEE is the question of resource depletion (Hargreaves et al., 2013; McCann and Wittmann, 2015). It is assumed that the recovery of waste and

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the use of recovered materials will imply a reduction of the use of natural resources (Huysman et al., 2015).

The recovery process of WEEE can be divided into 3 main steps (McCann and Wittmann, 2015; Tanskanen, 2013): (1) the collection, (2) the pre-processing and (3) the end-processing. The first step is the collection and consolidation of WEEE in different streams, provided that an Extended Producer Responsibility (EPR) scheme is set up. The second one consists in the separation of products into different output fractions that can be hazardous ones or valuable components and materials. The final step is the conditioning of the output fractions according to the requirements of the organisations interested in purchasing them.

Because of the great diversity of products and materials, there exist different technical solutions for the pre-processing of WEEE (Goodship and Stevels, 2012). Discarded products enter a mix of processes that usually include a selective disassembly/dismantling[1] phase followed by mechanical processes (Mathieux et al., 2008; Williams, 2006). Both processes have their benefits and limitations (Tanskanen and Takala, 2006). Selective disassembly is an important process in product recovery (Cui and Forssberg, 2003; Ilgin et al., 2015). It allows the extraction of hazardous components, higher quality of valuable materials and it allows reusing components (Ardente et al., 2014). Despite the fact that automated disassembly operations are being studied in the literature, they are nowadays not technically feasible and will probably not become economically feasible in the near future (Duflou et al., 2008). Disassembly is currently carried out manually or semi-automatically, which is very labour intensive (Duflou et al., 2008; Eriksen, 2008). Thus, WEEE disassembly takes considerable amounts of time that lead to high recycling costs (Cui and Forssberg, 2003; Williams, 2006).

In order to make the disassembly of electronic displays economically viable, it is necessary that Original Equipment Manufacturers (OEMs) integrate disassembly requirements in product development (Peeters et al., 2015). Since some of the components to be removed are deeply embedded in the product (Ardente et al., 2014), an optimisation of the product design could positively influence the efficiency of disassembly operations (Ardente et al., 2014; Harjula et al., 1996). Otherwise disassembly time could considerably increase, and time is considered as a critical factor for the economical profitability of disassembly (Eriksen, 2008).

Design for Recycling and Disassembly guidelines have been developed since the early 1990s (Active Disassembly Research Ltd, 2005; Dowie and Simon, 1994; Verein Deutscher Ingenieure (The Association of German Engineers), 2009, 2002). Guidelines are a collection of instructions (Gries and Blessing, 2003) and tools (Vezzoli and Sciama, 2006) to orient the design activity towards the minimisation of the environmental impact of products. Nevertheless, current Design for Recycling and Disassembly guidelines lack precise recommendations, prioritizing and recyclability performance feedback (Peters et al., 2012). Besides, there is a need for more specific guidelines that focus on one product and process at a time (Hultgren, 2012; Peters et al., 2012).

There is also a tendency in developing indicators to measure the performance of products at their End-of-Life (EoL) (Cerdan et al., 2009; iFixit, 2016; Issa et al., 2015). They consist in absolute or relative measures that monitor the effective ecodesign implementation (Issa et al., 2015). However, eco-design indicators for improving disassembly and recycling are very general and theoretical. They focus on product features and do not consider external factors related to the requirements of treatment operators[2] (Alonso Movilla and Zwolinski, 2015).

Vezzoli and Sciama (2006) state that guidelines should indicate, as precisely as possible, those design decisions that have the major potential to be sustainable. For that, they need to be customised with the aid of environmental experts (Luttropp and Lagerstedt, 2006). In the case of Design for Disassembly, the experts are treatment operators since they are the ones owning the knowledge and expertise on disassembly activities. European policy initiatives, such as the WEEE Directive (European Parliament and Council, 2012) or the Ecodesign Directive (European Parliament and Council, 2009), also highlight the cooperation needed between producers and recyclers in order to support the disassembly of WEEE through design.

Several research studies have been undertaken between academics, companies and WEEE treatment operators for the last years to obtain ecodesign recommendations (Froelich and Sulpice, 2013; Hultgren, 2012). We have noticed that developed guidelines are mainly based on discussions, interviews or surveys, hence based on subjective perceptions. Other researches produce quantitative data from general analyses of the disassembly processes, i.e., the case of LCD disassembly (Ardente et al., 2014; Ryan et al., 2011). However, the data provided do not constitute enough empirical evidence to support the development of specific and measurable design guidelines. This is mainly due to the absence of the application of a systematic method that allows studying in depth the disassembly activities of treatment operators.

The aim of this paper is to develop a method that enables the detailed and systematic analysis of disassembly activities in function of disassembly ability. We hold on to the hypothesis that such an analysis will provide solid evidence to support the development of quantified indicators and specific design guidelines adapted to the requirements of treatment operators. Since each WEEE stream and each recovery process has their own special features, the method focus on one case study that is been widely studied in literature, which is the recycling of Flat-Panel Displays (FPDs) through manual dismantling operations. We have chosen this type of device since up until the beginning of the 2010s only small quantities of FPDs were recorded at waste collection facilities (Salhofer et al., 2011). However, nowadays the amount of wasted FPDs is constantly growing and recycling infrastructures have been developed.

FPD televisions' shipments in the world are expected to reach a record of 265 million units in 2015, and are expected to grow 5% each year (IHS, 2015a). The type of FPD analysed are Liquid Cristal Displays (LCDs) since the current FPD market is mainly dominated by this type of devices (IHS, 2015b).

The outline of the article is as follows: Section 2 shows some background information about LCDs that helps better understand the case study. Then, a literature review is carried out on disassembly terms to better understand the vocabulary used in this field and on previous studies on LCD dismantling analyses (Section 3). Section 4 presents the foundations of the method for in-depth analysis of manual dismantling operations. At the end of the section we explain how it enables to provide reliable information for the design stage. In Section 5 the method is implemented to the dismantling of 12 LCDs that took place in one representative treatment operator in Italy. Section 6 presents the benefits and drawbacks of the proposed method. It also discusses the potential use for designers and policy makers through the development of specific and mea-

[1] 'Disassembly' refers to the careful, non-destructive removal of the parts of a product, while 'dismantling' refers to the potentially destructive removal of the components of a product that could destroy the functional integrity of the same (Ardente et al., 2014). For reasons of simplicity, in this paper the term 'disassembly' will be used to refer both to disassembly and dismantling unless specified otherwise.

[2] 'Treatment operators' are entities performing operations with WEEE that may include collection, handling, shipping, sorting, storage, transport, trading, treatment, or preparing for re-use (WEEE Forum, 2013).