DESIGN FOR END OF LIFE: A DESIGN METHODOLOGY FOR THE EARLY STAGES OF AN INNOVATION PROCESS

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ABSTRACT
The first phases of the engineering design process, such as the problem definition, the information gathering and the idea generation phase, are commonly considered as important steps in product development, since the cost of a product is assumed to be largely determined within these design steps. Besides limiting the product costs, designers are nowadays forced to reduce the environmental impact and to optimize possible economic gains over the total product lifecycle. Therefore, within this paper a design method is presented to assist designers to take into account different End-of-Life (EoL) treatment strategies in the early stages of the design process. During the proposed design method, designers are first introduced to the existing EoL treatment options and thereafter encouraged to apply different design strategies, such as design for (active) disassembly. Also, the results of adopting the proposed design method within the Erasmus European Intensive Program (IP2012) 'Green products through a multicoloured approach', a multidisciplinary two week workshop that was held at Howest (University College of West-Flanders) in Belgium, are presented in this paper.

Keywords: EoL treatment, front-end innovation, design for X, design method

1 INTRODUCTION

There are three key motives why designers commonly consider the End-of-Life (EoL) treatment during the product design process, namely: ecological impact, brand image and economics. Reducing the environmental impact of the EoL treatment is an increasing concern for the 6.5 million metric tons of Waste Electric and Electronic Equipment (WEEE) generated annually in Europe [1]. Moreover, a considerable amount of this WEEE is currently improperly recycled in developing countries [1]. As a result, pollution generation is increasing, affecting both the ecosystem and the people living in the vicinity of these recycling areas [2]. Accordingly, reducing environmental impact can be a corporate strategy, in line with the WEEE directive to increase producer responsibility [3].

Currently, customer's environmental awareness is creating opportunities for 'green marketing'. As a result, market trends and brand image reputation have become two of the most dominant drivers for sustainable product design and manufacturing [4]. Moreover, Western companies fear improper EoL treatment, since this could significantly damage the brand image reputation.

Furthermore, investments in certain design improvements can offer financial gains when evaluated over the total product lifecycle. For instance, different design improvements can significantly reduce disassembly costs and increase revenues through retrieved materials.

Up to 70 % of the cost of a product is assumed to be determined within the early stages of the design process [5]. Accordingly, the front-end of the design process is also assumed to have a significant effect on EoL treatment and its related costs and revenues. However, in the early stages of the engineering design process, improving the product design for the EoL treatment challenges many designers due to a lack of knowledge of commonly adopted and prior investigated EoL treatments. Therefore, a novel teaching method is presented here which helps to introduce different EoL treatment options to both novice and experienced designers during the early phases of the design process. The main goal is to stimulate designers to develop both product (re)designs and system innovations or business models that facilitate an improved EoL treatment. In the next section of this paper front-end innovation is further elaborated. In the third section an - for the brainstorm applied - overview of EoL options and crucial EoL treatment steps to which design strategies can be linked, is presented. In further sections the results of applying the design method in a multidisciplinary workshop with 93 students are presented.

2 EARLY STAGES OF INNOVATION

In the early stages of the innovation process the product strategy formulation, opportunity identification, idea generation, idea selection and concept development take place and decisions about new product development are taken [6]. These first phases in the engineering design process have the largest impact on the end result of the project [6, 7] and the highest payback to one's investments [6]. Accordingly, the front-end of innovation is often described as being the root of success for any company hoping to compete on the basis of innovation [7]. In ***Figure 1*** the relationship is shown between influence, cost of change, and available information during the innovation process. At the front-end, the degree of freedom and influence on the project outcome is high, while little information is available and the cost of changes is low. At later stages in the process one has more information available, but then the cost of change will increase. Decisions made in the front-end influence all subsequent phases of the innovation process. For example, quality, costs, and timings are mostly set during the front-end [8]. One possible method to deal with this is 'front-loading'. Front-loading is defined as 'a strategy that seeks to improve development performance by shifting the identification and solving of problems to earlier phases of a product development process' [9]. By spending more energy in the early phases on analysis and strategic design one gets more information while the influence is high and the cost of change is low.
Notwithstanding the logic behind integrating sustainability, and more specific EoL strategies, in the early stages of an innovation process, in practice it is flawed. Front-end innovation is a hot research topic, but there is still little research done on its relationship to design for sustainability. There are a number of tools available to guide designers, engineers and managers in the design process when the specifications of the product or service are already set. However, methods supporting target identification for sustainable innovations are rare [10].

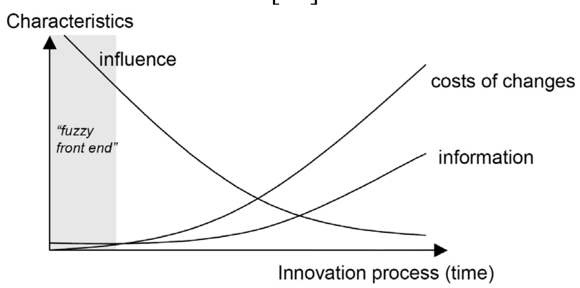

Figure 1. Influence, cost of change, and available information during the innovation process [8]

3 END OF LIFE TREATMENT OPTIONS

Within the presented design methodology designers are firstly introduced to the different EoL options and design strategies in the early stages of the design process, for example by means of an animated presentation. This first step can be described as 'front loading'. Thereafter the designers are given an overview of commonly applied EoL options and corresponding design guidelines. Whereas most techniques, such as lifecycle scenario design [11], mainly attempt to support designers to improve product performances within a specific lifecycle, the goal of this overview is to serve as a guideline for designers to generate ideas of how to avoid or improve different EoL options. Thus stimulating the generation of ideas for both system innovations, as well as technical incremental innovations and redesigns.

Figure 2. Lanskins' ladder

The overview of EoL options is in line with 'Lansinks' ladder', which is a hierarchically ordered list of EoL methods [12], as shown in ***Figure 2***. In this way, the designers are given both an overview of the different EoL options, as well as a hierarchy of ecologically preferable EoL options. Beside the five EoL options included in 'Lansinks' ladder' (which are described in the European WEEE Directive [13]), also the following EoL options are included in the overview: illegal waste treatment, reconditioning and remanufacturing, as illustrated in Figure 2. Illegal waste treatments are all waste treatment methods that are not covered by the European legislation, such as the export of WEEE to developing countries. Reconditioning is the process of returning a used product to a satisfactory working condition that may be inferior to the original specification. Generally, the reconditioned product has a warranty that is less than that of a newly manufactured equivalent. The warranty applies to all major wearing parts [14]. Remanufacturing is the process of returning a used product to at least OEM original performance specification from the customers' perspective and giving the resultant product a warranty that is at least equal to that of a newly manufactured equivalent [14].
Besides the different EoL options, the for the design method applied overview also includes the most crucial processes of the EoL options, such as collection, testing and (dis)assembly. The goal hereof is to highlight the importance of these processes and to stimulate designers to generate ideas to improve these steps and to apply different design strategies, such as design for the prevention of waste, for (active) disassembly [15] and for modularity [16] to facilitate these processes.

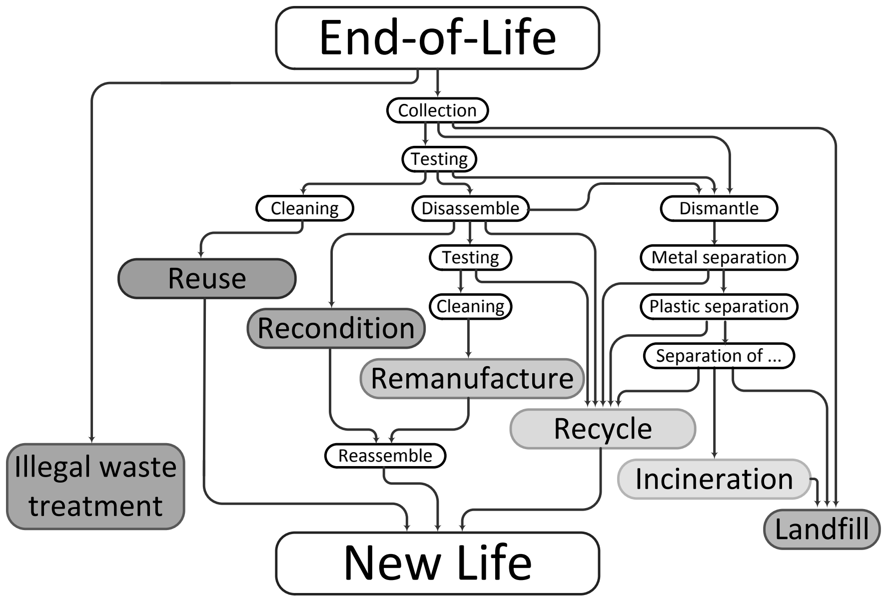

Figure 3. Overview of EoL options and crucial steps in the EoL treatment

4 A DESIGN METHODOLOGY FOR EOL DESIGN

4.1 Aim & Objectives of the Design Methodology

The aim and objectives of the presented design methodology are clustered in three competence groups:

- **General competences:** applied creativity and general problem solving, thinking and reasoning competences, information gathering.
- **General scientific competences:** research attitude, being able to apply research methodology and techniques, mastering scientific knowledge.

- **Domain specific competences:** linking different disciplines to understand the EoL treatment problems and processes, solving practical EoL engineering problems, lifecycle thinking, and being able to implement and use new technologies on product and system level.

4.2 Description of the Design Methodology

Bloom's Taxonomy [17], the classical 'Knowledge, Attitude, Skills' structure of a learning and evaluation method, underpins the design methodology presented in this paper, which is shown in Figure 4.

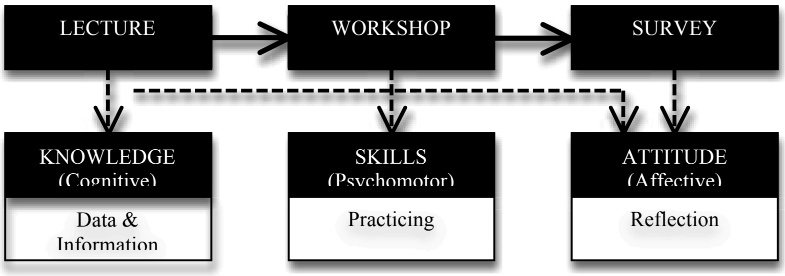

Figure 4. 'Knowledge, Attitude, Skills' structure of a learning and evaluation method

All participants are firstly invited to a lecture, which has two main goals:

- **Comprehending the problem:** understanding why EoL design is important, which also is the first step in Change Management.
- **Providing knowledge and inspiration:** giving an overview of commonly applied EoL options and processes, as shown in Figure 2 together with examples and movies of common EoL treatment processes and improved product designs.

The workshop after the lecture is organized as a guided brainstorm, based on the 5 main Front End activities [6]: opportunity identification, opportunity analysis, idea generation, idea selection and concept development. Within this workshop, teams up to 6 participants are firstly asked to reflect on relevant EoL treatments for the design problem that is given to them. Thereafter, they are encouraged to implement design guidelines. The aim of this creativity session is to stimulate the development of product designs and business models that allow an improved end-of-life treatment, from a business perspective, as well as from an ecological, economic and social point of view, through a list of clear design guidelines and consult from experienced supervisors.

Previous studies have found that asking people to explain the reasons for their attitudes can change these attitudes and lower attitude-behaviour consistency [18]. For this reason and to obtain valuable feedback, participants are encouraged to reflect on their own work by filling in two surveys, one individually immediately after the workshop and one at the end of the assignment on team level.

4.3 Background

The morning lecture and afternoon workshop described in this paper were part of the Erasmus European Intensive Programme '*Green products through a multicoloured approach*', a multidisciplinary workshop that was held at Howest in 2012 in partnership with Hanze University of Applied Science (NL), University of Wales Institute (UK), Escola Superior de Artes e Design (PT), Politecnico di Milano (IT), Monterrey Institute of Technology and Higher Education (MX), Istanbul Technical University (TR), Yeditepe University (TR) and Zvolen Technical University (SI). In total, 93 students divided in 19 teams, 20 academic tutors and 5 industrial partners, worked on real life industrial innovation case in this programme. Several education programmes were represented; Design Engineering (24%), Product Design (54%), Electronics/ICT (17%) and 5% other.

5 RESEARCH

5.1 Research Aim

The research in this paper aims at gaining understanding on the effectiveness of the presented EoL design methodology in the early stages of an innovation process and to get insights in the process of implementing EoL strategies in the front end of an innovation process.

5.2 Research Questions

From the research aim presented above, a number of research questions were formulated. The two main research questions were: (1) How effective is the presented '*front-end loading*' EoL teaching method in the early stages of an innovation process? (2) What are success factors and barriers for incorporating EoL treatments? (3) Do people with different backgrounds (field of study / nationalities) face different difficulties?

5.3 Research Method

At the end of the workshop, an individual online survey was conducted to evaluate the morning presentation and the progress of the afternoon workshop from the student's point of view. A second survey was launched to all the team leaders of the 19 groups at the end of the project, in order to get a clear picture of the effectiveness of an EoL session in the early stages of an innovation process, and the degree of implementation of the EoL strategies in the final result. Furthermore, through this survey, an attempt to evaluate the intrinsic motivation and the experienced difficulties was carried out.

5.4 Results and Findings

Within this research, the presented design methodology has only been tested during the IP2012. Accordingly only limited empirical data of the design methodologies' effectiveness, acceptance amongst participants, learning effects and depth of learning, was collected to make conclusive evaluations. Though, through oral discussions and the official surveys interesting observations have been made. Within the IP programme, all teams applied one or more design guidelines in their final design. The Design for Recycling and the Design for Disassembly guidelines were the most popular guidelines (60%), followed by Design for Modularity (40%). However, less than 15% opted for Design for Automated and Active Disassembly and no team opted for Design for Incineration or Landfill. Against expectations, Design for Incineration and Landfill was perceived as less clear by about 20% of the participants. The poor uptake of Design for Automated and Active Disassembly was mainly caused by a lack of knowledge on the available techniques.

The 3 most dominant EoL treatments in the final result were Reuse, Recondition and Recycle. This indicates that the teams aimed for the higher positioned EoL treatments in Lansink's ladder, as recommended during the lecture and workshop.

Integrating the EoL strategies in the early stages of the innovation process was an extra challenge for the participants. At that time, the participants had absolutely no idea how the final product would look like. Twenty percent of the participants indicated this in the survey as rather or very difficult. Besides the ecological improvements, many other improvements for the company were achieved, as represented in Figure 5.

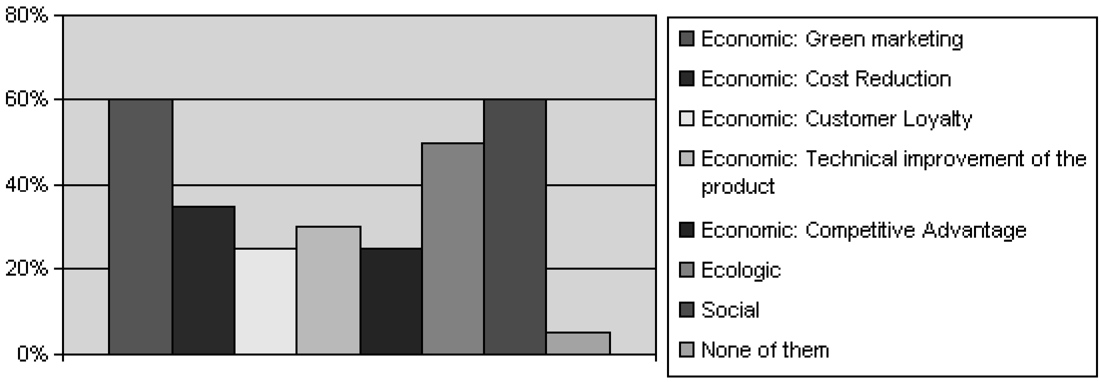

Figure 5. The by the participant estimated main improvements for the companies

Over 90% of the participants evaluated the lecture and the workshop as useful and inspiring for future design challenges. Furthermore, related to the intrinsic motivation, more than 50% of all design students indicated that they would invest more effort without reward towards a greener design. Remarkably, there was only a poor motivation for the electronic and ICT students; only 25% of these students indicated that they are prepared to do an extra effort without compensation in money or grades. This result may indicate different drivers for implementing sustainability. Future studies on behavioural psychology can help to gain more insight in this interesting outcome.

6 CONCLUSIONS

This paper demonstrates a design methodology that helps to introduce different EoL treatment options in the front-end of an innovation process. The presented methodology is based on Bloom's classical 'Knowledge, Attitude, Skills' structure of learning and applies front-loading techniques, which results in a high degree of implementation of the EoL strategies in the final result.

Further research should focus on fully understanding the differences between the diverse study programmes and nationalities, the acquired knowledge within this teaching method, as well as the degree of convincement of incorporating EoL strategies in the product design.

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