DESIGN FOR COMPLEX PRODUCT REBIRTH OR HOW TO PROTECT RESOURCES

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Abstract

This paper presents research conducted on a new design method for rebirth of complex products. Design for rebirth is a thinking method for protecting resources. Reuse, remanufacturing, upgrading and controlled recycling are effective ways to reduce costs, social impact and the consumption of energy and materials for equipment that has finished its service life. Other benefits include reduced pollution, transport, etc. Several issues are studied: existing end-of-life (EOL), selection methods for environmental fasteners and materials, modularization, design adequation. Subsequently, we describe a proposed method that allows the designer to select EOL, environmental fasteners and materials, and use modularization effectively during preliminary design. This integrated method is based on fuzzy logic data processing. Case studies are presented to demonstrate the method's validity. One way of solving rebirth of complex products is to optimize the product design process to include EOL. EOL options must be properly chosen from the beginning by the product developer with the aim of minimizing environmental impact and respecting laws, while at the same time maximizing economic profit.

Keywords: Sustainability, Decision making, Ecodesign, Rebirth, Preliminary design

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 21st International Conference on Engineering Design (ICED17), Vol. 1: Resource-Sensitive Design | Design Research Applications and Case Studies, Vancouver, Canada, 21.-25.08.2017.

1 INTRODUCTION

At the end of its originally intended service life, the value of an industrial product is compromised due to malfunctions, to breakage of some of its components or to obsolescence of components/functions. Some tougher new laws now impose constraints on industries, obliging them to modify their habits. It is therefore necessary to think of new strategies to optimize product life cycle and the treatment of products at their end of life (EOL). A particular case is the current aircraft industry, which is forced to adopt a product design process that includes EOL treatment (refurbishment, remanufacturing or upgrading, waste, reuse, recycling percentage, etc.). This research consists of reporting state of the art rebirth strategies as presented in published literature, and of proposing solutions for incorporating these strategies into the design process. It includes the development and tests of elements for an integrated method of general design that incorporates these five following EOL strategies: reuse, refurbishment and upgrading, materials recycling via semi or non-destructive dismantling and recycling by shredding. The new methodology takes into account semi-destructive dismantling. It enables a reduction in time and costs for this operation while at the same time optimizing the quality of collected alloys, but is limited by the presence of two elements: the composition of primers and paints on parts and the presence of attachments (rivets for an aircraft). The discovery of these elements and their influence on EOL options revealed the uncertain character of the data and the complexity of certain products and procedures in EOL treatment. We notice that for complex products with a long life cycle and period of development, the uncertainty engendered by time, technological evolutions of manufacturing, maintenance, dismantling and rebirthing of products, changeable environmental, social and economic requirements, and also the uncertainty surrounding the criteria value used in eco-design, the composition of part primers and paints and presence of the attachments, complicates interpretation of the results. The current work intends to answer the following question: how to design a complex product such as an aircraft to improve the rebirth of its modules and materials by quantifying the probability that the targeted rebirth can be achieved? In this paper, we develop a new method for product design that includes rebirth, beginning with a choice of the likely end of life scenario, modularisation, materials choice, attachment choice and evaluation of the obtained design.

2 BIBLIOGRAPHIC REVIEW

The proposed method of design for product rebirth includes five parts: choice of the likely end of life, modularisation, materials choice, attachment choice and evaluation of design adequacy. Applications in the literature that approach the proposed method are extremely rare (Umeda et al., 2015). But, in recent literature, circular economy provided some interesting considerations on design strategies for EOL (Devadula & Chakrabarti, 2015). For each EOL, several works dealt with design for X (e.g. design for remanufacturing (Hatcher et al., 2011), but rarely with several EOL in same time.

2.1 Product end-of-life selection

There is a limited number of works on choice of EOL (Gehin et al., 2007; Hula et al., 2003; Kiritsis et al., 2003; Rao & Padmanabhan, 2010; Rose et al., 1998; Willems et al., 2004). Rose has well documented product characteristics that enable a determination of EOL purposes and also developed the ELDA method, which was simplified by Xing (2003) (PEOLSP method). These methods give good results (concordance with the applied EOL in the industry), require few technical knowledge on the recovery of products and can be implemented with minimal data. However, the resulting EOL scenario is a single global option for the product and not for every internal module. The single scenario generated is considered the best, although there is no means evaluating this, which precludes possible negotiation.

2.2 Product modularization for the rebirth

Various works were found on modularization (Bonjour et al., 2009; Chang et al., 2013; Collado-Ruiz & Capuz-Rizo, 2010; Gershenson et al., 2004; Huang et al., 2012; Li et al., 2008), including Pimmler and Eppinger (1994) work on the reduction of system complexity using a modular structure based on physical and functional aspects. Environmental requirements are not taken into account. Gu and Sosale (1999) considered product life cycle and used the AHP method to attribute the corresponding weights. Qian and Zhang (2003) propose a quantitative analysis of a modular structure by considering the product life cycle. Many books and articles can be found on eco-design and material selection, but in this paper a non-exhaustive literature review is done, only the most pertinent for our research are presented.

2.3 Environmental selection of materials

The various methods for environmental selection of materials discussed in the literature can be divided into three categories; Rules of selection, Life cycle assessment and Multi-criteria methods. The rules of materials selection are numerous (Mascle & Deneu, 2013c; Chan & Tong, 2007; Giudice et al., 2005; Ljungberg, 2007; Prendeville, S. et al., 2014). They lead to more specialized methods. This can be explained by the fact that these rules are only submitted to evaluation by the designer, they have no theoretical frames (Telenko et al., 2008; Lin et al., 2003; Graedel & Allenby, 1995). The "Recycle" EOL option is the most treated in the literature. The Life Cycle Assessment (LCA) approach, on the other hand, provides a precise and normalized frame, allowing uniformity of procedures. It allows exact quantification of the environmental impact. However, LCA is mainly used during the "detail design" phase for confirmation of materials choice or simply for evaluation of the product environmental footprint. Indeed, the literature mentions clearly that LCA is not an ergonomic tool for selection of materials during the design process (Telenko et al., 2008; Graedel & Allenby, 1995; Allenby, 2000) due to time and precision of the data which it requires. It cannot be used during the "Concept Design" and "Embodiment Design" stages. Telenko (2008) adds that it is a tool more suitable for design review than for selection. Environmental multi-criteria decision-making methods are based on the evaluation of several categories of criteria; environmental (with the use of LCA Eco-indicators), technical and/or economic criteria. These evaluations provide additional information to the designer by integrating LCA environmental data with the technical and economic data of the product and manufacturing processes. The ranking must be generated by the user (Weaver et al., 1996). There are several types of multi-criteria methods including graphic, analytic or optimization. Environmental analytical methods are the most widely used. They allow the environmental and technical or economic criteria to be taken into account. Huang et al. (2006) uses a method based on environmental criteria and derived from TOPSIS (Shanian and Savadogo, 2006), for material selection. This method allows estimation of a significant number of materials properties. These properties are compared with the performance objectives of the designer. Chan and Tong (2007) propose a multi-criteria method which allows simultaneously selection of materials and product EOL. The Grey relational analysis is used to obtain the scores of materials-EOL pairs. The method is based on various environmental parameters influencing human health, ecosystem quality, the state of resources, etc. It also takes into account technical parameters (mechanical resistance, elongation, etc.) and economic parameters (purchasing cost of materials, production cost, etc.). The origin of the various data is not mentioned in the paper. Ribeiro et al. (2008) present the foundations of their materials selection method, which takes into account environmental, economic and technical factors. Ribeiro uses the eco-indicator "Eco Indicator 99" for the environmental data. Guidice et al. (2005) published a method of materials selection called "design for the life cycle". It rests mainly on LCA data with the "Eco Indicator 99", on the component mass and on the purchasing cost of materials.

2.4 Choices for fastening

The choice of attachments becomes a complex problem in the presence of a materials change, such as the passage from aluminum alloys to composites. Nevertheless, this can be reduced to a non-problem by reducing the number of attachments. But some attachments are always required for mechanical products because there is one inside and one outside and by the presence of mobile components. In spite of numerous research publications on the subject, dismantling of fasteners is still poorly understood. More detailed studies of methods specifically dedicated to the choice of the attachments can be found in Peeters et al. (2015), Duflou et al. (2008), Ghazilla et al. (2014), Güngör (2006). The first of these was developed by Güngör and leans on the Analytic Network Process (ANP) method of calculation. The objective is to classify alternatives which correspond to the 5 types of attachments defined by Sonnenberg (2001). To use this method it is necessary to first define the possible alternatives to achieve assembly and then apply the ANP to highlight the best choice. The second method is more recent and was developed by the team of Ghazilla et al. (2014). In this method, the PROMETHEE decision tool is used. The method puts special emphasis on the criteria linked with dismantling, but the assembly time and the relative costs of the attachments are also taken into account because they have an important influence on the final choice. This method presents interesting aspects however its field of application is limited to non-destructive dismantling and thus certain typical attachment types cannot be included.

These two methods do not consider the possibility of conducting semi-destructive dismantling. This aspect is essential for two reasons, it is rare that a product is completely disassembled without damage, and very often the main objective of rebirth is quick recovery of valuable parts (spare parts for instance). Our team at Polytechnique (Jeandin & Mascle, 2016) recently developed a method that uses an ANP tool to include semi-destructive dismantling. The two-by-two parameter comparison executed by the ANP is very effective as long as certain rules are respected. Also, it is difficult to apply the method to certain cases that do not present obvious or suitable opportunities for semi-destructive dismantling. The example of aircraft fuselage dismantling illustrates this situation, during the preliminary design phase it is difficult to predict the EOL losses of value. The method becomes long due to the large number of alternatives that must be considered. Costs are not directly taken into account in the method but rather integrated by means of certain parameters. Parameters such as assembly and dismantling time, tools or the skill level of workers serve as cost indicators.

2.5 Evaluation of design for rebirth

To evaluate conformity or adequation of a design, the literature contributions consulted reveal a weak understanding of the valuation concept, evaluation is made according to indistinct criteria and it is necessary for the designer to have some advanced knowledge in the environmental domain (Desai & Mital, 2003; Kroll & Hanft, 1998; Lee et al., 2014). The models and methods used in these research publications provide important partial information for engineers of product dismantling. But they are insufficient for complex real structures which are usually submitted to high stress, must be very resistant over time, and are not designed for disassembly. An additional limitation is that the works deal mainly with totally disassembly or complete shredding without considering intermediate methods.

3 METHODOLOGICAL APPROACH FOR PRODUCTS REBIRTH

The proposed design method for product rebirth is built on five parts and has no equivalent in the literature. It takes into account complex real structures subjected to high constraints which must be very resistant over time and are not planned to be dismantled. My research team developed a method and solution options for this problem (Mascle, 2013a and b; Remery et al., 2012; Mascle & Deneu, 2013c; Jeandin & Mascle, 2016). For the proposed method, the first stage is determination of an appropriate EOL. Qualitative and quantitative data are processed using an assessment method (criteria and level-weightings) to select the most environment-friendly options while assuring an economic profit. Modularisation of the structure is defined in three stages: identification of relations between components (functional relations, physical interactions and materials compatibility), basic notions for structural modularisation based on similarity, and an algorithm for structural modularisation. During the stage of materials and attachments choices we also work with data and assessment methods, but a certain complexity is encountered in classifying the attachments and their disassemblability. Finally, to evaluate design conformity we need to add the complexity of information reduction to more easily generate the improvement process of the product. In our work, we use a multi-criteria approach to decision-making, which enables a systematic evaluation of the alternatives based on a set of criteria. This approach is very appropriate for our case because it allows us to complete quantitative and qualitative evaluations with a high level of flexibility. It has often been used to handle environmental issues and waste management (Chan & Tong, 2007; Chiou & Tzeng, 2002; Salminen et al., 1998; Vego et al., 2008). Among all the multi-criteria decision methods which were applicable, we considered the most generally used: Weighted Sum Model (WSM), Weighted Product Model (WPM) (Triantaphyllou et al., 1998), Analytic Hierarchy Process (AHP) (Saaty, 1990), ELimination Et Choix Traduisant la REalité (ELECTRE) (Hokkanen & Salminen, 1997) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Lai, Y. et al., 1994). WSM and WPM are simple and intuitive but they are rarely used because of their property of invariable scale. AHP and ELECTRE are based on a comparison by pairs of criteria. Furthermore, ELECTRE does not give a global preference for the alternatives, but only a partial classification. The TOPSIS method, which is very often applied to environmental issues and waste management (Cheng et al., 2003; Gumus, 2009), has many advantages: i) it is logical and follows the reasonable nature of the human selection process; ii) for every alternative it takes into account the best distance as well as the worst alternative; and iii) it is simple to implement and can be easily programmed (Shih et al., 2007). We test various multi-criteria methods. Finally, we integrated the whole approach within the same methodology. The ultimate purpose is to establish a generic methodology based on the best design practices while protecting the creative freedom of the designer (interactive tools inside CAD system with decision assessment) and improving product flexibility.

3.1 Product end-of-life selection

All data obtained during the treatment of aircraft at EOL, in a precedent project, were analyzed to pull out pertinent parameters that are useful to guide choices of solutions during application of the design method. Once these parameters are established and verified, they can be used to determine the criteria for choosing a scenario for product EOL. To accomplish this task, we developed the EoL Scenario Evaluation Method (ELSEM) method (Figure 1) to help choose the likely EOL (Remery et al., 2012). Functional needs and criteria were established for every EOL. The performance of each EOL option based on each sub-sub-criteria evaluation depends on certain variable parameters characterizing the module. It is precisely these parameters that the designer must insert into the ELSEM method. Based on the research conducted in the literature and our own experience, we arrived at a set of 15 final parameters that influence the EOL decision and are relevant. To make this decision, two conditions were applied: Number of parameters has to be minimal in order for the method to be simple to use and quick; Selected parameters must be at least available for evaluation, during the early design phase.
The final 15 influence parameters take the majority of product recovery aspects into account and are described as follows: P1, *Adaptability*; P2, *Durability*; P3, *Module market value*; P4, *EOL condition*; P5, *Quantity of high-value materials*; P6, *Calorific capacity*; P7, *Difficulty with the module's disassembly*; P8, *Level of integration*; P9, *Quantity of parts*; P10, *Difficulty of dismantling part attachments*; P11, *Amount of different materials*; P12, *Amount of hazardous materials*; P13, *Imposed rate of material and part recovery*; P14, *Imposed energy recovery rate*; P15, *Module weight*. The best alternative is the one with the highest proximity coefficient. To **modularize the structure**, we used a scenario considering EOL and maintenance options, ease of dismantling, functional and physical constraints. The relations between components are calculated by considering 4 types of interactions: *spatial*, *energetic*, *informative* and *material*.

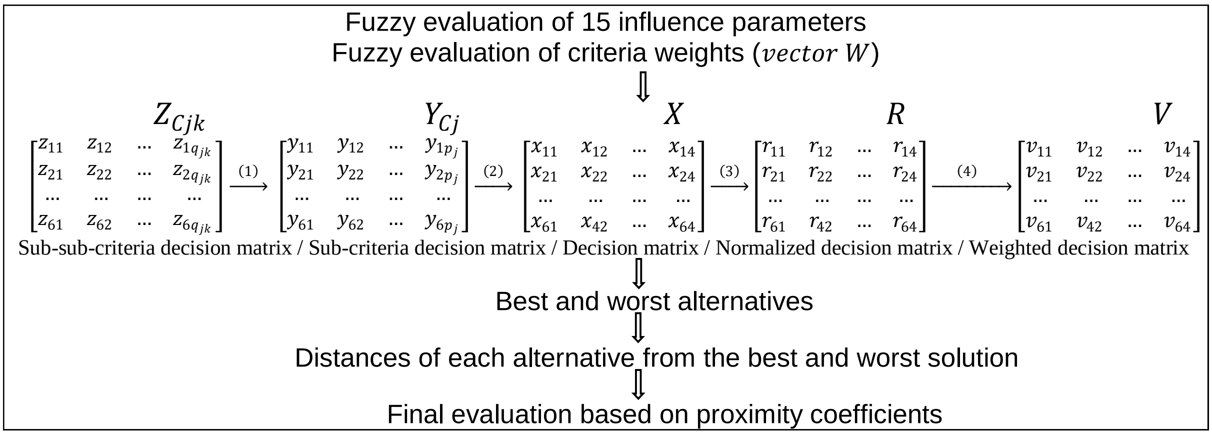

Figure 1. Summary of ELSEM steps (adapted from Remery et al., 2012)

3.2 Environmental selection of materials

For the materials choice, we developed a method (Mascle & Deneu, 2013c) that applies four well-defined property types: simple material and product, situational material-product and material-product-environment. The proposed method allows selection of environmentally-friendly materials for product EOL during preliminary design. Among the categories for environmental selection of materials, LCA stood out as the most appropriate. It is reliable and effective to select the most environment-friendly materials. However, it does not take into account the context of material use; product into which the material will be integrated and general environment of the product. The compromise between the technical, economic and environmental advantages and inconveniences of materials (Karana et al., 2008) becomes increasingly harder to achieve due to the multiplication of factors to be estimated. The materials selection method we developed is based on the following context considerations: 1. Product that incorporates the selected materials; 2. Environment in which the materials are used and thus the product is used. We therefore chose to treat the data using fuzzy logic as Thurston recommended for the evaluation of materials during preliminary design (Thurston and Locascio, 1994). This approach allows the engineer to choose the best materials while satisfying his constraints. The method proposed in this paper is based on a frame of fuzzy evaluation multi-criteria, Liao (1996). The frame of evaluation is based on the principle of extension which was presented by Zadeh (1965 & 1975) and completed by the theory of fuzzy arithmetic of Kaufmann and Gupta (1985). Our method for evaluation of materials developed requires progress through the following three stages; calculation of the index of EOL-ability Sij of every property j for every material i, calculation of the index of global EOL-ability of every material, Si, and defuzzification of the index of EOL-ability, Si. Nine properties are taken into account to estimate and select materials: *corrosion resistance*; *recyclability*; *degradability*; *uniformity of the material in the component*; *diversity of materials in the product*; *the materials marking on components*; *compatibility of recycling*; *capacity of sorting* and *durability*. These various properties are based on rules of environmental selection. The method was implemented in a software package programmed in C ++; Environmental and Contextual Materials Selector for Product End-Of-Life (ECMSPEOL). The software effectively automates the operations of data search and calculations. We use an external file to store the various values of the known properties of materials (corrosion resistance, recyclability, degradability, compatibility of recycling, capacity of sorting) and to store the data necessary for materials evaluation.

3.3 Choices for fastening

The choice of attachments is made using a decision-making aided method (Jeandin et al., 2016), Analytic Network Process (ANP), and a disassembly difficulty assessment (Zahedi et al., 2016) elaborated in a project with aeronautical industries. It is necessary to identify/define the various alternatives, calculate their assembly and dismantling times and evaluate the complexities of dismantling for each alternative. When selecting fasteners, we tried to represent the majority of problems encountered related to assembly, to product use and to the disassembly process. Our network includes 4 groups, one group that includes the proposed fastener alternatives and a group for each of the product life cycle phases. The parameters included in these groups are detailed as follows; **Group 1**: alternatives; **Group 2**: assembly complexity; number of attachments elements; space required; number of required steps; break probability; modification cost; difficulty to realize prototypes; **Group 3**: effects on appearance; adaptation to various environments; attachment reliability; **Group 4**: disassembly complexity; easy resale; automation potential; risk of damage. To reduce the time required to perform all pairwise comparisons with ANP method, we decided to use a global parameter that groups some parameters together, calculated outside the ANP. The number of parameters used is therefore reduced without losing information. A scale system is used to determine the Disassembly Effort Index (DEI). This score is easy to calculate and assesses the difficulties related to disassembly. Tseng et al. (2008) use a similar method of scale to estimate the liaison intensity among components. We used this method to calculate another parameter named **assembly complexity**. The parameters that are grouped together to calculate this parameter are; *Assembly time*, *Tools*, *Access*, *Operator qualification*, *Required protective equipment*. For each parameter, a scale of value and a weighting were defined. With these scales of value, a score is determined for each alternative and then converted to be used in the ANP method. The calculation of scores is fast and simple, so it's easy to make changes to refine the calculations. The operation is the same as before with parameters related to the **disassembly complexity**. However, it is necessary to distinguish between the two cases: non-destructively or semi-destructively disassembly. Since the problems are different, it is necessary to define two different scores with parameters adapted to the case studied. For non-destructive disassembly, the parameters are: *Disassembly time*, *Tools*, *Access*, *Required force for disassembly*, *Fixture*, *Operator qualification*, and *Required protective equipment*. For each parameter, several cases are distinguished. A weighting is given to parameters. For the most restrictive case the maximum value of the weighting is given. Intermediate cases receive lower values. Finally, the sum of the values given to the parameters is made to obtain the final score. The higher this score, the higher the complexity of assembly or disassembly.

3.4 Evaluation of design for rebirth

Once the product is determined, we must estimate the quality of the design for every EOL. Exploratory work was done using the method ELECTRE-TRI (Essalak, 2016). The main objective for this part of the method is to estimate the product design quality or product design adequation relative to the various possible options of EOL. Another objective is to fill the gaps of the existing methods by developing an approach that satisfies the following conditions; *Relative simplicity of use to assure that it is practical* *from the designers point of view in terms of time and the amount of data required for its application, Allow quantitative evaluation of every module or subset towards 5 scenarios of EOL treatment so that the method can be adapted to complex products, The method must be substantial, including environmental, economic and legislative aspects in the design evaluation*.

Vision 1: for an option of EOL treatment at the end of life FVk, we have to affect a product or all the subsets which compose it, according to its initial complexity to one of the two following categories; design adapted to FVk, design not adapted to FVk. This corresponds to a problem of sorting of the actions (subsets or products) by a procedure of affectation P(ß). *Vision 2*: the second procedure to achieve the main objective of the project was to conceive a method allowing selection of the best or most satisfactory subsets in design quality terms. This corresponds to a problem of selection, P(α).

A procedure of trichotomy segmentation corresponds to these visions and implies the classification of actions in 3 categories; actions that have sufficient reasons to be recommended to a decision-maker, actions that have important enough reasons to be rejected and finally the alternatives for which no decision seems solidly established. This third category reflects the imprecision of the method and the possibility of not being able to make some decision for certain actions; a weak point that we cannot neglect. To characterize the quality of design, we chose three categories of affectation, which involve two action standards b1 and b2 :

- The subsets where the design quality is bad (maladjusted) for the option FVk.
- The subsets where the design quality is average (acceptable) for the option FVk.
- The subsets where the design quality is good for the option FVk.

If gj(bi): corresponds to the value of criterion j for reference action bi then the product performance on a set of criteria noted gj(ai) are compared with criteria values of the reference actions gj(bi). At this level, ELECTRE TRI uses 3 types of thresholds in preferences modelling:

- Of indifference q: this is the largest value of (gj(bi) - gj(ai)) which represents total indifference between both actions on the criterion j.
- Of preference p: this is the smallest value of (gj(bi) - gj(ai)) which indicates a strict preference of the reference action bi on the potential action ai.
- Of veto vj (upper to p): defined as the difference from which bi is better than ai and ai cannot in any case be considered better than bi no matter what the performances of bi and ai are on other criteria.

The 2nd part of the new method is construction of the criteria. Parameters are identified corresponding to every EOL option that reflects the most elements influencing the design quality of the decision compared with a mode of valuation as well as the nature of possible consequences on the environment. In addition, for every criterion we determined the performances of both standard actions as well as 3 already defined thresholds of calculation and the weights of level-weighting. The criteria are; *the accessibility of components*, *maintainability*, *mechanical resistance*, *adaptability to characterize the possibility of module use and assembly in other products or systems*, *durability*, *economic viability of the operation of refurbishing*, *EOL Recycling Rate*, *chemical compatibility*, *lower calorific value*, *global warming*, *primary unrenewable energy*, *ecotoxicity*, *occupation of natural space*, and *degradability*. The following section presents the results of tests using the new method in case studies and includes an analysis of sensibility with which these results can be validated.

4 CASE STUDIES, RESULTS AND DISCUSSIONS

Various case studies were carried out applying the complete method during the design phase. The case studies included the following products; a vehicle engine (21 parts) for ELSEM, a simple mono-stable jack (6 parts), a door closer (29 parts) for ECMSPEOL, a small webcam (12 parts, Figure 2), and two blocks of plastic assembled with; 4 bolts and nuts, 2 screws through the blocks, 4 rivets, cantilever snap-fits, soldering and an adhesive joint. The case studies allows us to quantify various behaviors, such as the ranking evolution of materials according to end of life for every component (i.e. for ECMSPEOL). We calculated the rankings obtained by ECMSPEOL and made comparisons to a reference ranking (reuse) and rankings obtained for other EOL alternatives. Results for some parts of the complete method are presented in Figure 3: Proximity coefficients of each EOL alternative from the best and the worst solution by criterion for a car door (top), EOL influence on the supplied ranking (middle) and calculated Disassembly Difficulty Calculator is for *Cutting*, *Deep drilling* and *Minor drilling operations* providing that θ=90° between the thrust and cutting components (bottom). The graphic interface of modules facilitates use of the software. The engineer has only three types of information to enter; textual information, level choice of parameters, and choice of elements. Textual information is minimal; product name, the number of components and the name of each component. The first two types of information do not require a significant amount of input data. The third type is entered by the design engineer and requires more attention. Depending on the product EOL the number of parameters that must be entered is different. The case study was written to show the usefulness of a complete approach for a real case.

5 CONCLUSION

This paper presents a new method that can be applied during the preliminary design phase for environmental selection of EOL, modularization, materials, and attachments. It can also be used to make a final design evaluation that takes into account EOL alternatives. In addition, the method is adaptable to technical and economic constraints since it leaves freedom of choice to the design engineer. The method is of great interest for the aerospace and high-technology industries (Zahedi et al., 2016) because it enables precise models for predicting product behavior when dismantling constraints are applied, both during EOL processing and during maintenance interventions. Only a decrease of processing costs at the EOL will allow the development of viable infrastructures for responsible product dismantling (Zahedi et al., 2016). This is particularly true for complex installations (refineries, nuclear power plants, chemical factories, etc.). For this reason, it is essential that methods be developed that can be applied during design of these systems. The main innovation of this research is the multi-criteria provisional approach for the developed design method and the probability evaluation of the design quality for the chosen EOL. The case study shows that the method actually generates more usable information than existing methods. My research team are currently working on the evaluation of the disassembly associated with several alternatives in order to find the most feasible mix of alternatives based on the given part/module.

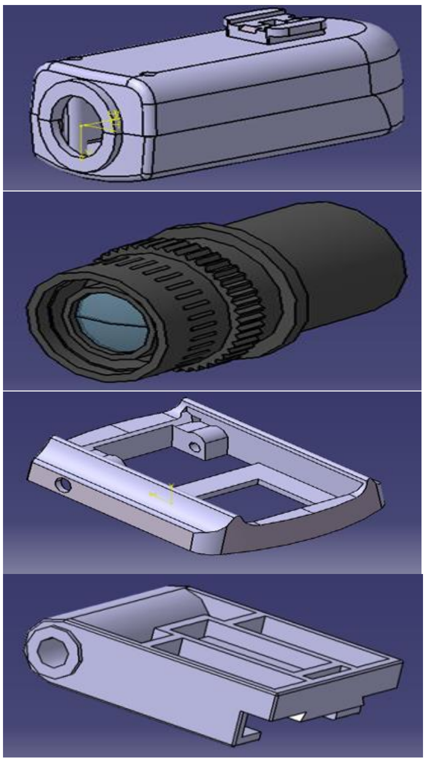

Figure 2. Webcam

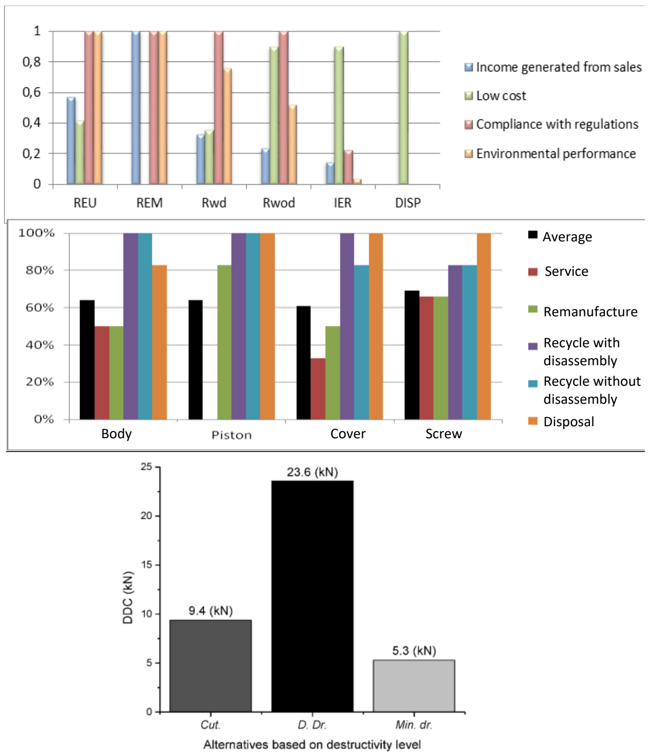

Figure 3. Results for several parts of the method

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