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INTEGRATION OF ADVANCED METHODOLOGIES AND TECHNOLOGIES OF DESIGN FOR DISASSEMBLY AND RECYCLING FOR SUSTAINABLE PRODUCT DESIGN

BY

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Abstract. The presented research is oriented on environmental on environmental sustainability, Design for Disassembly (DFD) and Design for Recycling (DFR) has grow into an important and characteristic aspect of entire engineering life cycle with the future preplanning to return a part/product back to the specific and helpful life. Growing the effectiveness and efficiency for disassembly can be achievable if the disassembly strategy and the development plan it is considered in the beginning stage, this represent first starting point of a product. Methodologies and principles have been suggested on the proper plans and strategy to disassemble and recycling a family of product in relations of chronology development. Design for disassembly (DFD) methodologies and specifications have been fixed to offer recommendations to the designers on the different design activities that may be integrating to help the disassembly process.

For the beginning a conceptual research model will be analyzed, discussed and proposed the converge of technology, principle, method, methodology and specifics factors to improve the disassembly strategy and process.

Keywords: methodologies; disassembly routes; AND/OR method; disassembly plans; Petri-Net.

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1. Introduction. Research Problem Statement

The development of a new lifecycle concept and ecological product design has led to the introduction of various recyclable products. Designers do not limit their efforts to just recycling materials, but they also consider the disassembly aspects of friendly design as a requirement for the reuse of sustainable and complex fresh produce (Penev, 1996).

To survive on the market, producers had to come up with new concepts, strategy, ideas for improvement, to provide resources and time for the sustainable development of tools and principles for modern engineering design (Merticaru and Ripanu, 2013).

Modern engineering design methodologies are present in our days, like the following:

– Design for Excellence - DfX
– Integrated Engineering, CAD/CAE/PLM/CAx (Merticaru *et al*., 2014).
– Sustainable Product Development

Disassembly methodologies becomes an important issue in industrial and mechanical engineering due to the growing interest of manufacturers to be aware of the environment. The need for disassembly occurs in more and more industrial activities, including maintenance, repair, rebuilding, recycling and disposal. The general disassembly problem can be addressed from a variety of perspectives, including the definition of mechanical design strategies that simplify complex product disassembly or automatic determination of disassembly sequences (Gungor and Gupta, 1999).

Design for Disassembly (DFD) and Recycling (DFR) is geared towards "complete elimination of the negative impact on the environment through a sensitive design" (McLennan, 2004). The philosophy of DFD-DFR is to master the product design process so that it can be cost-effective and easily / quickly removed at the end of product life, so that components can be recycled and / or reused with periodic maintenance (Crowther, 2005).

Design for Disassembly (DfD) involves the development of products that are easy to separate and thus facilitate the recycling and disposal of hazardous materials. DfD research has grown dramatically in recent years. Pending legislation on "takeover", European manufacturers have explored ways to dismantle their mid-1980s products (Wilder, 1990). Early investigations in this area, primarily by the BMW car company, were limited to pilot projects, but generated general guidelines on design for recyclability (Constance, 1992). The fundamental concepts of the DfD, such as the reinforcement of parts and the use of fast-fastening joints, have also been demonstrated (Bakerjian, 1992).

In today's environmental awareness, end-of-life goals such as the re-use of components (components of a product at the end of life used without modernization in a new product), reprocessing (components of a retired product used in a non- a new product after a technological upgrade) and recycling (material reuse, such as plastic recycling) are some of the most important reasons for disassembling products. This can be attributed to the staggering impact of industrial and household waste on the environment. The widespread use of consumer goods and shorter product life cycles have led to the elimination of an unprecedented number of used products.

This research work with the specific concept model present a structured methodology and principles of implement design for disassembly and recycling for sustainable perspective.

2. Research Approach Description. Conceptual Research Framework

First of all, a conceptual model for defining the research framework has been developed and is bellow presented (Fig. 1).

As starting point for the research approach conceptual model (Merticaru *et al*., 2014) for sustainable product development was to translating requirements in specification.

The DfD and DFR principles of Design for Excellence are particularly detailed to make the object of the research study, they are detailed within the model from Fig. 1, through some of the specific methodologies and technologies like hierarchical modular modelling of product, the AND/OR graph, etc.

The DfX principles and integrated Engineering converge together to elaborate the methodologies for DfD and DfR, and this methods/principles converge to supporting a Sustainable Product Development.

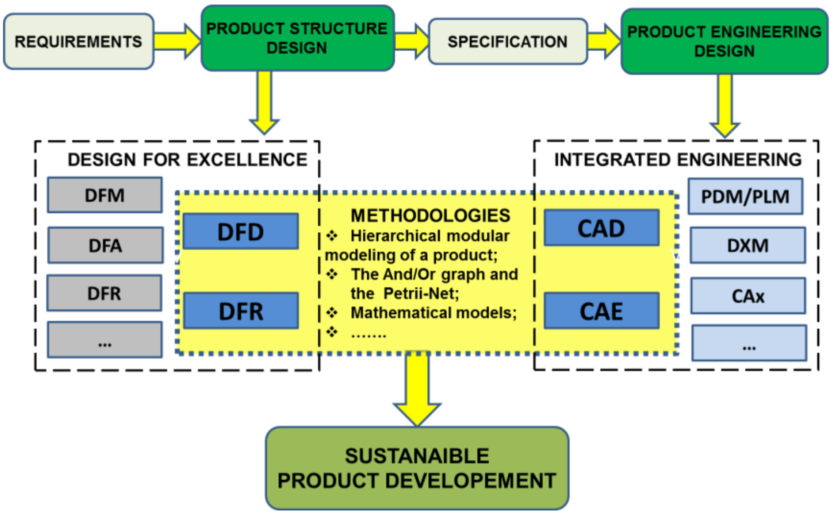

Fig. 1 – Conceptual model for the research approach.

3. Dfd and DfR Methodologies

In many circumstances, a product/assembly might be disassembled into a multitude of parts or subassemblies, and from each subassembly, into different parts and components. A product can have many subassemblies, and this can represent modular system, forming a mathematical hierarchical product tree (Fig. 2). There are many literatures, technical magazines and research studies which discuss the growth of design helpers, such as technologies, principles, methods and tools, to stabilisation the issues appeared in disassembly and these issues in many times appear in different shape of mathematical models (Hatcher *et al*., 2011).

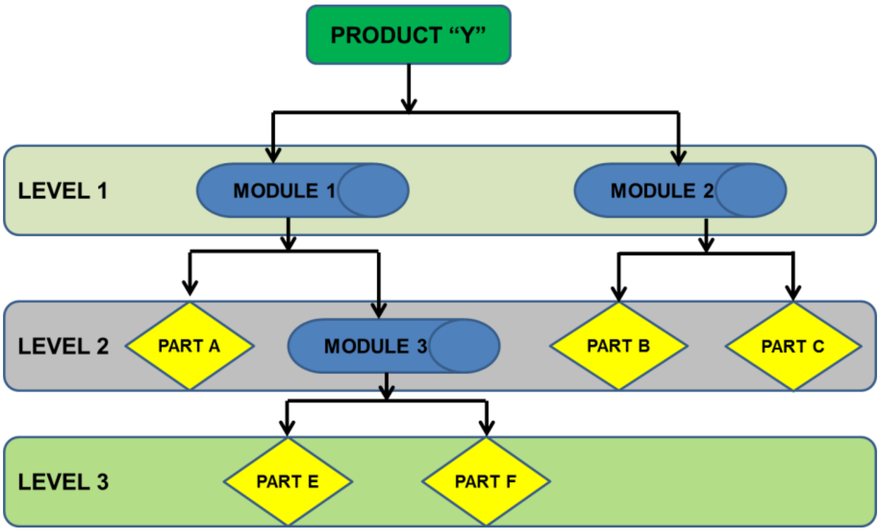

Fig. 2 – Example of a Hierarchical diagram for modular modelling (Soh *et al*., 2014).

One of the widely used approaches for planning, generating and selecting disassembly plans is to generate assembly plans. The assembly process has been described in detail, and the disassembly link has been highlighted. The idea of analysing them simultaneously is since many problems related to the determination of the assembly sequences are transferred to the determination of disassembly orders. For example, one of the used methods that automatically determines the assembly sequence using the CAD-based design methodologies is based on the following assumptions (Molloy *et al.*, 1991):

– Disassembly is a process in which each part can be removed from the structure of the assembly without collapsing;

– Assembly is the reverse process of disassembly.

Based on the below, certain steps have been taken to find the disassembly sequences. The following steps are included:

a) Grouping of components in relation to a presumed moving component;

b) Determining the possible moving directions of each component;

c) Determining the disassembly directions of each component;

d) Identify disassembly sequence by examining disassembly.

AND/OR graph representation (Homem de Mello and Sanderson, 1990) and the Petri-Net (Moore *et al.*, 2001) are some of the modular models that have been proposed to sustain the relationships between the parts and subassemblies of the components.

The AND/OR graph representation presented in Fig. 3 is based on the strategy to find all the durable subassemblies of the components and all the feasible decompositions of a subassembly/assembly, which can be processed by analysing the proper connection graph.

The problem of generating assembly operations is transferred to generating disassembly operations. This AND/OR graph is considered a systematic procedure that guarantees the generation of all feasible sequences. The expression “disassembly load” is considered the reverse of a feasible assembly task and each decomposition corresponds to a disassembly task. Looking at all decompositions of the assembly, we can find all the ways in which the disassembly can be decomposed into two subassemblies. This approach leads to an AND/OR graphic representation of the disassembly sequences and corresponding reverse assembly sequences.

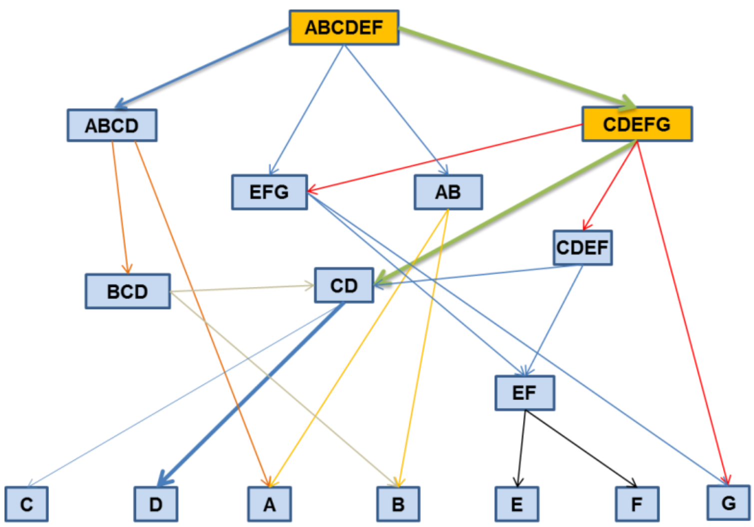

Fig. 3 – Example of AND/OR disassembly representation (Soh *et al.*, 2015).

4. Case Study

In the presented case study, a simple product mechanism (Figs. 4 and 6) is used to exemplify the proposed principle and methodology. To exemplification the purpose describes above, the Part B (PIPE) is the part proposed to be restored for remanufacturing.

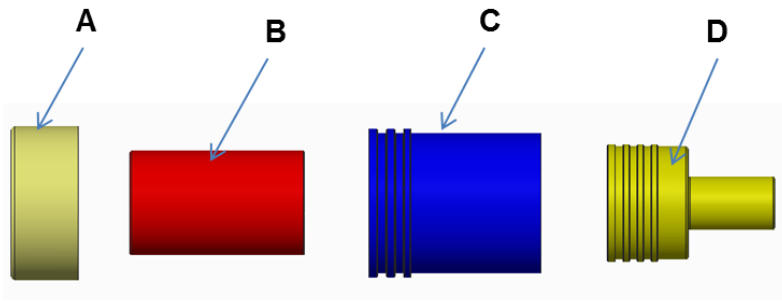

Fig. 4 – Exploded view of the simple product mechanism.

The methodology for disassembly AND/OR graph and the Petri-Net are different of the models that have been suggested to determine the connections between the components and subassemblies, and the potential ways to disassemble an assembly/product. The Petri-Net methodology can development a disassembly system resources and process together (Tang *et al*., 2002). The mathematical models described in disassembly process can be used to establish a proper disassembly chronology derived from the easy way to touch a core. These models in many circumstances may not be capable to recommend a product designer adequate which is the optimal disassembly route for a assembly product without regarding the concrete restraint which an worker might face trough the entire disassembly process.

In Fig. 5 is proposed an AND/OR graph for the simply product described above. The nodes in such a graph correspond to the number of components or subassemblies. The upper node, which does not have an ancestor, corresponds to the whole assembly. Nodes that do not have descendants correspond to the individual components.

Arrows are directed and represent disassembly operations. It should be emphasized that such a chart does not have a cycle. In other words, once a stage has been completed, it is not possible to return to the previous state. In addition, nodes corresponding to assemblies containing only one part are terminal nodes. This approach can be considered a step towards developing a systematic procedure for generating all feasible disassembly sequences and should be considered when dealing with dismantling issues.

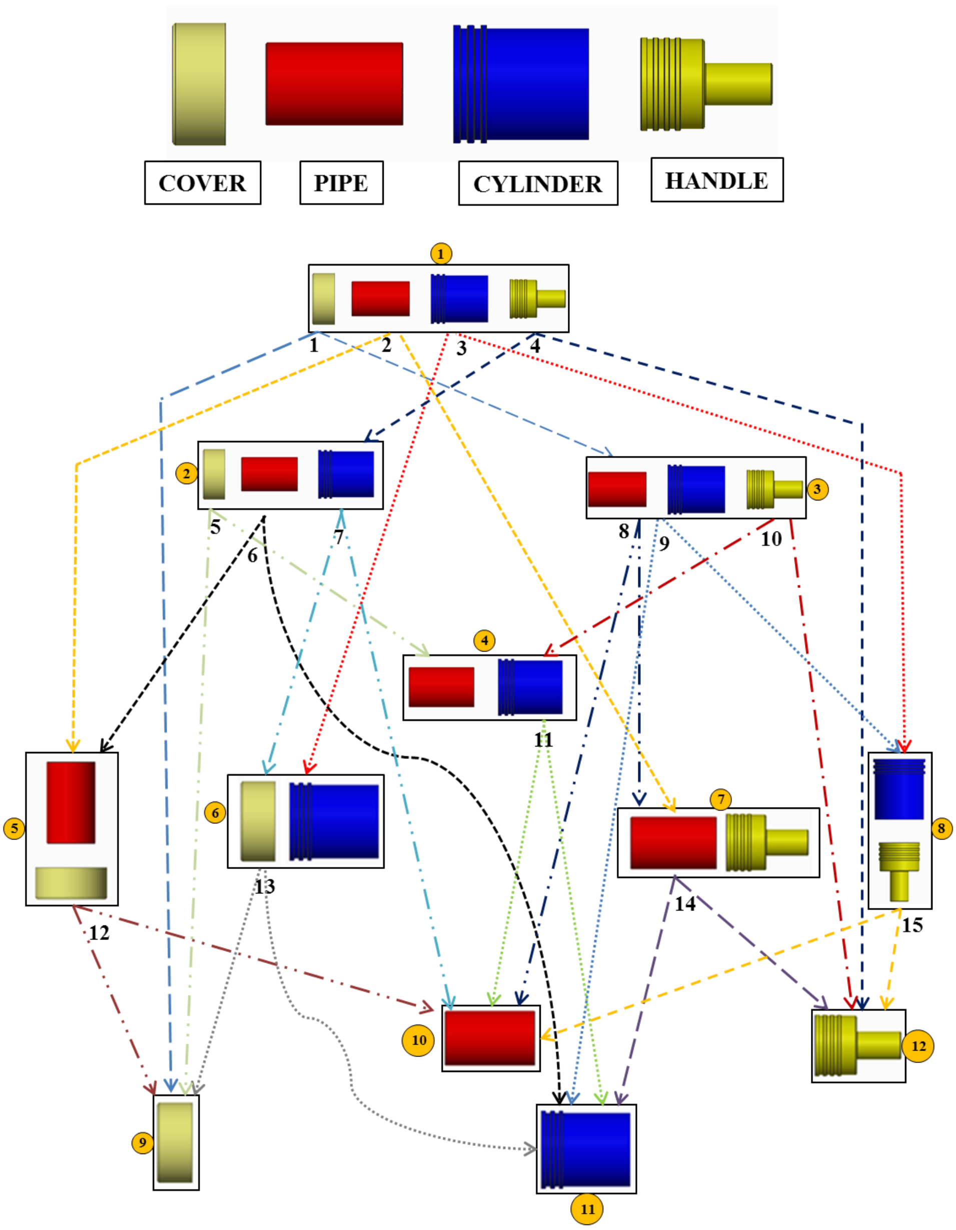

Fig. 5 – Sequences of disassembly represented by the AND/OR graph.

The complexity of the design product for evaluation has been established for design assess the difficulty in assembly the components of a product together. The standards and the methodologies have been created to evaluate and specification complexity of the assembly, this can be retaliated by allocate level of different difficulty factors to varied attributes for manipulation and introduction over the assembly process (Samy and ElMaraghy, 2010). To measure the corresponding difficulties of various quick methods, principles an approach, like the U-effort disassembly model was suggested in the research work (Das and Naik, 2002).

In this research the methodology proposed converge the particular detail of the assembly level of complexity analysis with the U-effort disassembly model to ensure a quantitative examination for disassembly process, difficulty built on the weighted average for difficulty index of parts I_{com}, as in the equation below (1) (Soh *et al*., 2015).

$$I_{com} = \frac{C_h \sum_1^J C_{h,f} + C_r \sum_1^K C_{r,f}}{\sum_1^J C_{h,j} + \sum_1^K C_{r,f}} \tag{1}$$

where:

$C_h = \frac{\sum_1^J C_{h,j}}{J}$ represent average handling complexity factor

$C_r = \frac{\sum_1^K C_{r,j}}{K}$ represent average removale complexity factor

C_{hf} – represent the difficulty factor defined in Table 1 for handling

f – represent the non zero handling atributes matched for each part

C_{rf} – represent the difficulty factor defined in Table 1 for removal

f – represent the non zero removal atributes matched for each part

Accessibility for the components represents the difficulty path with which a component can be touched. In many times, the more complexity to approach a component, the supplementary time is essential to remove it.

For the assembly describe above in Fig. 5 there are 1 disassembly routes to reach Part B (Fig. 7). To determine all the possible combination, assembly is rated based on the complexity/difficulty way of accessibility and the different level of difficulty for disassembly process.

Table 1
Attributes for Manual Disassembly (Soh et al., 2015)

Group	Attribute	Description	Complexity factor, C_f
MANIPULATION	Size	>15 mm 6 mm to 15 mm <6 mm	0.75 0.81 1
	Thickness	>2mm 025 to 2 mm <0.25 mm	0.27 0.5 1
	Weight	<4.5 kg >4.5 kg	0.5 1
REMOVAL	Mechanical process (U-effort)	Screw standard head Screw special head Nut and bolt Retaining ring/circlips Interface fit Key	0.56 0.88 0.84 1 0.72 0.6
	Tool required	0 tools 1-3 tools >4 tools	0 0.6 1
	Specialized tools	None Involved	0 1

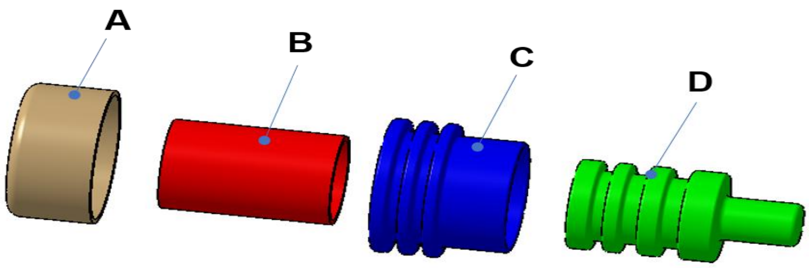

Fig. 6 – Exploded view of the simple mechanism.

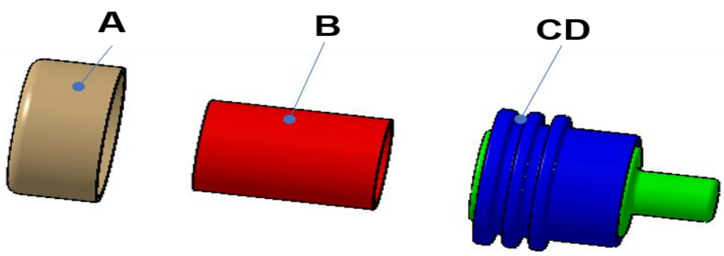

Fig. 7 – Exploded view for the disassembly routes.

4. Conclusions

As a first conclusion, we can say that the theoretical approach and the case study for all the aspects of design for disassembly approach can improve the disassembly process and they can contribute in different ways.

As another conclusion, the methodologies proposed in this research paper allow the designers to have an organized/structured manner in designing assembly products and they don't need to take in account the design for disassembly for entire components of the product assembly but only the components.

For the near future, a few research development directions are for identifying a right methods/concepts to generate an optimal disassembly sequence for a product design, fitting incorporated technologies, and a methodology that considers the ergonomics of the disassembly and the sequence for the process. Other investigation it's to see the complexity (I_{com}) and the accessibility (I_{acc}) metrics for the disassembly route.

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INTEGRAREA METODELOR ȘI TEHNOLOGIILOR AVANSATE DE PROIECTARE PENTRU DEZASAMBLARE ȘI RECICLARE PENTRU PROIECTAREA SUSTENABILĂ A PRODUSELOR

(Rezumat)

Cercetarea prezentată este orientată spre protejarea mediului în ceea ce privește sustenabilitatea acestuia, iar proiectarea pentru dezasamblare (DFD) și proiectarea pentru reciclare (DFR) a devenit un aspect major al ingineriei ciclului de viață, cu intenția de a aduce un produs sau o parte dintr-un produs înapoi la viață pentru a putea fi refolosit. Creşterea eficienței pentru dezasamblare poate fi fezabilă dacă perspectiva de dezasamblare este luată în considerare în timpul etapei de proiectare a produsului. Pentru partea de început se propune un model/cadru conceptual pentru cercetare, în care principiile DfX și ingineria integrată converg împreună pentru a elabora metodologiile pentru DfD și DfR, iar aceste metode/principii se transformă în susținerea dezvoltării durabile a produsului.

Ca studiu de caz, a fost considerat un mecanism simplu format din 4 componete. Acest tip de produs este prezentat pentru a ilustra și evidenția metodologiile propuse în lucrare (graficul AND/OR și Petri-Net).

Reprezentarea graficelor AND/OR și Petri-Net sunt câteva dintre modelele care au fost propuse pentru a stabili relațiile dintre subansamble și componente, dar și anumite posibile căi de dezasamblare a unui produs.

Abordarea teoretică şi studiul de caz pentru toate aspectele de proiectare pentru abordarea dezasamblării pot îmbunătăţi procesul de dezasamblare şi pot contribui în moduri diferite la sustenabilitatea mediului cât şi la reciclarea/reutilizarea componentelor după procesul de dezasamblare. Metodologiile propuse în această lucrare de cercetare permit proiectanţilor să aibă o abordare organizată/sistematică în proiectarea produselor şi nu vor trebui să ia în considerare proiectarea pentru dezasamblare pentru toate părţile produsului, ci doar pentru acele părţi găsite pe ruta identificată.