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Eco-design guidelines takeaways from the analysis of product repairability and ease of disassembly: a case study for electric ovens

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Abstract

One of the main aspects to increase the useful life of ErP and reduce waste generation is the product repairability. Key factors in assessing the ability to repair a product are the ease of disassembly, and the use of repairability indexes (i.e., eDiM, French repairability index, RSS, etc.). The goal of this paper is to retrieve eco-design guidelines analyzing the product repairability of target components belonging to four different types of electric ovens. The analysis adopts as baseline the report of the Joint Research Centre and the European standard EN 45554. Results provide interesting insights concerning the identification of disassembly issues and the mitigation of these hotspots through eco-design guidelines retrieved by the analysis of repairability.

Keywords: disassembly; repairability; design for disassembly; design for repairability; eco-design; circular economy; disassemblability index; cooking appliances; oven.

1. Introduction

Waste prevention is the fundamental pillar of the EU waste framework directive. Waste prevention seeks to inhibit products from becoming waste by the following actions: (i) the reduction of natural resources used for their production (raw materials), (ii) the extension of the product lifetime, and (iii) the adoption of circular economies. A way to extend the useful life of a product is the improvement of its repairability, allowing the consumer the disposal of the damaged component rather than the entire product [1]. Boyano et al. [2] showed how the repairability of appliances (e.g., washing machines) can be improved by increasing the legal guarantee since most failures occur after two years. Social movements throughout Europe (e.g., Right to Repair) demonstrated how consumers' awareness is higher on this topic and highlighted that one of the main problems of product repair is the cost (compared to the acquisition of a new product). This is why sustainable strategies like the ones adopted by Germany or Austria have emerged, creating a repair bonus program that incentivizes consumers to repair damaged products [3]. Indeed, an increment in these services in Austria showed that approx. 260 tons of e-waste were saved within the period September 2018 - December 2019 [4]. On the other hand, there are different standards (i.e., the EN 45554:2020 [5] developed on the basis of the Ecodesign Directive [6]) that seek to promote the durability of Energy-related Products (ErP) providing methods and criteria to establish the capability of a product or component to be repaired, reused, or upgraded. Based on these standards, several research works aiming at repairability analysis can be found in the literature. These studies encompass the following methods: (i) qualitative methods that establish pass-fail criteria [7], (ii) semi-quantitative methods that allow comparing products within a specific family [7][8], and (iii) quantitative methods that use measurable data to assess for example the ease of disassembly [9][10][11]. Among semi-

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quantitative methods, the Matrix for ease of Repair (AsMeR) [8] and the Repair Scoring System (RSS) [12] are the most used. Both of them are based on the calculation of a "repairability score" by analyzing the characteristics of a specific product family in order to establish the evaluation criteria that are most suitable for that range of products, such as key parameters, target components, etc., as well as the weight of each one of these criteria [7][8][13]. These methods are usually combined with the quantitative ones, like the ease of Disassembly Method (eDiM), which uses the Maynard Operation Sequence Technique (MOST) and allows to calculate the disassembly time of a component considering the skills of the operator along with other factors [5]. In this field, the work of Bracquené et al. [13] presents a complete and detailed analysis of the application of semi-quantitative methods to assess product repairability for washing machines, showing how the results obtained with both methods (AsMeR and RSS) are overlapping. However, two main gaps have been observed by the analysis of the literature: (i) there are no studies that focus the research on cooking appliances, despite the fact that food preparation activity is responsible for more than 8% of electricity consumption in the residential sector [14] [15], and (ii) there are no studies that provide useful guidelines to implement eco-design actions towards product repairability. This paper aims to present an analysis of product repairability and ease of disassembly concerning built-in electric ovens. The disassembly analysis together with the calculation of the Disassembly index (the first item used for the calculation of the Repairability index) allowed the spotting of disassembly issues for target components (priority parts) which have a considerable failure rate. In this research work, the adopted methodology has followed the Disassemblability Index (I_D) approach described within the Joint Research Centre report [12]. The knowledge retrieved by manual disassembly activities performed on the products, together with the data collected and the index analysis were used to identify design solutions towards an easy component disassemblability and product repairability. This knowledge can be reinjected in the development of new eco-design compliant products. The novelty of the paper is to evaluate a new product category (cooking appliances) for implementing repairability strategies and eco-design solutions since this type of analysis is highly dependent on the characteristic aspects of the product.

After this examination of the context and the state of the art, Section 2 describes the methodology followed to obtain the I_D, Section 3 presents and discusses the results of the application of the method to electric ovens, and, finally, Section 4 summarizes the main conclusions and possible future works.

2. Materials and Methods

Since the focus of this research work concerns the analysis of the ease of disassembly for a specific cooking appliance (built-in electric ovens), a dedicated methodology has been developed and presented in Fig. 1. The research methodology is based on four steps and includes: (i) project definition, (ii) laboratory tests, (iii) Disassembly index calculation, and (iv) eco-design guidelines definition.

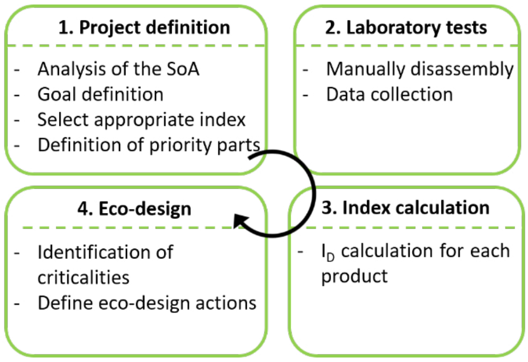


Fig. 1. Research methodology.

2.1. Project definition

The first phase of the research methodology concerns the definition of the research objective and scope of work. The goal of this study is to measure the Disassemblability Index of built-in ovens to develop eco-design guidelines. Four types of ovens that adopt different technologies have been analyzed obtaining a global vision of this product category (see Table 1).

Table 1. Types and features of the electric built-in ovens.

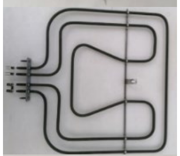
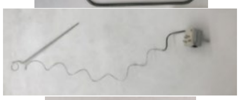
ID name	Type	Features
Oven_1	Standard	Standard functions, including top and bottom heating, grill, defrost and fan
Oven_2	Pyrolytic	Standard functions and additional functions, including the core temperature sensor, the eco function (optimization of the energy consumed during cooking), and the pyrolytic cleaning function
Oven_3	Combi microwave	Standard functions and additional functions (no pyrolysis) with smaller dimensions. Microwave technology included
Oven_4	Combi steam	Standard functions and additional functions (no pyrolysis, no microwave). Steam technology included

For the assessment of the Disassemblability Index and repairability analysis, a list of target components (priority parts) with a high average occurrence of failure is necessary, since they are the most frequently replaced. This list of priority parts has been prepared after carrying out a failure rate study of each component together with experts' opinion (see Table 2).

2.2. Laboratory tests

The second phase of the research methodology deals with the performance of disassembly tests tasks, by manually disassembling the priority parts. All the required data that will be used to assess the Disassemblability Index has been retrieved, which includes: (i) the number of steps needed to remove the component, (ii) the number and type of fasteners, (iii) the number and type of connectors (i.e., reusable, removable or neither removable nor reusable), and (iv) the types of tools used (i.e., basic tools, product group-specific tools, other commercially available tools, proprietary tools or not feasible with any existing tool) [5][12]. This phase also allows identifying criticalities that will be useful to develop eco-design actions, considering the difficulties found by the operator during the dismantling process.

Table 2. List of target components (priority parts).

Name	Picture
User interface	
Cooling motor & fan	
Hot air motor	
Fan	
Top heating element	
Ring heating element	
Bottom heating element	
Temperature sensor	
Lamp	

2.3. Disassembly index calculation

The Disassemblability index (I_D) assessed in this phase is based on four parameters: (1) disassembly depth, (2) fasteners, (3) tools, and (4) disassembly time [12]. In this paper, the disassembly time has not been considered (see Section 2.3.4) since the focus of the analysis is the identification of the design criticalities, rather than a calculation of disassembly time. For each parameter, a score (S_1, S_2, and S_3) is calculated and/or retrieved by the use of dedicated tables. On the other hand, a weight (W_1, W_2, and W_3) is assigned to each parameter and reflects the importance of that criterion in the determination of the index ($1 \leq W_j \leq 2$). The weight assignment is based on stakeholders' evaluation and literature analysis. Indeed, there is no available information related to the weight assignment for this type of product in comparison with other household appliances (i.e., washing machines). Thus, a sensitivity analysis was performed to tackle this issue. In this case, the weights of the parameters are set to 2 for "Disassembly Depth" and "Fasteners" (W_1 and W_2) and 1 for "Tools" (W_3) [12][16][17]. The equation used for I_D assessment is presented here below (equation 1). The index j refers to a specific parameter (j [1, 2 ,3]).

$$I_D = \frac{\sum_1^3 S_j \times W_j}{\sum_1^3 W_j} \tag{1}$$

The parameter score (S_1, S_2, and S_3) depends on the priority parts. Table 3 reports the equations used to assess the score associated with each parameter (j). The index i refers to a specific priority part within the product and N is the overall number of priority parts. Each score is dimensionless and ranges from a 0 to 1.

Table 3. Score calculation for I_D (disassembly time not considered – N.A.) [12].

Parameter score	Parameter equation	Parameter weight
Disassembly depth	$S_1 = \frac{\sum_1^N S_{1,i} \times w_i}{w_i}$	W_1
Fasteners	$S_2 = \frac{\sum_1^N S_{2,i} \times w_i}{w_i}$	W_2
Tools	$S_3 = \frac{\sum_1^N S_{3,i} \times w_i}{w_i}$	W_3

As did for the equation parameter, a specific weight w_i ($1 \leq w_i \leq 3$) is assigned to each priority part based on the failure rate of the considered part. The same issue for weight assignment is present also for the priority parts. The failure rate data of other product categories (i.e., washing machines) that have the same type of priority parts have been used, along with data provided by stakeholders (sale rate of spare parts, number of calls for a service repair intervention for a given priority part, etc.). Considering all the above, it has been established that all the priority parts have the same weight ($w_i = 2$). Once the weights have been defined, the I_D is calculated following the methodology proposed in Table 3 and equation (1).

2.3.1. Disassembly depth score – $S_{1,i}$

The disassembly depth score is based on the Disassembly Depth (DD) which is defined as the number of steps necessary to remove a part from a product [5]. For each priority part, the DD is calculated through laboratory tests. The disassembly depth score ranges from 0 to 1, with 0 being the most unfavorable and 1 being the optimal situation. Equations used to calculate this score is presented here below (equation 2):

$$S_{1,i} = 1 - \frac{(DD_i - 1)}{(D_{ref} - 1)} \tag{2}$$

Where DD_i is the overall number of steps necessary to remove the *i-th* part and D_{ref} is the reference depth for the product group specified at the product-specific level. In this study, D_{ref} is considered to be the most unfavorable case, that is, the maximum number of steps for the *i-th* priority part observed within the four models studied.

2.3.2. Fasteners score – $S_{2,i}$

The fasteners score considers the reversibility and reusability of the fasteners employed in each priority part. A matrix is used to input this score at each priority part. Indeed, a score of 1 is assigned when the fasteners are fully reusable, 0.5 if the fasteners can be disassembled without damaging the part but it cannot be reused, and 0 when the fasteners cannot be removed. If more than one fastener is disassembled for a given priority part, the worst score must be considered [12]. As can be seen, for scoring this parameter the number of fasteners is not considered, but only the typology. Despite this assumption, during this research activity, the number of fasteners has been counted because it can be useful in the future to assess the disassembly time.

2.3.3. Tools score – $S_{3,i}$

The tool score takes into account the type of tool required to disassemble the part. As for the fasteners score, a matrix is used to input this score at each priority part, always choosing the most unfavorable case if more than one type of tool is employed. When no tools are needed to remove the component or basic tools (standard tool) are used, the score is set to 1. On the other hand, when group-specific products tools are utilized, the score is set to 0.75, while for other commercially available tools, different than standard, the score is set to 0.5. In the case of proprietary tools, the score is set to 0.25. The worst case is when the part cannot be disassembled without damaging the product; in this case, the score is set to 0 [12].

2.3.4. Disassembly time score

Disassembly time affects repairability in terms of cost since a longer duration of the process implies higher costs. However, this project seeks towards a preliminary analysis of repairability for cooking appliances, thus the disassembly time calculation has been excluded from the analysis. This assumption does not affect the results of this study and future work will be performed on this aim. Although disassembly time has not been calculated, all the necessary information (number of steps, fasteners, tools, accessibility, etc.) has been recorded so that this calculation can be conducted in future works, using for example the eDiM index as in the Benelux study [8].

2.4. Eco-design guidelines definition

By assessing the Disassemblability Index, the comparison of the four ovens is allowed. In this case, the best manufacturing practices can be recognized and a series of eco-design actions can be established to solve the criticalities observed during the disassembly tests. These actions are classified as eco-design guidelines that drive the design of future cooking appliances toward sustainability and circular economies. The involvement of engineers and design experts (from both the industry and academic fields) allowed the development of these guidelines. In addition, the worst scenario has been identified for each priority part. By adopting the developed design guidelines and redesigning the target components, the new value of the index was assessed and compared with the worst scenario, highlighting the increment of product repairability.

3. Results and discussion

Based on the different ovens' characteristics a list of key components has been identified (see Table 4).

Table 4. Key components for each oven.

Priority parts	Oven_1	Oven_2	Oven_3	Oven_4
User interface	X	X	X	X
Cooling motor & fan	X	X	X	X
Hot air motor	X	X	X	X
Fan	X	X	X	X
Top heating element	X	X	X	X
Ring heating elements	X	X	X	X
Bottom heating element	X	X	X	X
Temperature sensor	X	X	X	X
Lamps	X	X	X	X
Door	X	X	X	X
Door lock		X	X	X
Clixon thermostat		X	X	X
Terminal block		X		
Power board		X	X	X
Core temperature sensor		X		
Microwave system			X	
Water tanks				X
Steam generator				X

Looking at the Table 4, most of the priority parts are common to all the models studied, with some differences related to specific models. When calculating the I_D in this study, only the common priority parts were taken into account so that the findings could be compared amongst the different models. However, for the sake of completeness, each target component has been disassembled and the same information has been collected. So doing, it is possible to identify criticalities and develop actions based on Design for Disassembly and Design for Repairability. Results of the disassembly tests have been compiled in a spreadsheet to facilitate further analysis. An excerpt of the information collected can be seen in Table 5. For the other ovens' target components, the analysis process has been performed in the same way. Using equation 1, the value of the Disassemblability index of all the target components has been calculated. The I_D result is a score that ranges from 0 to 1, with 1 being the ideal value (best performance in terms of repairability).

Table 5. Excerpt of data collected during disassembly tests: Oven_1

Priority parts	Steps (nr)	Fasteners		Tools	
		(nr)	score	(nr)	score
User interface	6	16	1	1	1
Cooling motor & fan	7	14	1	1	1
Hot air motor	9	9	1	2	1
Fan	5	5	1	2	1
Top heating element	9	10	1	2	1
Ring heating elements	8	10	1	1	1
Bottom heating element	6	5	1	2	1
Temperature sensor	11	16	1	1	1
Lamps	3	0	1	0	1
Door	3	2	1	0	1
Door glasses	5	2	1	0	1

As can be seen, for each component, outcomes have been presented with a symbol that facilitates the interpretation of results (see Table 6). The black circle (●) represents the priority part among the four ovens with the best index, while the white circle (○) represents the priority part among the four ovens with the worst result. Results in the middle between the best and the worst are reported with the other complementary circle configurations.

Table 6. Disassemblability Index of priority parts.

Priority parts	Oven_1	Oven_2	Oven_3	Oven_4
User interface	0.78 - ◕	0.69 - ◑	0.82 - ●	0.60 - ○
Cooling motor & fan	0.66 - ◑	0.71 - ●	0.60 - ○	0.60 - ○
Hot air motor	0.64 - ●	0.60 - ○	0.64 - ●	0.60 - ○
Fan	0.68 - ●	0.60 - ○	0.68 - ●	0.68 - ●
Top heating element	0.72 - ●	0.72 - ●	0.60 - ○	0.67 - ◑
Ring heating elements	0.72 - ●	0.68 - ◕	0.60 - ○	0.72 - ●
Bottom heating element	0.82 - ●	0.82 - ●	0.60 - ○	0.67 - ◔
Temperature sensor	0.60 - ○	0.80 - ●	0.72 - ◑	0.68 - ◔
Lamps	0.80 - ●	0.70 - ◑	0.80 - ●	0.60 - ○
Door	0.73 - ●	0.60 - ○	0.73 - ●	0.60 - ○

By analyzing the index of each priority part, it can be established the number of critical components inside each oven (the ones with the white circle - ○). By following this analysis, it can be noticed that the lower is the level of technology (Oven_1 and to a lesser extent Oven_2) the better is the product in terms of disassemblability and repairability (less than a third of components are critical). On the other hand, the ovens that obtain the worst results are the combi-steam and the combi-microwave. In these two cases, the highest scores for the disassemblability index are noticed for Cooling motor & fan, Top heating element and Bottom heating element among others. As a general outcome, the Disassemblability index calculated for the whole oven shows that Oven_1 obtains the best results (ID = 0.72), followed by Oven_2 (ID = 0.69), Oven_3 (ID = 0.68) and with the worst results Oven_4 (ID = 0.64). Considering all the above and the critical task highlighted during the experimental disassembly process, a series of eco-design actions that seek to improve the repairability of these components can be established. The list of eco-design guidelines has been defined involving engineers and designers from the manufacturing companies and experts from academia. Table 7 summarizes the defined guidelines.

Table 7. Eco-design guidelines.

Component	Criticalities	Eco-design action
Back panel	Unstable system based on the support of the back panel on the bottom panel without a “click system”. Hard to reassembly	Use a “click system” in which there is a thin part of the sheet stuck in the middle of a groove carved in the bottom panel
Printed Circuit Board (PCB) user interface	Number and position of the 4 tabs (in the plastic structure that holds the PCB) requires to use both hands to remove it. Hard for one person	Use only 2 tabs on opposite corners of the frame. This allows the PCB to remain in the fixed position and facilitates its removal with one hand
Nuts dimensions	Using different dimensions involves using more than one tool, increasing the time of the disassembly process	Try to use whenever possible components that have the same dimension, reducing the number of tools needed
Door lock motor	Since screws are oriented upside down, it is necessary to disassemble the entire oven door to be able to remove this part	Reversing the screws saves a lot of time and reduces the number of steps
Cooling motor	A screw was inaccessible, another component (the microwave system) has to be disassembled to unscrew it	Study the position of the screws to make them accessible without the need to disassemble extra components
Bottom heating cover	Disassembly phase is time-consuming due to the 2 metal tabs used as a method of joining the component to the front panel. It was necessary to remove two other components to be able to disassemble these tabs	The use of two guides instead of the tabs for the bottom heating cover can ensure the stability of the structure and at the same time simplify the disassembly (reducing time and number of steps)
Cable tie	There is a cable tie in Oven_4 that can be reused but it is needed a product group-specific tool during the assembly process	Change this cable tie allowing the disassembly and assembly with common tools

Fig. 2 displays two criticalities explained above. As can be seen in Fig. 2.A, due to the position of the four plastic tabs necessary to remove the PCB (user interface), the disassembly task is difficult to perform by one person. On the other hand, Fig. 2.B shows how just having one screw with the head oriented upside down, would require disassembling the entire oven door to be able to remove this part. The main benefit of these actions is the reduction of the disassembly and assembly time, so there is not a big difference in the values of the Disassemblability Index calculated after applying these solutions. However, there are some cases where it has also been possible to reduce the number of steps. For example, when changing the position of the cooling motor screws or modifying the joining method of the bottom heating cover (see Fig. 3).

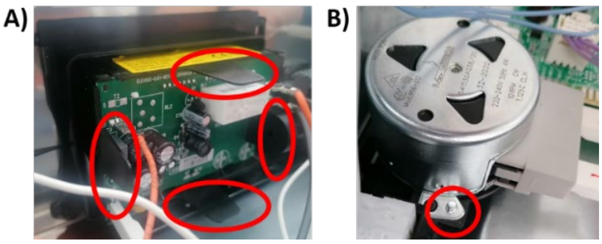


Fig. 2. Example of criticalities. A) PCB user interface hosting case and B) door lock motor assembly

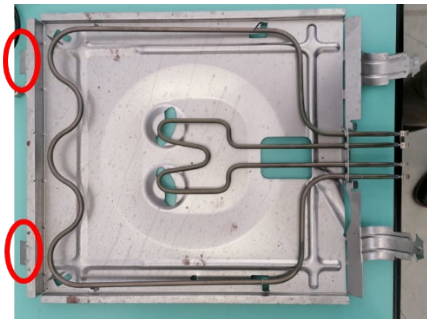


Fig. 3. Example of criticality: Bottom heating cover

Using these new parameters, an I_D of 0.72 is obtained for Oven_1, 0.69 for Oven_2, 0.71 for Oven_3 and 0.65 for Oven_4, respectively. As can be observed, Oven_3 perform better than Oven_1 thanks to these design improvements. Finally, although Oven_4 remains in the last position, it has improved its results. It is important to preserve the original maximum number of steps (D_{ref}) as a reference while implementing the changes in the index calculation. If this is not done, the outcomes will not be able to catch the true value of the eco-design action.

4. Conclusion and future works

This research was intended to start the repairability analysis in the cooking appliances sector. Guidelines presented in the RSS method have been followed and the simplified calculation of the I_D has been conducted for four electric ovens with different characteristics. It has been observed how the index obtains better results in the simplest ovens. It has also been proven how the identification of criticalities and the development of possible alternative design solutions is a technique that works to improve the repairability of a product. On the other hand, considering the limited information available about the failure rate of this type of appliance, it is convenient to carry out in future studies a sensitivity analysis with the weights assigned to the priority parts and parameters. In addition, this analysis can be completed considering parameters that were left outside the analysis, such as the disassembly time or the availability of spare parts. In addition, increasing the range of products studied, it would be possible to create a database of best practices for each component. Finally, a simple action that makes it easier for the consumer to repair some oven components (i.e., led lamp) is the provision of instructions by the manufacturer that allow the final user to change damaged parts as long as they do not pose a risk to their safety. That is why European eco-design standards 2019/2020 [18] obliges manufacturers to include it in the user manuals.

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