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# Decision making system for designing products and production systems for remanufacturing activities

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**Abstract**

Circular economy put in light the remanufacturing as a potential good scenario to encourage sustainability. However, designing sustainable remanufacturing systems is not an easy task. Many different tools and methods have been developed to help this design, but it is still difficult to identify them when you are a company starting on the subject or searching for a tool for a specific objective. To support decisions making for designing products and production systems for remanufacturing activities a method to classify all these tools is proposed. This method helps engineers to select the most appropriate tools in their development process regarding the system performance and the sustainable performance. A method and an interface to guide the designers in choosing remanufacturing tools/methods have been developed. A case study is used to illustrate this proposition.


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*Keywords:* Remanufacturing; Tool selection

## 1. Introduction

Critical resource constraint, climate change, and waste management issues have become among the main concerns in the industry for the past few decades. This is due to the increasing consumption of energy and material resources in Linear Economy by industrialized and developing countries, which applies “Take, Make, Dispose” industrial process. Considering those problems, many concepts have been introduced, including circular economy, which have the objective to maintain the value of products, materials, and resources in the economy as long as possible and to minimize waste [1]. Remanufacturing, which is defined as “returning a product to at least its original performance with a warranty that is equivalent or better than that of the newly manufactured product”[2] is one of the strategies in the circular economy.

From the environmental perspective, remanufacturing is predicted to conserve energy and raw material [3], to extend the lifetime of products and to reduce pollution. In addition, from the economic and social point of views, remanufacturing is seen as a business model that could satisfy consumers’ needs (quality product with a lower price), create new job opportunities and new stakeholders, and build favourable image for companies.

But to acquire and show such advantages is a challenging task, due to the complexity of the products and remanufacturing process and due to uncertainties in the remanufacturing process (in timing, quantity and quality of returns or with operation time) [4]. As a result, many tools, methods, and approaches were developed to help designers and remanufacturers to decide and plan their remanufacturing activity. The application of remanufacturing tools and methods in companies has become essential for results that are more accurate, shorter working duration, and earlier work planning.

Shu and Flowers [5] have recorded several significant studies as early as 1993 on the remanufacture structure matrix. According to Amezquita et al.[6], the formalized general design guideline for remanufacturing and recycling is found in


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German engineering standard, VDI 2243 in 1993[7]. It was then followed by significant studies from Amezquita et al.[6], Bras and Hammond [8], and Shu and Flowers [9] on the early design aids that focused on defining product's characteristics that facilitate remanufacturing from the aspect of economic and general remanufacturing process (disassembly, cleaning, recovery, reassembly, and inspection process). Since then, these tools/methods evolve in various ways, which make this topic richer and more interesting to be analysed. Hatcher et al. [10] and Fegade et al. [11] have written some useful reviews on Design for Remanufacturing (DfRem) tools and methods. While Goodall et al. [12] has reviewed tools/methods to support decision-making process in remanufacturing.

However, the large quantity of tools/methods used for remanufacturing might cause another problem related to the choice of tools/methods. Considering the numbers and various characteristics of DfRem tools/methods, the problem to choose an appropriate tool/method and the scarcity of these tools/methods being used by the industry, may be due to the lack of effort in classifying and managing the tools/methods in order to allow efficient usage. Pretending that remanufacturing tools/methods can be used as valuable academic resources, it is important to manage and classify the resources in order to allow an adequate retrieval process. The objective of this paper is to help designers to choose the most appropriate tool/method from the existing design for remanufacturing tools/methods using classification and management principle. The end goal is to permit designer/remanufacturer to design remanufactured product for sustainable development.

The paper is structured as follows. Section 2 describes the results of previous works: a two-dimensional framework to consider activities related to remanufacturing and a classification method for existing remanufacturing tools. Then, section 3 describes the method developed to help users to choose the most suitable DfRem tools corresponding to its activities using the previous results. The developed configurator supporting this selection method (which consists in a database and a user interface) is also presented. Section 4 illustrates the use of the proposed methods and configurator. In Section 5, we draw some conclusions and outline directions for further research.

### *1.1. 2DFR: A two-dimensional framework to classify DfRem tools*

This study reuse the 2DFR framework introduced in Ismail et al.[13] which integrates two aspects of remanufacturing: the point of view of the remanufacturing system defined by Barquet et al. [14] and the point of view of the sustainable development defined by Fatimah et al.[15]. From a literature review, those two authors defined the necessary elements in a remanufacturing system (6 for Barquet and 4 for Fatimah) and their interactions, to achieve; - the global remanufacturing system performance for Barquet – and the sustainability of the remanufacturing system for Fatimah. Barquet's aim was to organize the knowledge about remanufacturing. The methodology employed was a literature review, adopting the General Theory of Systems to characterize the remanufacturing system. Fatimah's aim was to propose a new framework to identify improvement opportunities, to make existing remanufactured products technically, economically, environmentally and socially sustainable

### *1.2. The 2DFR matrix*

Taking into account those two different perspectives on remanufacturing considered as a whole system, Ismaïl developed a matrix called "2DFR matrix". The matrix is constructed as "4x6 table" where the four elements of sustainable remanufacturing from Fatimah et al. [15] are arranged in columns and the six elements of remanufacturing systems from Barquet et al. [14] are arranged in rows (See Figure 1). For example, 1 (a) cell represented both elements of design for remanufacturing and economic perspectives such as product material's cost. The concept of pairing two elements together is applicable for the other cells. The table can be analysed horizontally to know the characteristics of each element of a remanufacturing system from sustainable development perspectives. The table can also be analysed vertically to know the characteristics of each element of sustainable development from a remanufacturing system perspective. Both ways of analysis can be used depending on the context of discussion.

| Elements of remanufacturing systems | 1. Economic | 2. Environment | 3. Social | 4. Technical |
|---|---|---|---|---|
| a. Design for remanufacturing | 1a | 2a | 3a | 4a |
| b. Reverse supply chain | 1b | 2b | 3b | 4b |
| c. Information flow in remanufacturing system | 1c | 2c | 3c | 4c |
| d. Employees' knowledge & skills | 1d | 2d | 3d | 4d |
| e. Remanufacturing | 1e | 2e | 3e | 4e |
| f. Commercialization of remanufactured product | 1f | 2f | 3f | 4f |

Elements of sustainable Remanufacturing

Fig. 1.The 2DFR Matrix

### *1.3. Remanufacturability definition from a 2DFR perspective*

Wu (2012) [16] defined remanufacturability as an attribute of a product that is used to describe the product's possibility and ability to be remanufactured. In this study, remanufacturability represents the design requirements for a product to be remanufactured. Following the previous 2DFR thinking concept, a list of design requirements has been established for each cell of the matrix. Those remanufacturing requirements were found in the scientific literatures and on remanufacturer's websites. An example is provided in figure 2, related to the environmental dimension but the economic, social and technical dimensions have also been developped.