Assessing barriers for available life-cycle information feedback transfer to product design

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Abstract

The design of products greatly influences the performance of the product in the rest of the product's life-cycle phases, e.g. manufacturing, use/maintenance and end-of-life processes. In order to design more sustainable products, information from all life-cycle phases should be implemented in structured ways via e.g. eco-design tools in the design process. Remanufacturing is one viable end-of-life strategy that is environmentally beneficial as it will preserve most of the material and energy put into the initial product and/or its components. Although the product design determines a large portion of the remanufacturability of a product, few companies apply design for remanufacturing on their products.

The aim of this paper is to show what type of feedback is available at remanufacturers, and to explore the barriers that prevent that feedback from reaching product development. Using the case study methodology, data have been collected through semi-structured interviews with four remanufacturing companies focusing on the information exchange between the departments of remanufacturing and product development.

The case study results show that there is feedback from the remanufacturers concerning a wide variety of design aspects. Furthermore, the remanufacturers have feedback about information they lack from design and the use phase including service. At present, however, there is no feedback provided from remanufacturing to design in the cases studied. Thus, the barriers for providing available life-cycle information feedback are assessed. There are both internal and external barriers. Between design and remanufacturing the barriers include e.g. lack of knowledge and organisational aspects. Further influencing the lack of feedback are managerial aspects such as the business case and specifications lacking remanufacturing aspects and thus not supporting design for remanufacturing. However, design changes such as different joining methods, a higher degree of standardization and different material selections could be very beneficial for remanufacturing and thus the environment.

Introduction

With a scarcity of raw materials and climate changes related to CO_2 emissions, measures have to be taken to stop this negative development. Sustainable ways of meeting the needs of our and future generations should be encouraged [1]. Remanufacturing is one viable end-of-life strategy, according to several research studies, that is environmentally beneficial as it will preserve most of the material and energy put into the initial product and/or its components [2].The design of products greatly influences the performance of the product in the rest of the product's life-cycle phases, e.g. manufacturing, use/service and (EOL) end-of-life processes. However, EOL aspects are often not thoroughly considered in the design phase [3]. In order to design more sustainable products, information from all life-cycle phases should be implemented in structured ways via e.g. eco-design tools in the design process. Although the product design determines a large portion of the remanufacturability of a product, few companies apply design for remanufacturing on their products [4].

The OEM (Original Equipment Manufacturer) and the remanufacturing relationship are very important operational factors for integrating DfRem (Design for Remanufacturing) into the design process [5]. Goodall et al. [6] perceive information uncertainty in the remanufacturing process as a key challenge of decision-making for remanufacturing. However, even established remanufacturers with a good relationship on paper with the OEM can lack information in practice [7].

Further, Hatcher et al. [5] point out the importance of a regular flow of information and feedback from remanufacturing to product design in order to achieve successful design for remanufacturing integration in the product development process. Literature shows potential feedback from remanufacturing to product developers, as seen in Table 1 [8]. In practice, however, little feedback from remanufacturing reaches design [5,9]. In order to reduce uncertainties and increase effectiveness, well-established information exchange is desirable.

Table 1. Product life-cycle feedback to product development according to the literature review presented by Lindkvist and Sundin [8].

Life-cycle phase	Information sources	Retreival	References
Manufacturing	Production process data	Evaluating how well the product was adapted to efficient production	Molcho et al. (2008), Baxter et al. (2009)
	Production personnel data	Suggestions of improvements	Molcho et al. (2008), Baxter et al. (2009)
Use	Conditioning monitoring data	Contrasting how the product preformed compared to expectancy	Fathi and Holland 2009, Abramovici and Linder (2011), Dienst et al. (2011)
	Customer data	Input from customer	Zhang et al. (2012)
	Service process data	Evaluating how well the product was adapted to efficient service	Baxter et al. (2009), Fathi and Holland (2009), Abramovici and Linder (2011), Dienst et al. (2011), Japtag and Johnson (2011)
	Service personnel data	Suggestions of improvements	Baxter et al. (2009), Zhang et al. (2012)
End-of-life	Remanufacturing process data	Evaluating how well the product was adapted to efficient remanufacturing	Doyle et al. (2011), Lee et al. (2011), Hatcher et al. (2011), Zhang et al. (2012)
	Remanufacturing personnel data	Suggestions of improvements	Zhang et al. (2012)
	Wear on components	Evaluating how well the product was adapted for its calculated lifecycle	Fathi and Holland 2009, Abramovici and Linder (2011), Dienst et al. (2011)

Aim

The aim of this paper is to show what type of feedback is available at remanufacturers, and to explore the barriers that prevent that feedback from reaching product development.

Results

The results in this paper are based on the findings and analysis of the results from companies that remanufacture. First, the four case companies are introduced. Then, the available feedback and lacking feed-forward types are discussed. Finally, the barriers discovered that hinder information exchange between remanufacturing and product design are presented.

Case companies

Of the four case companies presented in this paper, three are mainly based in Sweden and one is a contracted remanufacturer situated in Italy. The size of the companies varies, as does the size of the remanufacturing business compared to the number of new products produced (Table 2). Two case companies include both an OEM and a remanufacturer, where Case Company III has a contracted remanufacturer dedicated to that OEM. Case Company II is contracted by many OEMs. Case Company IV is an independent remanufacturer, and thus without connection to the OEM. Regardless of the current relationship to the original designer, the information needs and requirements have been explored. At present, no design for remanufacturing activities are explicit at any of the case companies, regardless of the remanufacturing type.

Table 2. Characteristics of the case companies.

	Case I	Case II	Case III	Case IV
Company size	Large	Medium	Small	Large
Sector	Machines	Automotive	IT	Machines
Product complexity	Medium	Low	High	Low
Remanufacturing for	10 years	20 years	10 years	10 years
Remanufacturer type	OEM	Contracted	Independent	Contracted
Remanufacturing business compared to manufacturing	Medium	Minor	Minor	N/A

Information feedback

At the case companies there is no established system for collecting information feedback from remanufacturing. This is true regardless if the remanufacturer is an OEM, contracted, or independent. This means that the OEM that remanufactures (Case I) is no better at requiring or providing feedback from remanufacturing than the independent company (Case III).

This puts the all the remanufacturers in the case studies in a similar situation as the design activities and the remanufacturing activities are decoupled.

However, just because there is no feedback provided or sought after does not mean that there is none to be given. The perceived opportunity amongst the remanufacturers to have an impact on the product design varies. Indeed, the remanufacturers are not articulating any particular feedback, except for in one case. Case Company III, the independent remanufacturer, has lists of design requirements that it wishes would be observed/considered. These lists come out of the frustration from seeing a lot more potential for an increasing number of units being remanufactured if the original products were designed for remanufacturing. Ironically, the company in Case III is the remanufacturer with the least connection to the OEMs, and as it is independent, it is not likely to have any impact on the design. However, its wish lists show that there is plenty of feedback to be given to product development.

The other three case companies also have feedback to provide once the surface is scratched. They were not considering providing any particular feedback since there is no such request or channel to provide the feedback through. Despite this, once asked they could give examples. Case Company I for instance saw a trend in using more fragile materials in its newer products, resulting in higher costs and less reuse of components in the remanufacturing process. Further, the attitude towards providing feedback varies. Case Company IV claimed that it had no feedback to provide to design. Indeed, providing or even knowing what information to provide was outside of their competences.

Similarly, at the design departments there is varying perception of what information could be useful to have from remanufacturing. There appears to be a general opinion amongst the respondents that the information that could be provided would be outdated, such as design issues already altered in the newer releases or alterations of products already obsolete. There is generally very little contact, if any, between design and remanufacturing. This results in limited insight in what the remanufacturers actually do. Indeed, lack of knowledge about the remanufacturing concept itself is sometimes apparent.

Despite these conditions, the case studies display a wide a range of specific feedback about the product design. The findings can be divided into certain categories of design-related issues:

- Cleaning aspects
- Component quality
- Component quality of purchased parts
- Disassembly qualities
- Finish/surface issues
- Material selection
- Packing aspects
- Standardisations sought for
- Verification aspects
- Weak component analysis

The common denominator of these design issues is that alterations of them could benefit remanufacturing. In particular, the feedback listed above is directly related to DfRem aspects; more aspects of DfRem can be found in e.g. Sundin, 2004. In Table 3 the feedback available at these case companies is matched with feedback sources found in the literature (Table 1).

Table 3. Available information feedback types from remanufacturing to product development (adapted and extended from Lindkvist and Sundin [4]).

Information sources	Information type	Retreival
Remanufacturing process data	Cleaning aspects	Evaluating how well the product was adapted to efficient production
	Disassembly qualities	Evaluating how well the product was adapted to efficient production
	Finish/surface issues	Evaluating how well the product was adapted to efficient production
	Packing aspects	Evaluating how well the product was adapted to efficient production
Remanufacturing personnel data	Material selection	Suggestions of improvements
	Standardisations sought for	Suggestions of improvements
	Verification aspects	Suggestions of improvements
Wear on components	Component quality	Evaluating how well the product was adapted for its calculated lifecycle
	Component quality of purchased parts	Evaluating how well the product was adapted for its calculated lifecycle
	Weak component analysis	Evaluating how well the product was adapted for its calculated lifecycle

Information feed-forward

At the case companies, the information that is available to them varies significantly. Case Company I has the most access to information; it has drawings of most of the machines remanufactured, but not all. When it comes to the service history of the incoming cores, however, the information is only stochastically provided via some established personal contacts. Case Company II has cores that cannot be easily inspected. A simple notification of the use cycles of each core would help it save a lot of time in its remanufacturing process, and thus increase efficiency and reduce costs. In fact, all the remanufacturers in the case studies lacked information that would greatly facilitate their remanufacturing processes. However, the disconnection to the other actors in the product life-cycle hindered them from providing such feedback.

Despite not always recognising what information feedback to provide to design, all the case companies could see needs and the potential of facilitating their processes if they had access to certain information. This means that they require more information to be fed forward from the earlier stages of the product life-cycle. However, in order to receive the correct information, the remanufacturers should also voice their needs and provide feedback about what information they require.

The types of information missing at the remanufacturers in the cases studied can be divided into the following categories:

- Use cycles
- Use conditions
- Service history
- Alterations of the original set up
- Condition after use
- Instructions
- Drawings

The information sought is often related to use and service matters. Furthermore, drawings and instructions can be missing at the remanufacturers. The right people at the OEM might not necessarily know that the remanufacturers lack this information. Thus, information feedback from the remanufacturer need not only include design aspects, but what information is needed ,when, and in what format.

Information feedback barriers

As presented above, there is plenty of feedback to be provided from remanufacturing to design. However, there is no feedback provided at present in the cases presented in this article. The case studies show that there are several barriers for feedback to reach design.

In product design, there is a lack of awareness and knowledge about the remanufacturing process. When designing the products, remanufacturing is not considered; thus, their immediate needs cannot be adhered to. Hence, there is no DfRem. Another aspect is that remanufacturing's true needs are not known at the design departments. Rather, the remanufacturing process is considered similar to service. A case company had supplied the remanufacturing technicians with the software the service technicians required. It was believed to be useful in the remanufacturing processes as well. In practice, however, it was not and the software was returned. This is one example of a lack of knowledge of the remanufacturing process. According to case studies presented by Hatcher et al. [5], an understanding of remanufacturing would imply a gradual understanding of DfRem. The respondents in this study from design have a very vague and sometimes even incorrect picture about remanufacturing.

There is even more evidence that the remanufacturers are lacking the requirements they need. All the case companies, for example, lacked information about the condition that the core will have upon arrival before they are able to assess the condition themselves. With a transfer of information, the core is evaluated at the customer's site to access if the core lives up to the condition in the leasing agreement. The remanufacturers ask for information available at the customer before the arrival of the core. They are, however, not used to stating their needs.

Here, other barriers become evident. The remanufacturers need to know what information to provide and ask for. This means changing their perception of what to do. In the current situation they rely on skilled technicians and personnel, making sure that the remanufacturing process work. Their task is to do what they do best under the circumstances they have. This means problem-solving, but also rework in the sense that they have to create information that has already been created in another life-cycle phase of the product, e.g. simulations (Case II). Indeed, when asked the contracted remanufacturer in Case IV claimed that providing feedback was outside its scope, and indeed competences. On the contrary, Case Company III had lists of desired feedback items in their archives, a sort of "wish list" that it would like to communicate to the OEMs. However, as this company is an independent remanufacturer, there is no receiver that it would easily perceive as open or willing to adhere to its feedback.

In order for the information transfer to work, both product developers and remanufacturers need to broaden their perspectives. On one hand, if remanufacturers knew more about the other actor's activities in the product life-cycle it is appealing to think that remanufacturers would know what information to feed back and what information to ask for. On the other hand, product designers would know more about the design requirements and the information needs of remanufacturing. However, in order to exchange information in an efficient and structured manner there needs to be channels for feedback. Currently, there are no established ways of giving feedback from remanufacturing to product designers. Thus, the resistance to actually providing feedback will be higher.

The lack of established feedback channels can be connected to the organizational structures of the case companies. In Case I, the remanufacturer belongs to the sales organisation, not the producing organisation. The information exchange between these parts of the organisation is traditionally poor. In Case III, the remanufacturer is contracted and thus not a part of the OEM's organisation. The OEM has voiced concern about opening up its databases to other parties, and information sought after has to be provided via a representative at the OEM. This is not a very efficient way to get information, and not very satisfying for the remanufacturer.

Here, another barrier becomes obvious. It is neither design nor remanufacturing that sets the business case or plans for future products or owns the original product specifications. Thus, it is not in their power to decide to change the current situation. The design projects are, in short, focused on delivering high quality at a low cost of production. Thus, OEMs are mostly focused on reducing cost for manufacturing, i.e. on DfM (Design for Manufacturing) rather than DfRem. This traditional focus will not benefit remanufacturing activities. On the contrary, the remanufacturing activities become an ad-on activity, especially when the manufacturing volumes are significantly higher than the remanufacturing volumes.

It can be argued that with the low share of the overall turnover, remanufacturing can never be a core business for an OEM. However, several studies point to the advantages of the remanufacturing process. Remanufacturing typically has higher profit margins than originally manufactured products. Further, in the case of PSS and leasing, the cores remain the OEM's property and the remanufacturing process becomes a value-creating process, enabling the OEM to keep its products in the loop and give it multiple opportunities to "milk the cow" (see e.g. [10].). However, in order to make the most of remanufacturing the scope and budget of the design process needs to be adjusted accordingly. If the design for remanufacturing aspects are to be implemented, the decision parameters need to allow for it. That will most likely imply some added initial costs, such as increased thickness or more durable and costly materials. The key decision should be if the design solution is preferable from a life-cycle perspective, and ideally, both from an economic and environmental standpoint.

This brings attention to another barrier. A purely economic viewpoint when considering design for remanufacturing may not be enough; the overall performance of the product from a life-cycle perspective should also be considered. Recycling requirements for products are pushed by legislators, e.g. the EU WEEE directive, etc. There are numerous examples of legislators enforcing producer responsibility. Such initiatives have had an impact on the design of products. However, thus far few regulations or standards for remanufactured products have had a noticeable impact. It can be argued that if actions were taken from legislators, the pace of the development of the remanufacturing business could increase. Further, it could empower the incentives of design for remanufacturing.

Yet another stakeholder to consider is the customers of the remanufactured products. Their voice is not typically considered at the OEMs in the cases presented in this paper. Given the life-cycle perspective argued for, the customers of remanufactured products should also have a voice. Agreed, a remanufactured product should perform as well as a new product, but there are other aspects to consider such as their perceived quality performance, timing of delivery, exterior, etc.

The barriers stated above are interrelated in different ways. There are barriers to bridging the gap between design and remanufacturing where little or no information is transferred. Further, there are the managerial aspects that influence the information sharing. These are the business case for each project that determines the budget and time constraints, etc., for the development teams. The business cases relate back to the plan for future products and product lines, what versions should be revised and when, and further new releases and generations of products to come. For each product there is a main specification stating all the requirements that the product has to fulfil. Aspects outside of the specification will be harder to include later on as all decisions will be compared to the initial requirements in the specification. However, how to interpret and break down the requirements is up to the departments, and design will work towards fulfilling the specified requirements.

Outside of the organisation there are some external factors that will affect the aspects discussed above, and therefore could have an impact of the information transfer between design and remanufacturing, such as regulations and laws concerning take-back and environmental performance of products as well as intellectual properties aspects, etc. Also to consider is the customers' voice, as well as market demands for remanufactured products, which both need to be assessed.

Discussion

Despite the disconnection to product development, the studies presented here show that there is a lot of potential for information to be fed back to product development. Design changes such as different assembly methods, a higher degree of standardization and different material selections could be very beneficial for remanufacturing and thus the environment. Most remanufacturers are independent remanufacturers that would have information to feed back to product design, but there is no real receiver who would be interested in getting this feedback. It is easier to perceive the benefit for the OEM that also remanufactures, or has a contracted remanufacturer that would go the extra mile to include remanufacturing in its design activities.

The trend is to include downstream actors in the product life-cycle in the design processes as well. Concurrent engineering, DfM/DfA, lean production and similar initiatives include manufacturing in the design process. Current trends, where selling services and business models such as PSS are becoming more important for the companies' revenue streams, design for service activities and design for PSS and the like, are likely to pave the way for service representatives included in the development process (see e.g. [11].).

Foregoers such as Caterpillar, Fuji Film, etc. have been known to apply design for remanufacturing (see, e.g. Sundin and Lindahl [12]). Furthermore, given the trends towards a more pronounced awareness of sustainability issues and extended producer responsibilities, the next step could very well be to also include remanufacturing in the development process as an actor representing not only the end-of-life management of a company, but also as a value provider of the company.

The results presented in this paper highlight the potential to include DfRem aspects in the design process. The market-oriented product development projects with budgets linked closely to production costs tend to complicate design for remanufacturing efforts. Design for remanufacturing aspects are not considered a natural part of the product development costs. Regarding the structure of the product development project teams, they often involve life-cycle actors such as manufacturing and service maintenance to some extent. However, remanufacturing is not included in the company cases studied. Thus, DfRem aspects are generally not considered in the product development phase. Including representatives from remanufacturing in the design projects seems the natural next step. According to case studies presented by Hatcher et al. [5], an understanding of remanufacturing would imply a gradual understanding of DfRem.

During the case studies, the case company's development processes have changed in the direction of a more integrated development process. This initial mind-set can act as a barrier to finding out the true needs of remanufacturing in some of the case companies. If remanufacturing is regarded as a value provider in the product life-cycle, the extrapolation of the development to include actors in the later stages in the product life-cycle would help remanufacturing to be invited as a natural party in the development projects. This could be an initial step towards integration design for remanufacturing aspects in the product design. However, having a representative does not guarantee the desired effects. There are more barriers to overcome (Figure 1).

Managerial aspects will determine whether requirements from remanufacturing will ever be adhered to. The business case has to allow for aftermarket activities to be included. Cost and time issues commonly have high priorities, and admittedly design for remanufacturing may imply higher initial costs and even longer development times initially. However, if effective the initial expenditures will become savings in the long run. Thus, a life-cycle perspective on the development cost is therefore necessary.

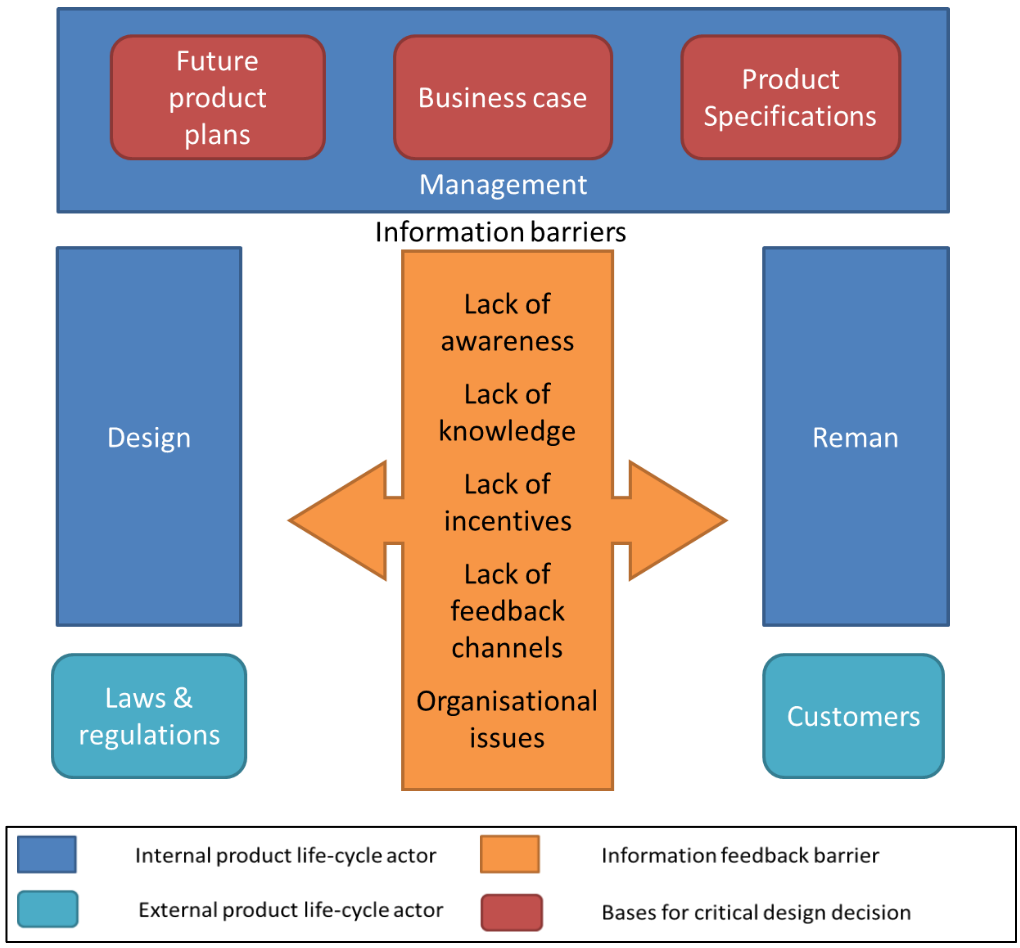

Figure 1. Factors influencing the information transfer between design and remanufacturing found in the case studies.

Conclusions

The results from the case studies show that there are different feedback types from the remanufacturers to be provided to product development such as design aspects, component design features, standardisation issues, material selections and finish/surface issues. Further, there is feedback about what information remanufacturing needs to facilitate its processes. Such information could be concerning the use and service phase such as the product's use cycles, use history and condition after use.

However, at present there is no feedback from remanufacturing to product development at the case companies. Thus, several barriers that prevent feedback from remanufacturing from reaching product design were identified:

- Lack of awareness and knowledge about the remanufacturing process.
- Remanufacturers need to know what information to provide and ask for.
- Lack of feedback channel – there are no established ways of giving feedback from remanufacturing to product designers.
- The OEMs are mostly focused on reducing cost for manufacturing, i.e. on DfM rather than DfRem, especially when manufacturing volumes are higher than remanufacturing volumes. Organizational issues that make the OEMs focus on

design and manufacturing rather than making things better for the sales companies usually responsible for OEM remanufacturing and/or contracted remanufacturing companies.
- Decision parameters to allow for implementation of design for remanufacturing aspects are lacking.
- Lack of regulations or standards for remanufactured products' environmental performance.
- Lack of feedback from the customers of the remanufactured products.

Methods

Data collection methods

The method for collecting data for this paper was semi-structured interviews at four case companies. The companies are based in Sweden and Italy, but the main organisation is Swedish. The interviewees worked in remanufacturing organisations on a managerial level. Product development managers on different levels were also interviewed in two of the cases. The interviews have been combined with tours of the remanufacturing facilities with remanufacturing managers. During those tours, interview questions were also asked as well as follow-up questions based on what was shown in the facilities. Furthermore, each company has presented its remanufacturing business at project seminars.

Authors' contributions

The authors have planned and executed the research together. Ms. Lindkvist performed most of the interviews with the product designers, while the other interviews and company visits were carried with Mr. Sundin.

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References

1. Bruntland Commission (1987) Development and international economic co-operation: environment and development. Report of the World Commission on Environment and Development, Forty-second Session, Supplement No. 25 (A/42/25).
2. Sundin E and Lee H.M. (2011) In what way is remanufacturing good for the environment? Proceedings of the 7th International Symposium on Environmentally Conscious Design and Inverse Manufacturing (EcoDesign-11), ISBN: 978-94-007-3010-6, November 30 – December 2, Kyoto, Japan, pp 551-556.
3. Kutz M.Ed., (2007) Environmentally Conscious Mechanical Design. John Wiley & Sons, Inc. Hoboken, New Jersey, USA. ISBN: 978-0-471-72636-4
4. Hatcher, G. D., Ijomah, W.L., Windmill, J.F.C., 2011, Design for Remanufacture in an OEM-Remanufacturer Organization, Proceedings of the 1st International Conference on Remanufacturing, pp.286
5. Hatcher G.D., Ijomah W.L., Windmill J.F.C., Integrating design for remanufacture into the design process: the operational factors, Journal of Cleaner Production, Volume 39, January 2013, Pages 200-208, ISSN 0959-6526

6. Goodall P., Rosamond E., Harding J., A review of the state of the art in tools and techniques used to evaluate remanufacturing feasibility, Journal of Cleaner Production, Volume 81, 15 October 2014, Pages 1-15, ISSN 0959-6526
7. Kurilova J, Lindkvist L and Sundin E. (2015) Towards facilitating circular product life-cycle information flow via remanufacturing. Procedia CIRP 22nd CIRP conference on Life Cycle Engineering (LCE) April 7-9 Sidney, Australia. In printing
8. Lindkvist, L., and Sundin, E. (2012), Life-Cycle Information Feed-back to Product Design. Proceedings of the Swedish Production Symposium 2012 pp. 99-105, Linköping Sweden 6-8 November 2012
9. Lindkvist, L., Sundin, E., and Sakao T., Exploring the Use of Product Life-Cycle Information in Two Value Chains Including Remanufacturing. Proceedings of the Eco Design conference. Jeju Island, South Korea 4-6 December 2013
10. Sundin E. and Bras B. (2005) Making Functional Sales Environmentally and Economically Beneficial through Product Remanufacturing. Journal of Cleaner Production, Vol. 13, Issue 9, pp 913-925.
11. Sundin E., Lindahl M. and Ijomah W. (2009) Product design for product/service systems - design experiences from Swedish industry, Journal of Manufacturing Technology Management, Vol. 20, Issue 5, pp 723-753.
12. Sundin E. and Lindahl M. (2008) Rethinking Product Design for Remanufacturing to Facilitate Integrated Product Service Offerings, Proceedings of IEEE International Symposium on Electronics and the Environment (IEEE-08), San Francisco, USA.