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TOWARDS A DISASSEMBLY PROCESS-ORIENTED DESIGN OF SUSTAINABLE PRODUCTS

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1 Introduction

Efficient use of resources and the environmentally benign disposal of used products have become widely accepted mission statements in manufacturing industry. This is also a result of increased legal pressure in recent years. New legislations, e.g. the Japanese End-of-life Vehicle Recycling Law or the European Directive on Waste Electrical and Electronic Equipment (WEEE) will sustain this trend.

Recycling is a strategy that diverts the stream of used products away from landfills and increases the efficiency of resource-usage by re-using assemblies, parts and raw materials. In order to retrieve components and parts, but also to obtain high-quality raw materials, it is necessary that products undergo a disassembly process prior to recycling [1].

The efficiency of disassembly and recycling processes is strongly determined by the design of the product, giving today's designers a never-known level of product responsibility. Design for disassembly and recycling is rewarded, however, by giving products many desirable side effects such as increased ease of repair and maintenance.

This paper discusses how designers could profit from disassembly processes when information is fed back from disassembly processes to product development.

2 Industrial disassembly

On a large scale, economically feasible disassembly processes can only be carried out at an industrial level within factory-like structures [4]. However, industrial disassembly processes are constricted by boundary conditions like unknown quantities, product alterations due to use or simply the wide spectrum of different products to be disassembled.

Since 1994 the Collaborative Research Center Sfb 281 at the Technical University Berlin has been developing technologies, tools and methods that are needed to realize "Disassembly Factories for the Recovery of Resources from Product- and Material Cycles. The research focuses on four areas:

- deriving novel concepts for disassembly tools and installations from the systematic examination of common manufacturing processes;
- designing the logistical structures of an internal and external disposal network for technical consumer goods considering urbanistic integration;

- formulating the fundamentals of evaluating the recyclability of products and developing methods for planning and controlling future disassembly processes;
- providing the methodical and IT-based tools necessary for supporting designers in developing products optimised for disassembly and recycling.

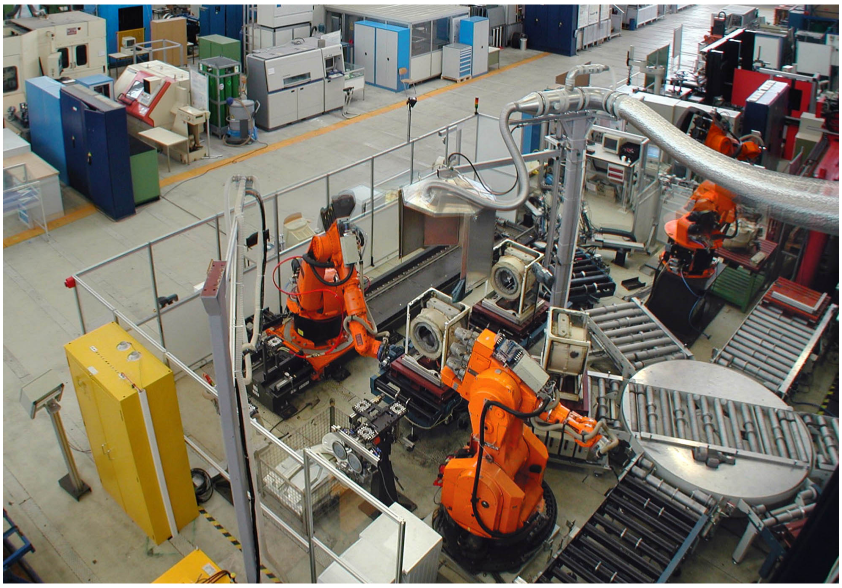

Figure 1. Automated disassembly of washing machines at the pilot disassembly cell of Sfb 281

Industry meanwhile has picked up the issue of industrial disassembly as well. IBM, for instance, operates nine major "Asset Recovery Centers" in the United States, Japan, Germany, France and Australia that process approximately 10,000 pieces of equipment a week [3], [8]. Currently, most of the units are end-of-lease return products, typically three to five years old. Upon receipt, it is decided whether the equipment is going to be resold "as is", refurbished and resold or disassembled either for the recovery of service parts or for material recycling. IBM estimations for its 1998 North America operations claim that (based on weight) 40 percent of processed equipment could be resold or reused, 56 percent was scrapped for recycling and only four percent had to be landfilled.

In a 2001 joint venture, Sharp Corporation together with six other companies has set up a recycling facility with a processing capacity of 600,000 units per year [2]. "Kansai Recycling Systems Co., Ltd." does not only serve as a facility that recycles four home appliance categories under the Japanese Home Appliance Recycling Law (air conditioners, TV sets, refrigerators and washing machines) but is also thought of as a competence centre for disassembly and recycling providing feedback to development departments e.g. by offering training to designers.

IBM too regards its Asset Recovery Centers as a source of disassembly and recycling related knowledge [5]. Channels of sharing expertise with product development include an annual "Product Stewardship Workshop" held at the Endicott, NY site, where design engineers meet with recyclers.

3 Motivation

As the above-mentioned industry examples suggest, it makes sense to let in-house disassembly experience influence product design. Obviously, this requires some communication of evaluative and/or corrective information – which is one definition of feedback.

The nature of feedback in design organisations has been investigated by Busby [7]. He points at its central role because it contributes to:

- the accumulation and retention of knowledge among designers;
- the adaption of design goals and design practices to a changing environment;
- the evaluation of changes to the design process as a result of new practices or design tools;
- the motivation and maintenance of interest among designers.

Accordingly, the occurrence of design failures can often be attributed to problems with feedback. Success with specific design guidelines can breed complacency, especially when lack of negative feedback is interpreted as success.

A guideline for the *design for reconditioning and reuse*, for instance, includes instructions such as “enable cleaning without damaging”, “limit wear to specific, easily adjustable or replaceable elements” or “facilitate the assessment of wear” [1].

The difficulty, as with any “design for x”, is that designers are rarely directly involved in any activity that the “x” represents (e.g. disassembly) whereas those confronted with design flaws (e.g. recyclers) usually cannot judge if these flaws are caused by

- not following a design guideline,
- inappropriately following a design guideline or
- appropriately following a flawed design guideline.

Design for disassembly and recycling seems to be particularly susceptible to this dilemma due to another fact: the *organisational*, *geographical* and, above all, *temporal distance* between development and disassembly processes (see Figure 2).

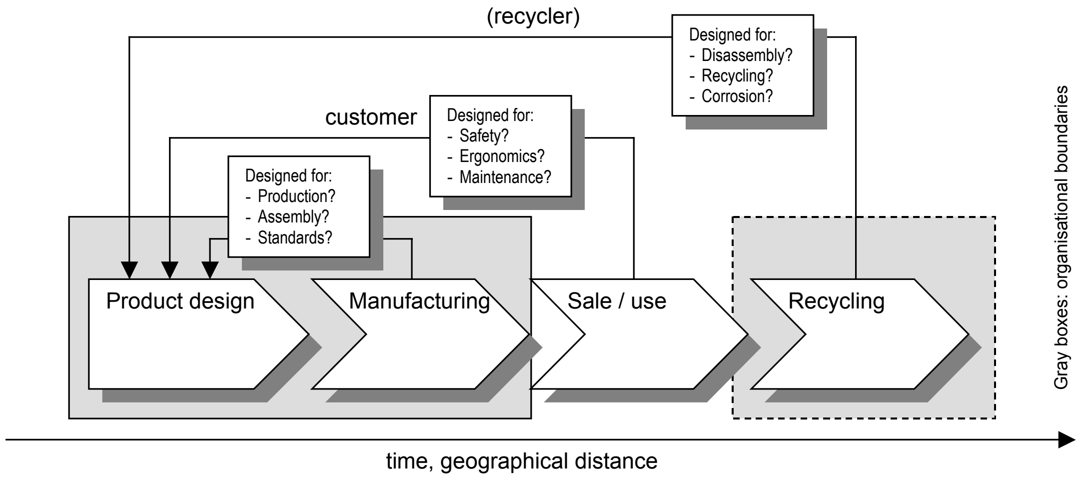

Figure 2. Possible feedback on applied design guidelines at different stages of the product life cycle

Depending on the life span of the product, several years might lie between development and disassembly in quantities necessary for the establishment of an experience base from which useful information can be fed back. In a global economy, it is quite common for new products to travel thousands of miles from manufacturer to customer. Still, in most cases, returning the used products to the origin of their making would render their disassembly highly uneconomical [4]. Consequently, most scenarios involve few centralized manufacturing sites that are outnumbered by many (possibly subcontracted) decentralised disassembly facilities – multiplying the organisational gap.

Insufficient information however, not only affects large design decisions but can also be a problem when performing seemingly unassuming design tasks such as the dimensioning of parts. When selecting a bearing for instance, the designer has to estimate the expected total number of revolutions. If this number is chosen too small, this design fault is disclosed by the failure of the part. Over-dimensioning on the other hand must be considered a design fault as well, leading to increased costs, weight, etc. Its detection is much more difficult though, since an intact part is hardly an indicator of over-dimensioning.

Strictly speaking, the question whether a part has been dimensioned correctly for reaching but not overly exceeding its intended service life can only be answered by logging all acting stresses and influences and, at the end of the life cycle, comparing this data with the dimensioning parameters. Examining the wear of parts does not always solve the problem due to a number of reasons. In most cases, the correlation between lifetime stress and wear is yet unknown. In some cases, stress leads to forms of wear that are difficult or impossible to detect. In the setting of industrial disassembly, however, impossibility can be a question of required detection effort.

4 Feedback of design relevant information from disassembly processes

Apparently, disassembly processes are a source of a variety of information that can be classified as *process*- or *product*-related. Process-related information includes e.g. disassembly quantities, times and problems whereas product-related information refers to the condition (i.e. age, wear, degree of fouling, etc.) of parts, components and products.

While the retrieval of this information can be relatively problematic itself, it is far from sufficient. It needs to be interpreted and documented to eventually be turned into design knowledge. Just about the most important step, however, is to decide what information is relevant for either the design of a specific product or product design in general.

Obviously, the most competent group of persons to define this relevance are the design engineers. Their role is currently rather passive, though. Mostly receivers of disassembly related design knowledge, their means of contributing to it are quite limited (e.g. to the aforementioned workshops).

Consequently, the proactive integration of designers is a key element in any process that effectively communicates design relevant information between disassembly and product design. This approach could comprehend the following steps:

4.1 Step one: Definition

At any (preferably early) point within the product development process, the designer identifies a part or assembly and defines which piece of (process- or product-) related information shall later be retrieved from it. This “provoked feedback” is later supposed to give answers to questions that are raised during development and cannot adequately be answered due to insufficient information. Those questions could address the choice of materials, dimension of parts or whether disassembly-oriented design guidelines were applied successfully.

4.2 Step two: Retrieval

For a specified period of time or quantity of products, the requested pieces of information are collected. While some information (e.g. disassembly time) can be gathered quite easily, the assessment of certain product conditions can prove to be difficult, as has been discussed above.

A very useful development for collecting data during the use of a product is the so-called "Life Cycle Unit", an electronic system for acquiring life cycle relevant sensor data developed at Sfb 281 [6]. Currently, a prototype LCU-fitted washing machine collects sensor data such as carbon brush length, heating rod temperature, solenoid valve switching cycles, drum rotations, operating time, etc. Processing this data while the product is still in use, can give feedback for service and maintenance and useful information about actual use to the designers. Furthermore, processing of the collected data during use helps identify changes in parameter values, such as increased vibrations, which may indicate forthcoming failure.

Processing this data during disassembly makes it possible to quickly and individually assess the wear of the involved parts, to decide if these can be reused or to determine the necessary amount of reprocessing.

4.3 Step three: Application

Once the information is collected and possibly statistically analysed, it has to be evaluated, re-connecting it with the underlying design question. This also includes conventional feedback – answers without questions, in a sense.

In order to understand the fundamental difficulty of applying the feedback, it is necessary to take a closer look at the nature of the products that are disassembled. Regardless of the type of the product there are three categories: out of production, currently in production and prototypes. Figure 3 shows how the life cycles of these product categories overlap and how design changes resulting from the inspection of products belonging to these categories can be implemented.

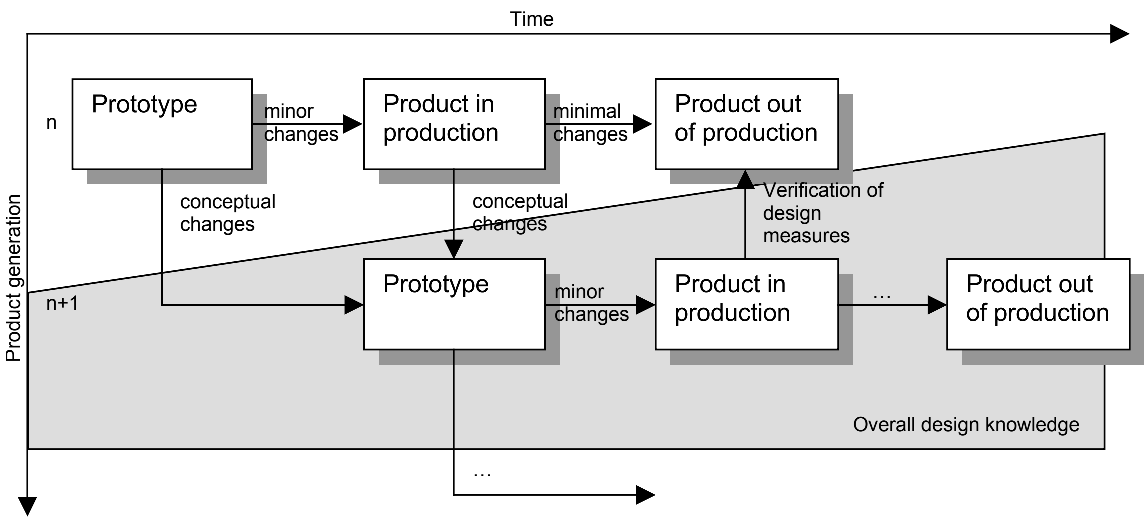

Figure 3. Overlapping product life cycles and possible design influences

Testing the disassembly of a product is only possible at a stage of product development where the product has already gained physical shape – in form of a prototype. Information that indicates the need of major design changes is therefore difficult yet not impossible to implement. Changes that cannot be implemented in the current product need to be documented and considered for follow-up products.

Disassembling products that are currently in production implicates that information which points at design changes is even harder to apply than with prototype products. Only changes with little interference with current production processes can be realized. An example would be choosing different bought-in parts or adding material identifiers to plastic parts when the corresponding die needs to be reworked. As with products at prototype stage, documentation of unimplementable changes is vital.

Outdated products serve as the evaluation base against which current and prototype products are measured. Their identified weak points are an important driver for design changes. Furthermore, the effect of design changes that could not be implemented at the time of production but were considered in the development of the prototype of a follow-up product can be verified.

In some cases, it is not immediately possible to incorporate fed back information into the development of a specific product. This might occur with unsolicited feedback or with information retrieved from products of a type, currently not being developed. In this circumstance, it is important not to discard this information, but to embrace it for the sake of increasing overall design knowledge.

5 Conclusion and Outlook

The systematic, development-driven feedback of design relevant information from industrial disassembly can be a method of continuous product optimisation if the long-term character of this process is recognized.

The *temporal distance* between the development and the disassembly of a product can be several decades – a period of time after which the developing company might not exist anymore. This, of course, cannot be prevented by feeding back design relevant information either. Although obviously more practical for products with a comparatively short life-span, this approach can as well be useful for long-lived products, considering that disassembly is not necessarily an end-of-life option but also part of, for example, maintenance.

In the current situation, the *organisational distance* could be shortened by assigning the designers a more active role in the retrieval of information from disassembly. If it is them who decide what information they require, recyclers could be relieved from this task, avoiding the “design for x dilemma”. Closing the organisational gap, however, would require even closer co-operation of external recyclers and manufacturers. Ideally, manufacturers should take the disassembly of their products into their own hands, which would be compliant with the emerging concept of Product Service Systems (PSS) [9].

To solve the problem of *geographical distance* between disassembly and development processes, it is, needless to say, still not necessary to return the used products to their source, since it is information that has to be exchanged. For that purpose, IT-based tools need to be developed where existing ones – e.g. product data management (PDM) systems – cannot be adapted.

Still open to consideration, the approach discussed in this paper is in any case meant to supplement, not replace current practices.

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