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IMPLEMENTATION OF DESIGN FOR ENVIRONMENT PRINCIPLES AND METHODS IN A COMPANY - PRACTICAL RECOMMENDATIONS

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ABSTRACT
This paper presents findings from a transfer project aiming to implement methods and tools of Design for Environment (DfE) in the business practice of Alfred Kärcher GmbH, a manufacturer of cleaning equipment. During the course of the project, different approaches and methods have been tested. The spectrum ranges from easy-to-use tools like checklists to complex methods, two of which are compared in this paper in order to illustrate the properties, which decide on the implementation success in this case. These two are the UTeMa-matrix, developed specially for use in the Kärcher design process and a variant of the Eco-QFD, which has been adapted to the boundary conditions posed by the existing Kärcher QFD. Both methods are intended to gather environmental requirements to products and insert them into the development process. The results of the comparison are interpreted and general recommendations are given.

Keywords: Life Cycle Design, Ecodesign, implementation, application, case study

1 INTRODUCTION
DfE aims at reducing the environmental impacts associated with products. In theory, this encompasses all the processes which occur during the lifetime of the product, starting with the extraction of raw materials needed for parts of the product and ending with the final disposal in landfills or through incineration. In between, a huge number of processes take place even with the simplest of products, from refining the materials to production of parts, assembly, packaging, distribution, use by the customer, possibly recycling, etc. [1]
In practice, the goal is in finding those processes with the highest contribution to the overall impact or, corresponding, those with the highest potential for improvement. These impacts are then to be reduced by applying design measures in such a way, that an improvement does not lead to an increase in impacts at another point of the life cycle, which outweighs the benefits of the improvement.

Design for Environment faces a number of obstacles in industry practice. Among the issues, any implementation of DfE principles and methods in a company has to address, are:

- Awareness of the environmental relevance of products, individual product features and processes among the participants in the design process
- Expertise in DfE-relevant areas present in the company – Some authors identify the lack of previous experience and know-how as one of the main barriers to DfE implementation. [2]
- Organisational structures for communicating relevant information
- Allocation of responsibility for initiating environmentally motivated activities

At Darmstadt University of Technology (TUD) the possibilities and limitations of applying DfE principles in an industry environment are explored in the project "Implementation of Life Cycle Design in Industrial Product Development". The project is carried out in collaboration with Alfred Kärcher GmbH & Co. KG and is planned to take three years to complete. Kärcher is a leading manufacturer of cleaning equipment for the business and consumer market and produces e.g. pressure cleaners, vacuum cleaners and car-wash facilities.

During the last decades, a lot of research into environmental matters in connection with industrial products, production and product development has been performed. It has generated a large number concepts intended to help practitioners in science and industry handle environmental aspects. Although not necessarily life cycle oriented, they may be drawn on to formulate a DfE strategy for a company. Among those are:

- Guidelines for company-wide strategies, e.g. “Integrated Product Policy (IPP)” [3]
- Proposals for Environmental management systems, e.g. according to ISO 14001 [4]
- Methods for collecting information about the environmental impacts of a product and the processes occurring during it’s lifetime, e.g. Life Cycle Assessment according to ISO 14040 [5] and various abbreviated assessment methods (EcoIndicator [6], KEA[7])
- Numerous individual methods and tools for addressing various environment-related tasks in product development, e.g. Eco-QFD for reconciling consumer and environmental requirements (see Chapter 4.4).

[8] presents a survey of the research field of DfE (or “green product development”), partly with regard to the last point. The shortcomings of the state (in 2002) of DfE research and method development are highlighted. According to this article, one of the problems is in the lack of linkage between strategic intent and actual product related content of the process, resulting in a gap between “top-down approaches to environmental issues (with policies, etc) and bottom-up approaches (daily activities)” ([8], p.421). In addition to the company perspective, demands are placed on DfE methods and tools by those, who are supposed to use them: the engineering designers. [9] elaborates on the designers perspective on DfE method use, stating that methods and tools are employed because they facilitate communication, provide structure and serve as knowledge and experience repositories.

This paper aims to illustrate, how these factors have influenced the DfE implementation in the case of Kärcher GmbH.

2 GOALS

2.1 project goals

The project aims for a lasting implementation of environmental concerns in Kärchers product design process. This includes making changes to organisational or informational procedures, empowering the company to deal with environmental requirements to its products presently as well as in the future.

The main goal from the research perspective is in applying and validating the methods and tools developed in CRC 392 [1], refining and improving them if necessary and determining an operational procedure for incorporating them as seamlessly as possible into ongoing processes of the company. Specifically, the following questions are posed:

- Where can a company wide-implementation of Design for Environment start?
- What is a realistic procedure for building up DfE know-how and competences in the company?
- How can suitable tools and methods be determined, given a certain company situation?

The goals of Kärcher in employing DfE are:

- Satisfying customer demands in connection with the environmental properties of the product
- Keeping track of, and reacting to, environmental requirements posed by legislation
- Gaining an overview of design options and technological possibilities

The main criterion for success of the measures taken during the course of the project is acceptance by the persons in charge of the respective company functions.

2.2 project outline

In order to make the best use of the time, the project was organized in two parallel strands. After the obligatory phase of task clarification (examining Kärcher’s design process and the boundary conditions, negotiating the timetable, etc), pragmatic approaches for addressing individual problems are applied in parallel with measures aiming at the long-term organisational inclusion of environmental aspects into the company procedures.

Under the heading of “pragmatic approaches”, all activities are subsumed, which target individual activities or participants of the design process. This entails determining and addressing immediate needs for support and background information, e.g. through interviews, presentations and easy-to-use tools

As a test bed for these pragmatic approaches, a current development project has been designated. Although the project is a redesign of an existing product, the scope includes possible changes to major subsystems and not only a mere facelift. The product is a hot water pressure cleaner for industrial application. The machine produces its pressure with an electric motor. It has a heating boiler that uses oil for fuel.

The “organisational” efforts constitute a top-down approach, starting at the management level and carrying environmental requirements through to the operational level.

3 DFE IMPLEMENTATION WITH KÄRCHER

3.1 Company Situation and Boundary Conditions

As a manufacturer supplying to both business and private customers, Kärcher has a large product portfolio, ranging from household cleaning devices like hand-held steam cleaners to stationary cleaning facilities for trucks and trains. Consequently, the tasks in product development have an equally large span in terms of expenditure of time and money and a mix of minor facelift processes for established products and innovation processes for new products.

Environmental requirements differ between business and private customers. Business customers are predominately concerned with fulfilling environmental regulations that apply to their line of business. The demands of private customers are mostly related to the fact that Kärcher offers premium products. For Kärcher, this means that the expectations concerning overall quality of the products are high and this includes an implicit expectation that the products are environmentally sound.

In order to determine the boundary conditions for the project, a thorough analysis of Kärchers development processes has been carried out. The analysis was conducted in a series of structured interviews with members of the departments involved in product development. Special attention was paid on finding out the real sequence of events and activities, as opposed to the formalized process set out in the company guidelines. The process analysis and its interpretation for the purposes of conceptualization of the implementation approach have been described in detail in [10].

To subsume the results of the analysis, Kärcher employs a standard stage-gate process. Characteristically, between fixing the product specification sheet and the requirements list, a concept phase serves to evaluate design options. In this phase, different solution principles are investigated. Only after this step are the final requirements defined. By this time, the product in its performance characteristics and general appearance is all but completed.

As a result of the process analysis, several areas of interest were defined:

- Strategic product planning
- Generating and evaluating new product ideas
- Product definition
- Requirement specification
- Aesthetic Design
- Embodiment and detail design
- Project completion

The activities in these areas can broadly be divided into strategic (“What to do?”) and operational (“How to do it?”) parts. The distinction however is not as marked as the first item on the list suggests.

In identifying the design activities, information concerning the responsibilities of the participants was collected as well. While the initiative for a new design process lies with the manager of the product line and is basically driven by market needs, the product development department is brought into the process immediately. Therefore, the lead designer, as part of the product strategy planning team, has influence on the general direction the product is supposed to take.

In terms of tools used for EcoDesign purposes, Kärcher previously relied on a product checklist. It was handled by the lead developer in time for the Concept freeze milestone. The checklist contains determinations concerning both product strategic aspects (e.g. “best product on the market concerning emissions?”) as well as aspects relevant for detail design (e.g. “product must meet RoHS standards”).

3.2 Previous work

A short overview of the previous initiatives is provided here in order to depict the environment for DfE in the company.

3.2.1 Environmental guidelines

In cooperation with Kärchers management, a set of guidelines was formulated, defining the organisational and strategic goals in connection with the handling of environmental aspects. They are intended for internal use. Their purpose is to inform employees about the larger goals behind environmentally motivated changes to company procedures.
Among these guidelines are:

- Kärcher places great importance on the motivation and know-how of its employees with regard to environmentally sound design
- Kärcher is aware of the environmental impacts of its products
- The company aims for a continuous and verifiable of improvement of the environmental performance of its products

The guidelines help define focal points of the project and serve as a basis for evaluating the proposed measures.

3.2.2 Life Cycle Assessment

A full Life Cycle Assessment study of the pressure cleaner was prepared by the university researchers. The software “SimaPro” was used, as were the included databases for performing inventory analysis and impact assessment. The use phase of the pressure cleaner was considered in the form of two use scenarios. These represented the extremes concerning the intensity of use. In one scenario, use in an agricultural business was assumed, with a short overall operating time in the course of the product life. The second scenario was concerned with use in a commercial car wash facility, where the pressure cleaner is very intensely used, leading to a total running time of several thousand hours.
The major contributors to the overall environmental impact are:

- Energy usage of the motor
- Material usage of the motor (copper and aluminium)
- Fuel use of the boiler
- Emissions of the boiler
- Material usage of the high pressure pump (brass)

These results were discussed with the environmental department and designers. One aim was to provoke a discussion about how best to address these environmental impacts. Thus, the need for support in dealing with environmental requirements was established. Interestingly, introducing the results already prompted questions from designers about tools, which might be applied in order to tackle the impacts. Some small tools (a materials checklist, a spreadsheet for comparing cost, weight, and energy usage of electric motors) where provided by TUD researchers.

4 TWO METHODS FOR DFE REQUIREMENT GATHERING

4.1 UTeMa – product strategy for environmental improvements

On the cross-project level, a means for information gathering, storage and decision support was devised. The so-called “UTeMa- (Umwelt-Technik-Markt = Environment-Technology-Market)” Matrix was established to quickly and inexpensively gather the information and opinions of the decision makers responsible for the product strategy. It has been presented in [11] in detail and is therefore reiterated here only briefly. The structure of the matrix is depicted in Figure 1.
It serves two distinct purposes:

- Gathering current information needed to decide on an environmental product strategy for a forthcoming design project
- Preserving information about the reasoning behind the environmental product strategy for future redesign processes of the product, thus illustrating focal points and changes in product policy over a longer timespan and increasing awareness of the need for continuous improvement

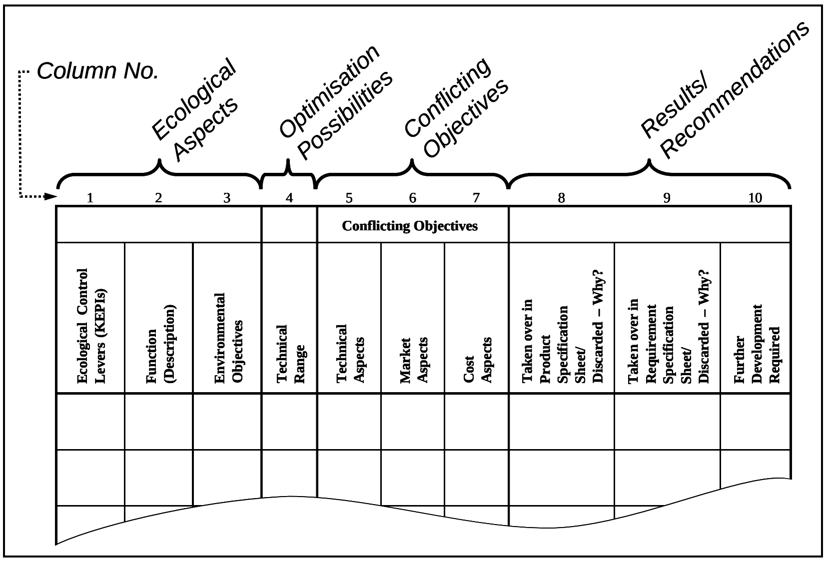

Figure 1: UTeMa matrix [11]

4.1.1 Preparations

In preparation of the application, the dominant environmental impacts ("environmental levers") are collected. This is the responsibility of the environmental department. Due to the lack of experience in conducting environmental assessments, determining environmental impacts for development projects is handled by the researchers at TUD at the moment. The definitive mechanism for gathering environmental impacts is still being developed, but the aim is to avoid having to perform a full LCA in every instance. In case of the pilot project, the results of the LCA study for the pressure cleaner were directly entered into UTeMa. A functional description of the part or subsystem in question is given along with the aim of an improvement (Figure 1, column 1-3). To give an example: if the environmental lever is "energy consumption of the electric motor", the description is "providing mechanical energy for the pressure pump" and the optimization goal would be "as low as possible".

4.1.2 Application within the design process

The matrix is applied first in the preparation of the product strategy planning. The matrix, with environmental levers filled in, is handed on to a number of participants in the strategic product planning in sequence. These are:

- Members of the design department – Designers are asked to give their assessment of the improvement potentials available by utilizing existing technology (figure 1, column 4). In the case of the electric motor, useful information could be: "the best available motor has an efficiency of X%". In column 5, the conflicts of technical objectives with the environmental objective are listed. (e.g.: environmental objective= low energy consumption; technical objective= high power output; higher efficiency= higher weight, more space needed, more copper used) Furthermore, an estimate of the production costs of possible alternatives is given (column 7).
- The marketing department contributes it's assessment of the market potentials of these improvements in terms of marketability of the resulting product features and an estimation of the willingness of consumers accept higher retail prices. Relevant information is entered in column 6 and could be for example: "a competitor advertises a comparable machine with an energy efficiency of X", or "energy consumption is (not) relevant in the market at this time".

Each participant is asked to contribute a rough assessment of the potentials and risks in targeting the environmental levers in product development.

The last three columns are addressed in a joint meeting of the product strategic planning team. In addition to the contributors involved so far, the category manager responsible for the product line is present, as are members of other departments. In a discussion, the different aspects are weighed and the decision is made, whether to postpone the improvement of the environmental lever until a future product development, to address the environmental lever in the current development process, or to

refer the matter to technology development, if it is seen as beneficial to gain broader competences in developing and manufacturing the respective subsystem in the future.
In case the environmental lever is addressed in the current development process, the goals to be set in the product requirements specification are then agreed on.

UTeMa is revisited at the end of the design process, after the serial production has been initiated. At this point, the results of the activities concerning the environmental levers are collected and evaluated. Furthermore, experiences from the design process which may be of value in future projects are documented and attached to the matrix. Thus, the main aim of supporting the continuous improvement of products is pursued. In the future, the environmental department will be responsible for collecting those matrices, extracting the relevant information and making it available for design processes.

4.1.3 Evaluation

UTeMa has been applied to the pilot project in workshops with members of the design, marketing and environmental departments. The pilot project was already to far advanced at the time of application, so the results are theoretical in nature. It has to be added, that the full potential of the matrix as a repository for experiences and information about product related environmental concerns may only become apparent after a number of design processes have been carried out.
So far, the following observations can be made:

- The discussions were brief and focused on the environmental levers at hand.
- All participants were able to make contributions on the level of detail required. Although the information was not always accurate, this suggests that the amount of work needed for data collection beforehand can be kept relatively low.
- During discussions, some relevant information was exchanged, which was already known to individual participants, but not put into an environmental context before.

4.2 Eco-QFD

Quality function deployment (QFD) was assessed as one way for translating strategic goals (which environmental features to implement) into operative ones (how to weigh them against functional requirements and which parts/assemblies/systems to improve). QFD was made popular in Europe by Akao [12] and encompasses a whole methodology rather than an isolated method. Since many variants are known, different in scope and terminology, only a very rough outline can be given here. The focus is on the central correlation table or “House of Quality (HoQ)”, the main tool for connecting quality properties of the product with product features, properties and engineering metrics.

4.2.1 Kärcher QFD

Kärcher already applies its own QFD variant. Characteristically, it resembles the design process as described above, in including a concept phase before mapping the customer requirements to the product features. The general layout of the QFD process is depicted in Figure 2.

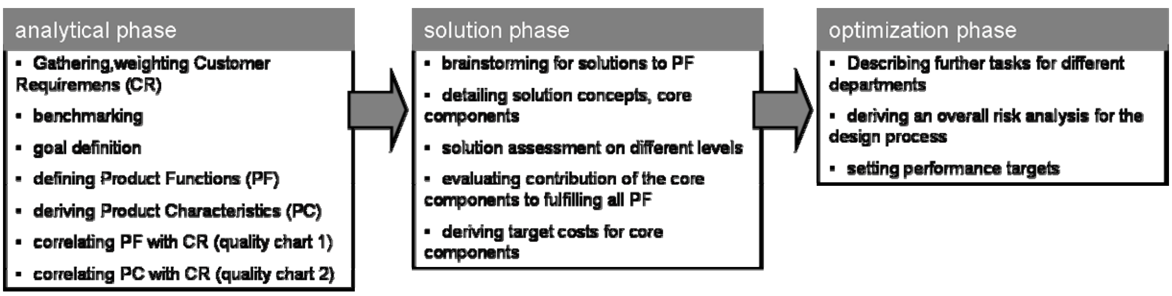

Figure 2: Kärcher QFD

Kärchers QFD is divided into three phases. In the initial analytical stage, customer requirements (CR) are translated into neutral product functions (PF, e.g. “easy handling”) and put into product characteristics (PC, e.g. “weight”, “size”). Both are correlated with the original customer requirements. In the case of product functions, the influence of fulfilling any one function on fulfilling the others is determined. In correlating product characteristics with customer requirements, the basis for defining target values for PC is established.

A creative phase follows, in which solutions for the functions are generated. The solutions for the basic product functions are combined to form several rough concepts. A rough concept is picked, consulting a number of different criteria. It is then detailed further. Again, different variants are produced and assessed. In the concepts, core components are described. These are now entered into the quality chart and correlated with the customer requirements. Target costs for the components are then determined. In this, the method follows the standard QFD procedure.
In the third phase, called "optimization phase" the results of the QFD are detailed. This includes e.g. deriving to-do-lists for the different departments, and providing an overall assessment of the outcome for management.
It has to be added, that the QFD is not a part of the standard design process. It is used infrequently, if the circumstances in the project suggest it. Whether or not to employ QFD is decided during the planning of the project.

4.2.2 Eco-QFD

A number of environmentally oriented QFD variants (Eco-QFDs for short) have been reviewed. Among these were the "QFD for Environment (QFDE)" according to Masui et al [13], "Green QFD" according to Zhang et al [14] (originally developed by Christofari et al [15]), and "Life Cycle QFD (LCQFD)" according to Ernzer [16] (a result of the CRC 392). The main distinguishing feature is where the additional information is located, whether as an addition to the vector of customer requirements or in additional correlation tables (Figure 3).

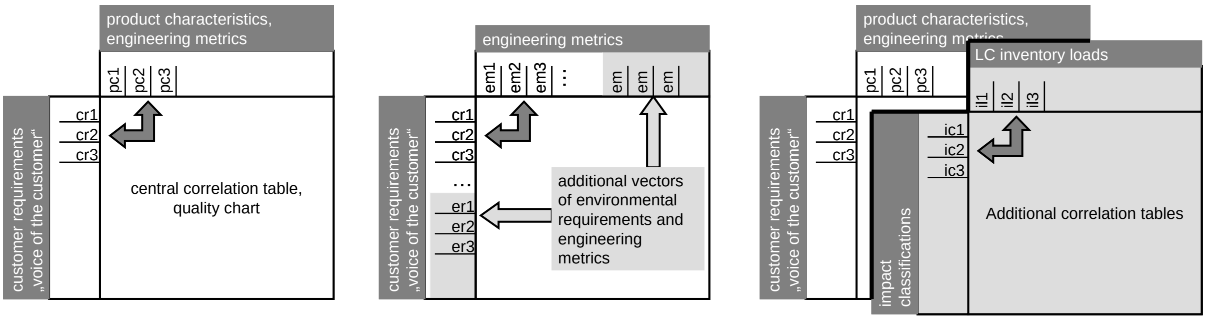

Figure 3: Eco-QFD – principal distinguishing features

QFDE extends the quality chart by appending a "voice of the environment" to the vector of customer requirements or "voice of the customer". Also, additional engineering metrics are derived, representing the environmental characteristics of the product. These are later correlated with the product characteristics in a second correlation table. This allows comparing the scores for the importance of the product characteristics with and without considering environmental requirements. Moreover, a theoretically possible improvement rate can be calculated, which can be reached by improving either specific components or specific engineering metrics. Thereby, requirements for the redesign of the product are acquired.
Green QFD achieves the treatment of customer and environmental requirements not by enlarging the central correlation table, but by adding two more tables, the "Green House" and the "Cost House". The Green House deals exclusively with environmental requirements and takes the results of a LCA as input. The environmental loads of the life cycle phases are assessed and an expert opinion on whether they rate as high, middle or low (on a scale from 1 to 10) in the impact classes is given. The weighting is performed by environmental experts, as well as from the customer or public view and from a marketing angle. In the Cost House, life cycle costs are determined, corresponding to the life cycle impacts in the Green House. The next step is the concept phase. In the "Concept Comparison House", the aggregated values of different concepts in the three houses can be compared.
The EI2QFD resembles the Green QFD in that it adds an extra "House" for environmental requirements rather than appending them to the customer requirements vector. The House of Quality is applied in two steps, first rating product characteristics against customer requirements and then rating components against product characteristics. Instead of using LCA results provided by environmental experts, EI2QFD relies on an EcoIndicator rating of the product. The use phase is treated separately from the other life phases, resulting in the addition of an extra correlation table. This ensures that environmental impacts from the use phase can be assigned to product components through a

correlation with the product characteristics from the House of Quality. The method produces a portfolio diagram, rating environmental over customer requirements.

4.2.3 Adapting the Kärcher QFD

Both the Kärcher QFD and the various Eco-QFDs were divided into individual steps using the eMAP method ("elementary Method Activities in design Processes") [16]. eMAP describes methods in the form of a flow chart, detailing inputs, activities/tasks and outputs of each step (Figure 4). The emphasis in eMAP is on determining of elementary activities. A number of possible elementary activities are provided by Ernzer, e.g. "search", "complete", "combine", "sort", or "group". Since the QFDs contained a number of very similar activities between them, those were directly transferred to eMAP, without further separation into elementary activities. Such basic QFD activities were e.g. "correlating of X against Y" (where X and Y are the two input vectors of the quality charts, e.g. "customer requirements" against "product characteristics"), "benchmarking", or "deriving target components". Likewise, complex activities which were unchanged by the alterations were not divided further.

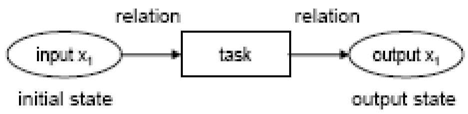

Figure 4: basic eMAP elements [16]

The additional activities from the different Eco-QFDs where then aligned with the existing Kärcher QFD. Figure 5 shows a small excerpt of the eMAP graph for the combined Kärcher-QFDE.

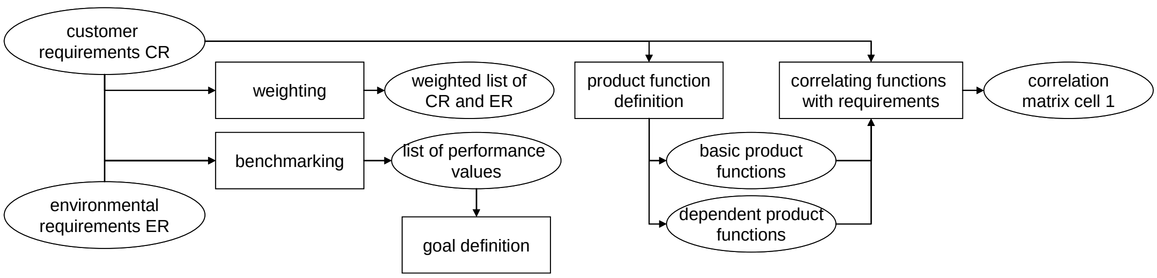

Figure 5: eMAP graph for QFDE (excerpt)

Furthermore, the amount of additional input in form of information or competences was evaluated, as well as the need for extra meetings and calculations.

4.2.4 Evaluation

The results were presented to those responsible at Kärcher. In discussion, it proved difficult to communicate the alterations made to the QFD, even to those intimately familiar with the original Kärcher QFD. Of the proposed variants, none was considered fit for implementation. Two basic arguments were made against the inclusion of environmental concerns into QFD:

- The amount of extra work was judged to be too high. Especially in those variants, which establish correlation matrices parallel to the House of Quality (Green QFD and EI2QFD), additional sessions would have been necessary.
- In the QFDE variant, it was doubted that a weighting of customer requirements against environmental requirements was at all possible. The responsibility for the adequate consideration of environmental matters was thought to be misplaced with the QFD team, since few of the participants possess background knowledge or information.

Aside from these arguments, the technical difficulties were in part connected with the different scopes of the methods. In particular, the creative phase in Kärchers QFD prohibits the application of Eco-QFD variants which require a prior assessment of environmental impacts, such as the Green QFD. The reason is, that a number of alternative concepts are produced, all of which would have to be subjected to a LCA.

5 RESULTS, INTERPRETATION AND RECOMMENDATIONS

In the meantime, Kärchers design process has been revised (independently of the transfer project) and a part of the project results have been integrated. At crucial points in the process, environmentally motivated additions have been made.
Starting this year, UTeMa is a fixed part of every design process. It will be circulated by the environmental department and filled in by those concerned prior to the start of the design process (approx. two weeks in advance), so that category managers can consider the ecological levers and the respective design options in drafting the product specification sheet. The actual decisions, whether any of the major impacts given in UTeMa will be addressed in the forthcoming project is made by the product strategic planning team, in conjunction with other strategic product targets.
The UTeMa matrix will be revisited at the end of the development process. The experiences with the treatment of the targeted impacts will be noted and preserved for future design processes.
On the initiative of the environmental department, category managers will receive a briefing on current trends and developments in the area of product related environmental activities, from the legislative, political and societal perspective. These briefings are scheduled at irregular, roughly quarterly intervals. They provide background knowledge for the drafting of the product specification sheet, beyond the immediate deficiencies of the predecessor product

The comparison of the attempts to implement UTeMa and Eco-QFD are interpreted in the following way:
The mode of assessment differs greatly between the two methods. In the example of UTeMa, the participants are asked to provide an assessment of facts they handle in their daily activity. Precisely because they are not environmental judgements in the first place, the participants feel comfortable making them. In Eco-QFD the assessment of how product functions and core components influence the fulfilment or environmental requirements is one, for which no background experience exists.
In implementing UTeMa, the need for a scheme for reliably learning the levers influencing environmental performance of the product, including performing LCAs, was immediately recognized and accepted by the company, whereas the need for expending resources for performing assessments of hypothetical components, many of which will be eliminated further on in the design process, can not be reasoned easily.

In the case of Kärcher, the conclusion is that Eco-QFD only has a chance, if sufficient background knowledge in the various departments is acquired and organisationally rooted in the company.
The coaction of the strategic and pragmatic approaches has proved to be beneficial to communicating environmental requirements. Pointing out the LCA results and the company's environmental guidelines prompted the developers to raise the question about prioritising and handling the environmental requirements themselves. The tools mentioned in chapter 3.2.2 were provided on the demand of the developers. Hence, the tools were immediately accepted.
On the whole, however, the designers were more interested in receiving clear and achievable environmental goals out of the product strategic deliberations, than in new methods and tools.

From the observations made during the course of the project, the following recommendations are drawn:

- A strategic decision and commitment of the management to engage in Design for Environment is the precondition for any activity in this area. This concerns not only questions of which resources to commit during the design process, but also questions related directly to the product, e.g. how to weigh environmental performance against functional parameters.
- Information needs to be handled on a level of detail appropriate to the task at hand and, perhaps more importantly, in a form the recipient is accustomed to. Strategic decisions at the beginning of a design process are usually made based on rough assessments and opinions. This means that complexity needs to be reduced at the early stages for the benefit of decision makers.
- Methods need to be carefully assessed in terms of information requirements. The difficulty in getting hold of relevant product information for the purposes of e.g. performing a LCA study is not to be underestimated.
- A large part of the implementation is in getting people to understand the purpose of Life Cycle Design and, more important, how it applies to their work. Here, the top-down approach may be

applied, meaning that participants are confronted with the need to address a certain problem by an earlier decision on a "higher level". The benefit is that requirements towards methods and tools supporting the solving of this problem are formulated in a target oriented manner and the tools themselves are accepted readily.

- On the other hand, applying easy-to-use tools like checklists can be instrumental in building up know-how and experience.

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