

2 Case Study Vacuum Cleaner: From Vision to Reality

This chapter demonstrates the product development procedure for the environmental optimisation of a vacuum cleaner that has served as an example product and common reference for the CRC 392. It also presents the results obtained in various steps of product development work and the power of a methodical and holistic product development approach. The improvements reflect the results from different projects in the run time of the CRC 392.

The development process presented in this chapter was carried out according to the phases of VDI 2221 clarifying the task, conceptual design, embodiment design and detailed design (VDI 2221 1993). The goal of the process was to environmentally optimise a conventional vacuum cleaner with standard filter bags. The described process is just an excerpt and one possibility for a typical development process. The chapter is structured in such a way that the methods are briefly described first and references for further reading are given. Additionally, results for each method are given afterwards using the vacuum cleaner as an example. Most methods described in this chapter will be elaborated on in detail throughout the rest of the book.

2.1 Clarifying the Task

The goal of this phase is to clarify the product development task to such a degree that a requirements list can be drawn up. The requirements list defines and documents the characteristics of the product. Fig. 2.1 shows different information source for deriving the requirements list, which are described in the following sections.

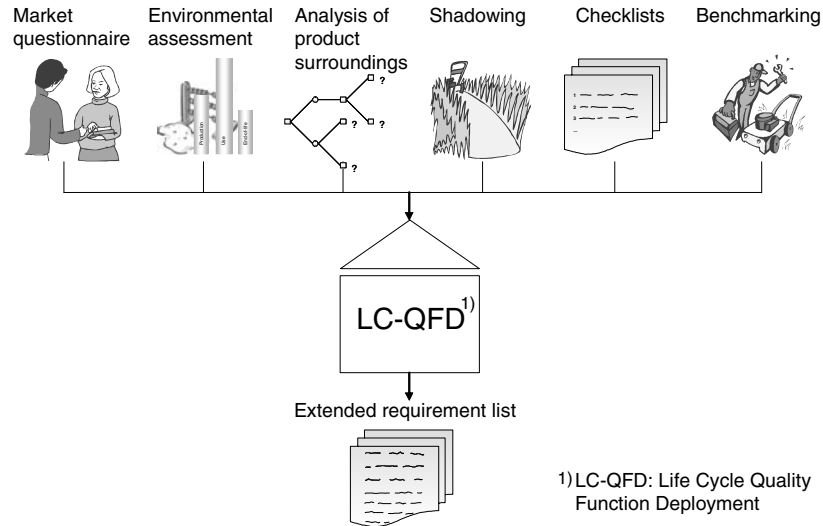


Fig. 2.1. Requirements gathered from different sources

Market Questionnaire

In the first step, a market questionnaire is carried out in order to determine what the customer wants and to get a feeling for the customers' concerns about and interest in the environmental impacts of the product.

Experience shows that the environmentally friendliness of a product itself is not a guarantee for its success on the market. Therefore, knowledge about the customer, especially in anonymous customer markets, is very important in developing an environmentally friendly and marketable product (Wiese et al. 2001, see also chapter 5.2).

Questions concerning the environment must be handled with special care since, in most cases, the politically correct answer, and not the real opinion, is given. This problem is increased by the customer's lack of knowledge about environmental impacts. They are not able to assess products' effects and impacts. Therefore, it is important to scrutinise the customers' answers using different interviewing methods and to acquire the real environmental impacts from environmental assessment or expert knowledge.

Fig. 2.2 shows that the rated power is the most important buying factor, followed by the price and the handling of the vacuum cleaner.

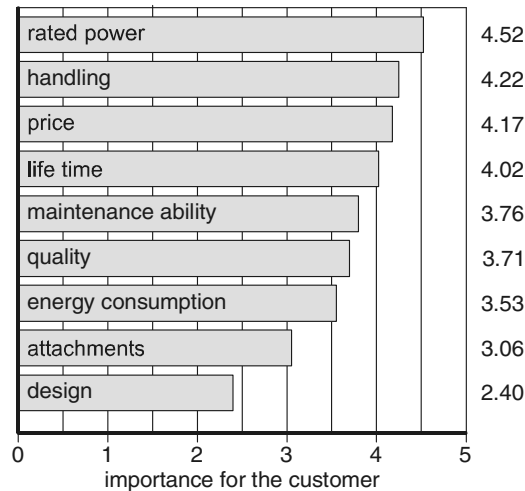


Fig. 2.2. Example results of the market analyses: decision factors of the purchase

Environmental Assessment

After ascertaining what the customer wants, it is important to assess which impacts the product has on the environment (chapter 4). For this, three basic method types exist: life cycle assessment (LCA), abridged assessment methods and assessment checklists. The methods vary in the accuracy of the results and the effort required for their execution. LCA is the most accurate method, abridged assessment methods are less accurate and time-consuming, and checklists simply give a rough overview of the environmental impacts of a product.

Life Cycle Assessment. LCA is an accurate assessment method, but is often neglected as it requires too much effort to carry out during the product development. Nevertheless, it is advisable to carry out a LCA for verifying new product concepts, especially if they are not comparable with previous LCAs, for materials whose environmental impacts are not well-known, and for establishing company-specific checklists or guidelines. Since an LCA is under normal circumstances too complex and time-consuming for a company to carry out, cooperation with research institutes or universities is helpful.

Abridged Assessment Methods. More suitable methods for environmentally friendly development are the abridged assessment methods such as Eco-indicator 99 (Goedkoop et al. 2000) or Meta-Method (see section

4.3.2). For these methods, a specific factor is multiplied by a material weight or energy consumption in order to calculate the environmental impact. Despite some criticism from a pure-science point of view, these methods are well-suited for identifying and prioritising a product's weak-points (Ernzer and Birkhofer 2003a). The advantage of these methods is that they do not require great expertise, time and investment. The main drawbacks include not being able to do a tracing-back and the lack of accuracy compared to a LCA following ISO 14040 (1997).

In the CRC 392 an abridged assessment with Eco-indicator 99 for a standard vacuum cleaner using filter bags was applied. The use phase with its electricity consumption was identified as the phase causing the most environmental impacts (Fig. 2.3).

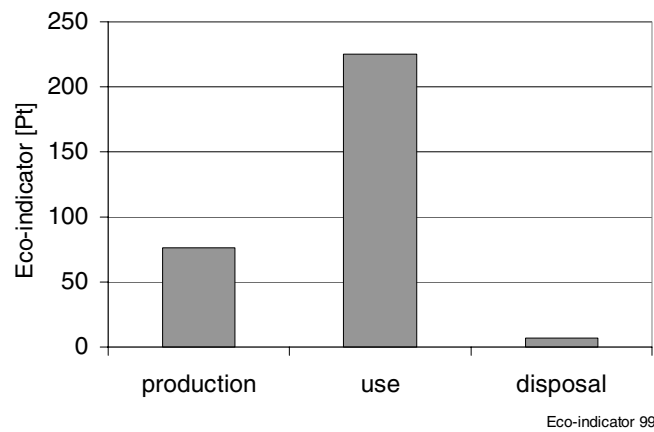


Fig. 2.3. Environmental impacts of a vacuum cleaner with filter bags

Assessment Checklists. The least accurate yet fastest method of environmental assessment are checklists. Examples of such checklists are the MET-Matrix (Material, Emissions, Toxic substances) (Brezet and van Hemel 1997) and ECM (Ecodesign Checklist Method) (Wimmer 1999). In order to increase the efficiency of these checklists, it is possible to create company- or even product-specific checklists like the Kodak Guideline (Betz and Vogel 1996) or the Fast Five from Philips (Meinders 1997).

Analysis of Product Surroundings

One way to better understand the product system and to deduce requirements is to analyse the product's surroundings, the interaction with its neighbouring systems, such as other technical products, other people and their surrounding. The interactions are directed from the neighbouring sys-

- What are the neighbouring systems (products, people, surrounding)?
- Which interactions exist between the product and the neighbouring systems?

- The questions must be answered for the operational, stand by and off modes of the product.

Shadowing

[illegible]

The actual observed “real user behaviour” is defined as a superposition of optimal (desired) and erroneous (undesired) behaviour (section 3.3). It can be expressed as a statistical distribution between the two extreme values and the normal behaviour as the expected value (Dannheim et al. 1998).

The reasons for environmentally erroneous behaviour can be divided into a lack of knowledge about the use process, habitual, unconscious behaviour, and conscious wrong behaviour. The effects of such false use are usually higher environmental impacts, e.g., increased electricity consumption. The effort for carrying out empirical studies is in general high, but the results are very telling. Furthermore, it is possible that by observing only four to five people, up to 80% of process mistakes can be discovered (Virzi 1992).

Environmental impacts caused by erroneous behaviour of the user can be reduced through various strategies (Table 2.1).

Table 2.1. General development strategies for environmental use process optimisation (Dannheim 1997)

Type	Measure	Example
Direct measures	Moving the system's border in the product, use of environmentally friendly working principles	Automatic selection of power level
Indirect measures	Treatment of negative environmental impacts	HEPA Filter after the motor
Demonstrative measures	Feedback loops, instruction manuals, labeling	Indicator of current level of dirt on the carpet

HEPA Filter = High Efficiency Particulate Air Filter

Use tests (Fig. 2.5) showed that the vacuum cleaner was not turned off while moving furniture, plants, etc. This resulted in higher energy consumption during the use phase. The optimal behaviour would have been to move all hindering objects before starting to vacuum. Therefore, a function for turning off the vacuum cleaner or putting it on stand by while idle is a good opportunity for improving the environmental performance through a direct measure. This improvement option will not be followed up in this chapter, but will be implemented in improved prototype.



Fig. 2.5. Shadowing of users while vacuuming

Checklists

Besides the assessment checklists two general checklists for identifying environmental requirements on products have been developed in the CRC 392 (Fig. 2.6). The first checklist is a general checklist for the development of environmentally friendly products and covers all life stages of a product. The second checklist is a specific checklist for Design for Recycling (DfR) and consists, besides the checklist, of guidelines and rules. Both checklists are context-sensitive and allow the product developer to browse through the checklist to become inspired by the checkpoints. Using these checklists, various requirements for making the vacuum cleaner conform to the Directive on Waste Electrical and Electronic Equipment (WEEE 2002) were identified. These aspects will be realised in the improved prototype, and thus, are not covered in this chapter.

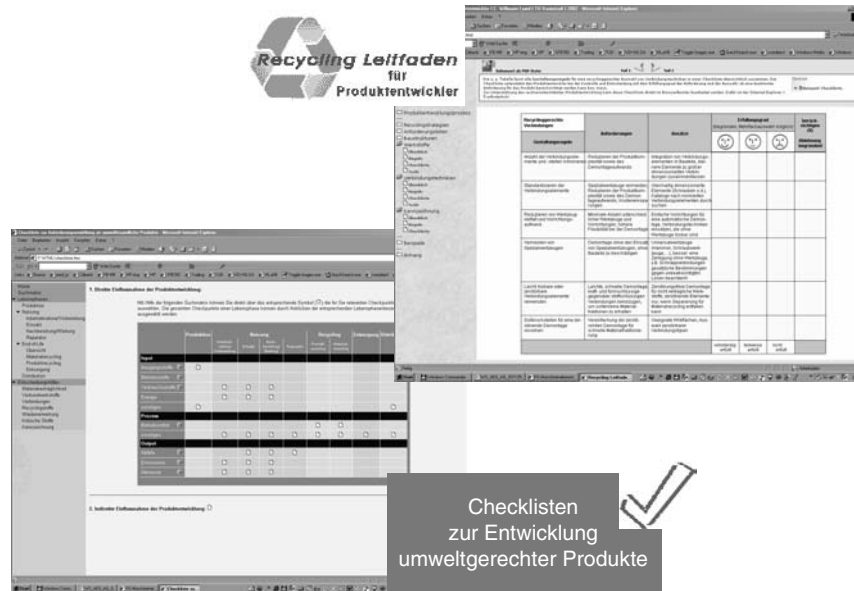


Fig. 2.6. Checklists for identifying environmental requirements on products

Benchmarking

Benchmarking consists of comparing competitors' products to determine how they achieve certain functions and why they use particular assemblies and parts. The overall goal of benchmarking is to combine the best practiced solutions for each sub-function in order to make an "optimal" product.

First, the overall product function must be compared. This includes an analysis of the electrical energy consumption (operational, stand by and off modes), as well as the consumption of other processes and auxiliary materials. Besides the overall function, the function of each assembly and part must be understood by simply disassembling and analysing the product. After analysing each product, the "cross-product comparison" begins to identify the best solution for each sub-function, evaluating the environmental, economic and technical performance. A good approach can be found in Eenhoorn and Stevels (2000).

In the following examples, the focus was on different filter systems and different cleaner heads. For comparing different filter systems a life cycle assessment using SimaPro 4.0¹ was carried out (Fig. 2.7).

¹ SimaPro 4.0 LCA software. PRé Consultants bv, Amersfoort, The Netherlands.

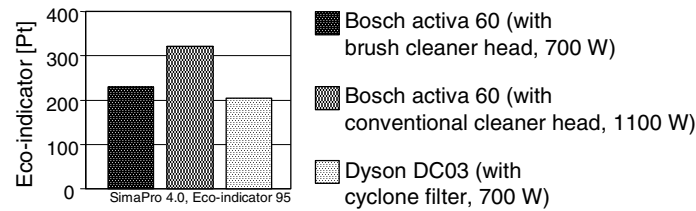


Fig. 2.7. LCA of different systems of vacuum cleaners

Besides this, an abridged assessment was carried out comparing a vacuum cleaner with a water filter (from the company L'Ecologico) and a conventional filter (from the company Bosch). Because of the high water consumption, particularly for cleaning the dust container, the environmental impacts of the water filter are generally much greater (Fig. 2.8).

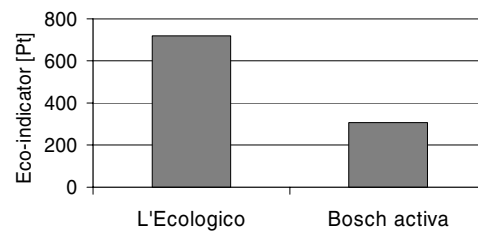


Fig. 2.8. Eco-indicator 99 of the use phase of vacuum cleaners with water filter (L'Ecologico) in comparison with paper filter (Bosch)

Furthermore, benchmarking for different cleaner heads was carried out. One was a conventional cleaner head and the other was a brush cleaner head. For the benchmarking a carpet with an area of 1 m² was covered with a specific mixture and amount of dust. The dirty carpet was then cleaned with one of the heads and the dust taken in was ascertained. This experiment was repeated 12 times. The result was that the brush cleaner head takes in more dust than a conventional cleaner head (Fig. 2.9).

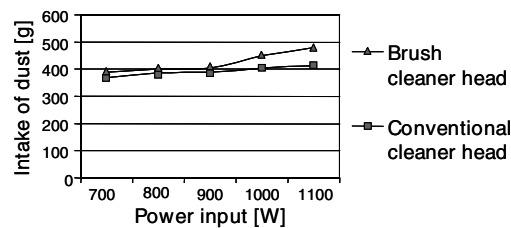


Fig. 2.9. Intake of dust through different cleaner heads

Life Cycle Quality Function Deployment (LC-QFD)

Insights to the product, environment and market must be transferred to the requirements list (section 5.4). This is supported by a Life Cycle Quality Function Deployment (LC-QFD), an extension of the conventional QFD (Akao 1990). At first glance, it seems unreasonable to carry out an LC-QFD since the customers' lack of knowledge concerning environmental impacts results in an uninformed Voice of the Customer (VoC). This argument against the LC-QFD is supported by the tendency of the customer to give the politically correct answer concerning environmental issues rather than his personal opinion (Wiese et al. 2001, see also section 5.2). But still the customers' opinion about the environment is important since he purchases the product; therefore his opinion must be considered within the customer specification. Furthermore, the environmental expertise must be revealed separately by an expert team or an environmental assessment. Since those customer specifications might be contrary to the environmental impacts it is important to reveal the contradiction using the interrelation matrix (section 5.4.3) in order to consider them during the next development steps (Dannheim 1999).

Looking at the LC-QFD of the vacuum cleaner identifies the ability to pick up dirt as the most important feature (Fig. 2.10). This is strongly related to the filling capacity of dust bags, filter efficiency, suction power and dust intake; therefore, it positively influences the environmental impacts as well as the customer specifications.

			product characteristics																							
			technical characteristics											visu. charact.	control / utilization											
						drive			dust bag			electr.		materials		housing	general handling				sucking action		maintenance			
						power	efficiency	lifetime	filling capacity	dust bag	filter efficiency	lifetime	indicates dust bag filling	motor control	brush accessibility	filter accessibility	cleaner head dimensions	flexible pipe	...	suction power	dissipated energy	dust intake	...	sum weighted
customer specifications	primary	secondary	tertiary																							
	handling	at transportation	...																							
		at vacuuming	...																							
	sucking power	picks up the dirt well	picks up a lot of dirt	3	3	9	9	3	3	3	3								3		9	3	9	9	92.4	
			high power	9	1	1					3											3	9	3		64.2
			indicator for changing dust bag		1	1	9	9	9																	52.1
			visible cleaning effects	1	3														3		3	1	3			19.3
			no unpleasant smell				3	3																		22.9
	environmentally oriented	at use	air filter			1	3																			13.6
			little noise	9			1															3	1			22.8
		little current	9	9								9				1	3				3	9	3		48.4	
design	shape/color	...																								
cost	at buy	cheap as possible	3	9	3	1	1	1	9	9							1				3	1	1		54.4	
	at maintenance	maintenance by user	1		3		1																		20.7	
		sum total weighted	66	37	54	30	40	38	47	53						19	12	29	26		60	44	73			

Fig. 2.10. LC-QFD of a vacuum cleaner (excerpt)

Definition of the Extended Requirements List

For the development of environmentally friendly products it is advisable to extend the conventional requirements list according to Pahl and Beitz (1996) by the functional unit (section 5.4.5). The functional unit is known from the goal definition of a LCA. According to ISO 14041 (1998), the functional unit defines the quantification of performance characteristics. The primary purpose of the functional unit is to provide a reference to which the input and output data are normalised (ISO 14041 1998). Fig. 2.11 shows that, besides the maximal capacity, the user scenario is integrated by which the product can be optimised. During the whole project the extended requirements list is continuously being specified and updated.

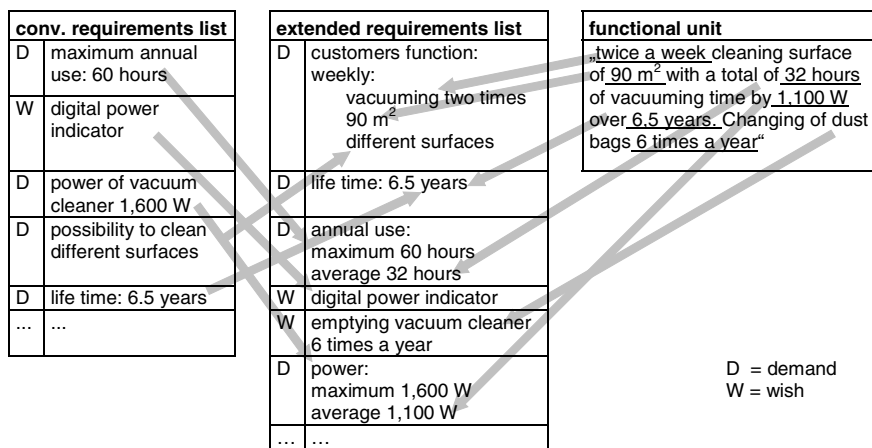


Fig. 2.11. Extended requirements list including the functional unit (excerpt)

2.2 Conceptual Design

In the conceptual design phase the focus is on three areas of improvement: the cleaner head, the filter system and the problem that the user cleans areas of the carpet too intensively. In order to fulfil the main customer specification “picks up dirt well” the brush cleaner head is systematically varied to improve the dust intake.

Furthermore, the Theory of Inventive Problem Solving (TRIZ²) is used to find a solution for the contradiction “good filter quality” and “low air resistant” of the filter system. The so-found solution is improved using the Environmental-FMEA from the Ford Motor Company (Schmidt 2001) and finally evaluated.

For finding a solution to the problem of vacuuming carpet areas too often, creativity techniques are used. The type, order and intensity of the methods used vary from problem to problem; thus the processes described below are just one possible example.

Improving the Cleaner Head Applying Systematic Design

Since only two different types of cleaner heads were found during the benchmarking, a more detailed solution field was systematically developed (section 5.5.2).

Morphological matrix

In the first step, the function of the cleaner head was divided into the following sub-functions:

- remove particles
- transport particles
- move on floor
- drive

For each of the sub-functions different solutions were sought using design catalogues, e.g. Roth (2000).

Once solutions are found, they can be structured in classification schemes to systematically add new solutions. The variants thus-found are combined into a complete solution using the morphological matrix (Zwicky 1948).

In Fig. 2.12 the sub-functions of the cleaner head are combined into one complete solution.

² TRIZ is a Russian method and the abbreviation for Teorija Rezhnija Izobertatel'skih Zadach

sub-functions	sub-solutions					
	1	2	3	4	5	6
remove particles	mechanics	pneumatics	adhesion	electro-statics	acoustics	physics
transport particles	airflow	conveyor belt	tribo-electricity	photo-phoreses		
move on floor	sliding surface	rolling body	armoured chains	air cushion		
drive	turbobrush	electr./network	electr./accu	mechanical	user	no drive

Fig. 2.12. Combining principal solutions using a morphological matrix

Systematic variation of the working principle of the brush cleaner head. With the knowledge from the morphological matrix, the brushes for the cleaner head must be optimised to better absorb the dust. Therefore, a systematic variation (Pahl and Beitz 1996) of the number of brushes, the type of motion, and the direction of motion were altered and 17 possible solutions found (Fig. 2.13).

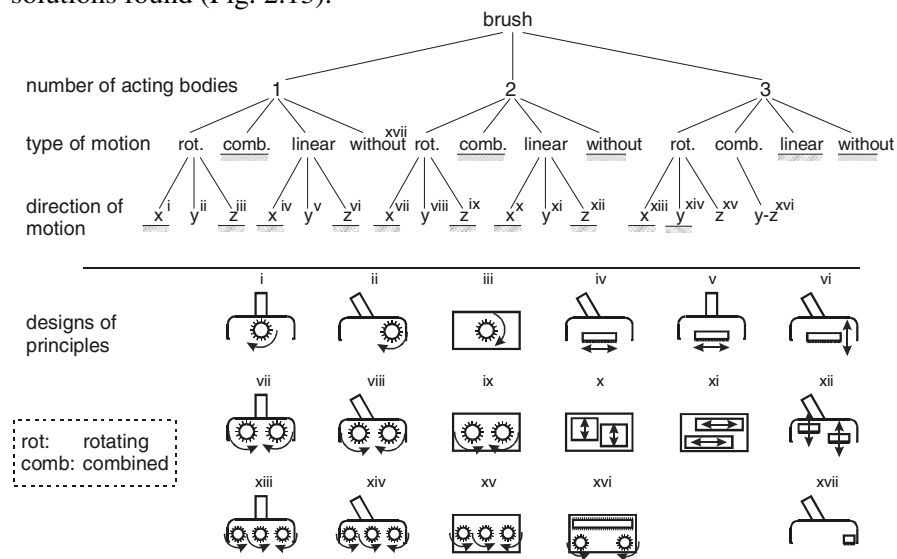


Fig. 2.13. Systematic variation of a cleaner head with brushes as a working surface

Evaluation. Finally, the various solutions for the cleaner head must be evaluated to select the best solution. This was done by a pair-wise comparison with the result that the standard cleaner head with one brush achieved the highest points due to its simplicity.

Conceptual Design of the Filter System

TRIZ methodology. TRIZ is especially suitable to solve contradictions revealed by the interrelation matrices of the LC-QFD (section 5.4.3) or by the functional analysis. These contradictions are solved by using one of 40 principles. These principles are arranged in a contradiction matrix and can be accessed via 39 engineering parameters (Altshuller 1999). This methodology is implemented in a computer tool called TechOptimizer by Invention Machine³. The tool consists of the following eight modules: product analysis, process analysis, effects, principles, prediction, feature transfer and internet assistant.

Functional Analysis Using the Product Analysis Module

From clarifying the task it was revealed that a main topic of improvement is the filter system. Therefore a functional analysis using the TRIZ formulation technique was carried out for this component. This formulation is easy to use since each part's function is clearly defined at the beginning. The TRIZ functional model distinguishes between useful and harmful actions which describe the interactions between the functions, objects or tools. Reducing the harmful actions decreases the environmental impacts without sacrificing the quality of the product. Furthermore, reducing the functional model to the minimal functional model first (focus on the main functions), and then adding the auxiliary functions as needed helps to minimise the environmental impacts. The costs and environmental impacts of each added (desired) function, as well as its technical feasibility and marketability, must be carefully screened. Other successful possibilities to vary the function model are shifting the system boundaries, adding or removing functions, changing the arrangement of functions, and reducing, simplifying or combining similar functions.

The example in Fig. 2.14 shows that the paper filter bag has the harmful effect "hinder air flow". The motor protection filter also hinders the air flow and is needed for protecting the motor from the dust, thus eliminating the smell of "burned" dust.

By reducing the harmful action ("hinder air flow") of the two filters, the energy consumption of the vacuum cleaner during the use phase is decreased and is, therefore, one goal of the product developer.

³ Invention Machine Corporation, TechOptimizer 3.5 Professional Edition. Boston, Massachusetts

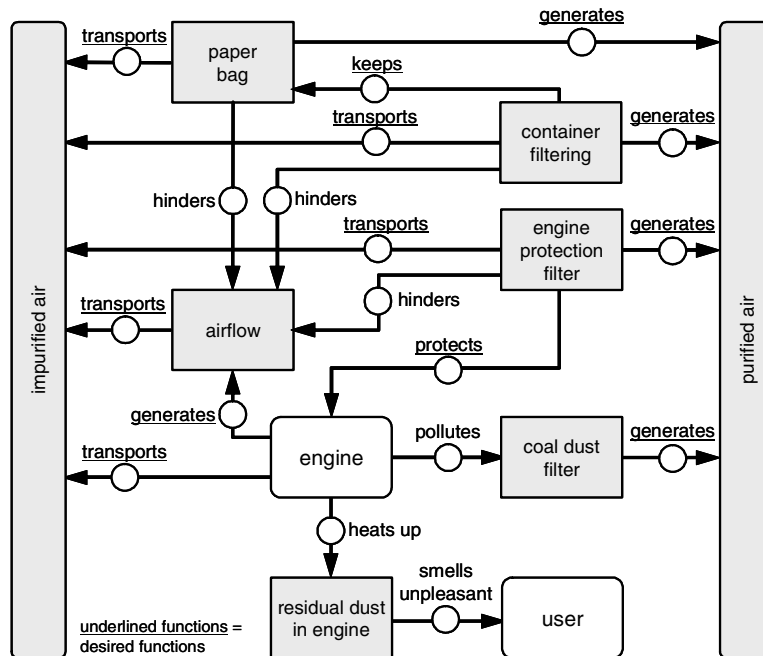


Fig. 2.14. Function model for the filter system of an existing vacuum cleaner (excerpt)

Solutions Using the Effects Module

In order to find a solution for the contradiction “good filter quality” and “low air resistance” of the filter system, the effects module of the Invention Machine was applied. The effects module consists of manifold effects based on an analysis of over 2.5 million patents. Each effect is illustrated by examples. Using this effects and examples database in a workshop, 28 solutions were created for filtering the air flow. One example of an idea was triggered by the example to “Principle 6 – Multifunctionality” (Fig. 2.15).

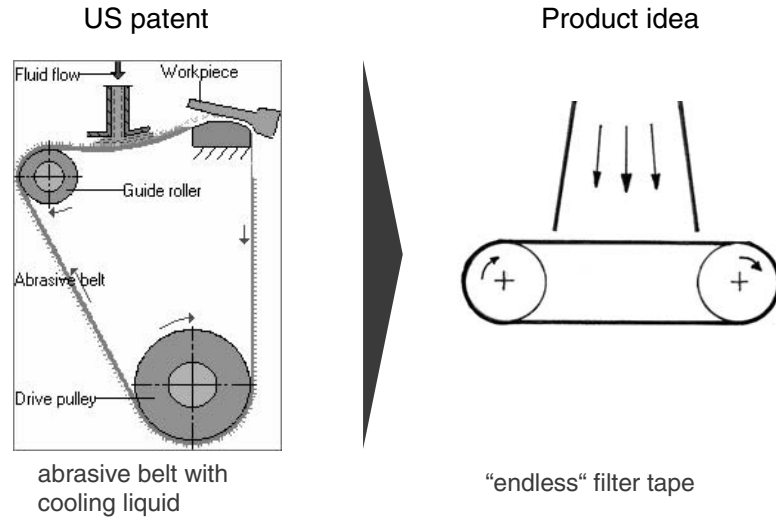


Fig. 2.15. Tensing an abrasive belt with cooling fluid (on the left side) led to the endless filter tape (on the right side)

The Environmental-FMEA and its Benefit for Improving Solutions.

With an Environmental-FMEA, a modification of the conventional FMEA (Failure Mode and Effects Analysis) (Stamatis 1995) with focus on environmental aspects, it was found that the problem with the above-described filter tape is that the tape is still in the air flow and its air resistance rises with the pollution degree. To minimise the air resistance of the filter tape, it is transported depending on its pollution degree. This is done by measuring the pressure difference in front and behind the filter tape with a difference pressure sensor.

The second problem was that the dirty part of the filter tape on the back-side hinders the air flow. Therefore, the design was improved and a filter box was developed (Fig. 2.16).

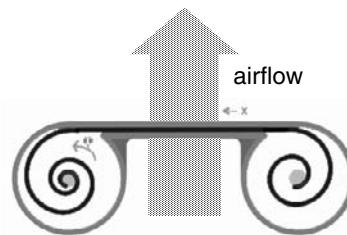


Fig. 2.16. Improved filter box after Environmental-FMEA

Technical, Environmental and Economic Evaluation. In order to evaluate product concepts, the evaluation criteria must be derived from the requirements list. It is important that the product is evaluated on environmental, technical and economical criteria to develop an overall improved product which is also marketable (section 5.5.3). Since not all criteria are equally important, the criteria must be weighted at the beginning. The results of the LC-QFD can serve as weighting factors. The evaluation process can be carried out according to VDI 2225 (1998). The results can then be illustrated in a polar diagram (Grüner 2001). Fig. 2.17 shows exemplary evaluation results for the loss of suction of different filter systems as a result of vacuum experiments.

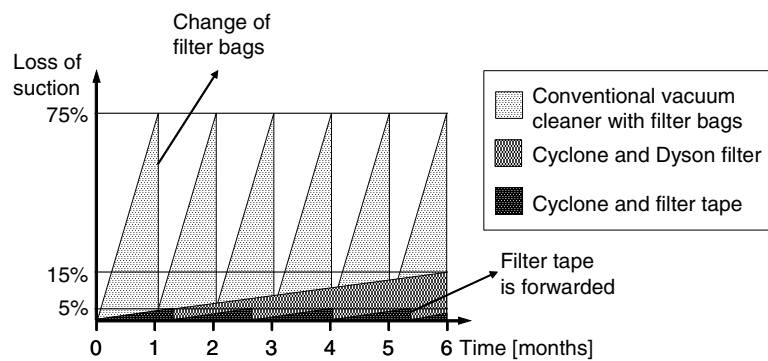


Fig. 2.17. Loss of suction of the developed filter system compared existing systems

Dust Sensor Found by Creativity Techniques in Conceptual Design

Creativity techniques, such as brainstorming or method 635 (Pahl and Beitz 1996), can be carried out in moderated team sessions to find new solutions for different functions. Brainstorming is used if the problem is neither specific nor strictly defined. The thus-found solutions are vague and not yet detailed. The method 635 supports the successive generation of ideas based on the ideas of other participants. It is used when more detailed solutions are sought and the problem is more clearly defined.

In the case of the vacuum cleaner a brainstorming session was carried out for the problem “cleaning carpet areas too intensive”. The solution found during brainstorming was to integrate a sensor in the suction pipe which measures the amount of dust going through the pipe to able to indicate the cleanness of the floor.

2.3 Embodiment and Detailed Design

The embodiment and detailed design phases are grouped together since the methods and tools used during these phases are interchangeable. Embodiment design leads from the principal solution to a definitive layout. Detailed design ends in the product documentation. For this detailing process, the design rules and guidelines, the creativity techniques, the morphological matrix, and the evaluation method described before are also helpful. For the vacuum cleaner, these two phases were roughly carried out in order to develop the prototype. Currently these phases are being carried out in detail together with industrial designer in order to put the finishing touches on the prototype.

The Role of Design Rules and Guidelines

Throughout the whole product development process, design rules and guidelines exist to guide the product developer. Different rules and guidelines are assigned to each strategy, which can be followed. A good set of measures, design rules and guidelines can be found in the computer-based ECODESIGN PILOT (Wimmer and Züst 2001).

Material Selection Tools

Material selection tools support the product developer in choosing materials with low environmental impact. The material selection is, besides the consumption of process and auxiliary materials in the use phase, the most influential factor for most environmental impacts (Atik 2001). Therefore, it is necessary to pay special attention to the material selection. One of the most comprehensive databases with material characteristics and environmental impact data is the IdeMat database⁴. A good addition to the IdeMat database is the Campus database, which has detailed information about the characteristics of plastics of different producers⁵.

Evaluation of User Behaviour

In order to develop a product feasibility study, a prototype must be built. Since new solutions are developed for the user (consumer) it is further advisable to carry out an evaluation of user behaviour (Sauer et al. 2001).

⁴ IdeMat, TU Delft, Design for Sustainability Program, Delft, The Netherlands

⁵ CAMPUS®, Computer Aided Material Preselection by Uniform Standards, CWFG mbH, Frankfurt/Main, 1991

The aim is to assess the user's acceptance of the new solution and the real user behaviour.

ecoDesign Workbench of CRC 392

A powerful tool for supporting product development during the detailed design is the ecoDesign Workbench of the CRC 392 (Fig. 2.18). The ecoDesign Workbench enables the product developer to carry out an environmental assessment during its detailed design phase in a CAD system. A first prototype was implemented and evaluated using an electric kettle. Based on this evaluation the prototype was improved and evaluated using an impeller fan of an electric heater (Felsing et al. 2004a). The results show that the ecoDesign Workbench is a suitable tool to efficiently and effectively support the product developer during this design phase.

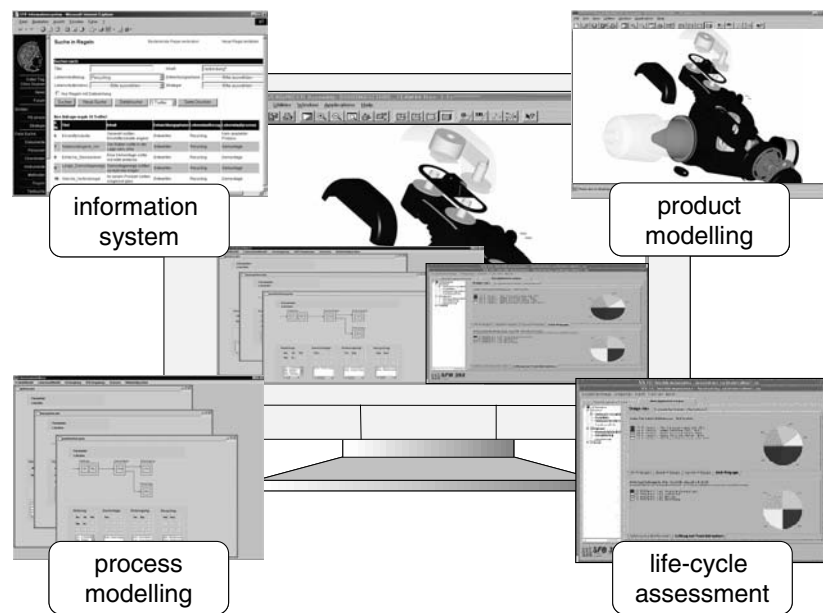


Fig. 2.18. ecoDesign Workbench of CRC 392

2.4 Result: The Vacuum Cleaner Prototype

As a first result of the product development process, the improved solution for the brush cleaner head, the filter system and the dust sensor in the suction pipe are described below in whole. At present, all improvements are realised in one prototype.

Brush Cleaner Head to Reduce Suction Losses by Enclosed Air Canals

In order to reduce suction losses in the cleaner head, enclosed air canals were integrated into the cleaner head Fig. 2.19. The drive for the rotating brush is located in the centre of the head. This improves the dust intake close to edges and corners. By this, the brushes can additionally easily be dismantled for cleaning or replacement. Furthermore, it should be emphasised that the transparent cover delights the user when vacuuming by visualising the cleaning process (Fig. 2.20). Besides this, the brushes are in a contra-directional double-helix arrangement to transport the dirt to the opening of the enclosed air canals (Fig. 2.21).



Fig. 2.19. Brush cleaner head with enclosed air canals



Fig. 2.20. Brush cleaner head with transparent cover

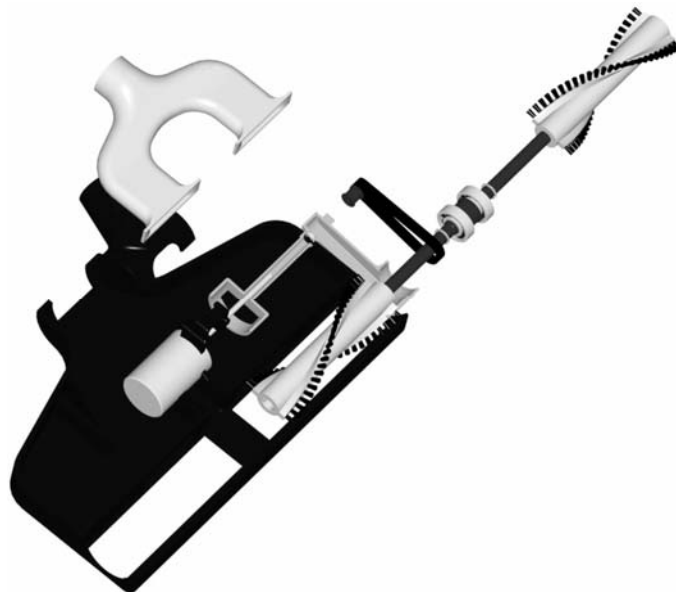


Fig. 2.21. Exploded view of the brush cleaner head showing the contra-directional double-helix arrangement of the brushes

Filter System to Minimise the Loss of Suction

One aim in determining the conceptual design was to minimise the loss of suction due to clogged dust bags and fine-mesh filters. This goal should be reached independently of the user's behaviour.

Therefore, as stated above, the best solution is to separate the coarse-grained dust with a cyclone filter. Its airflow resistance is nearly independent of the fill level. The separation of fine dust is achieved by a rolled-up filter tape. Just a little part of the filter tape is in the airflow (Fig. 2.22).

In the first step, a CAD prototype of the environmentally improved vacuum cleaner was developed (Fig. 2.23).

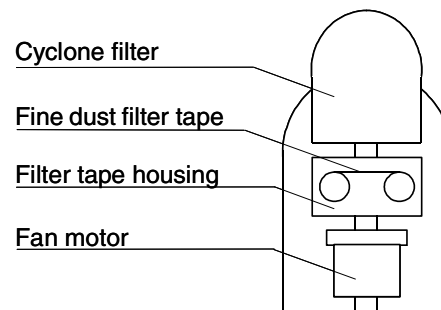


Fig. 2.22. Design concept to reduce the process conditional loss of suction power



Fig. 2.23. CAD prototype design of the vacuum cleaner

The identified design measures must be evaluated. Therefore, a function prototype has been built (Fig. 2.24). With this prototype, it is now possible

to test the functionality of the filter system. For this purpose, vacuum experiments were being carried out. It was found out that it is possible to integrate enough filter tape in the housing to make the tape lasts the whole life time of the vacuum cleaner. Thus, the customer does not need to change the tape and to spend money on new filter tapes.

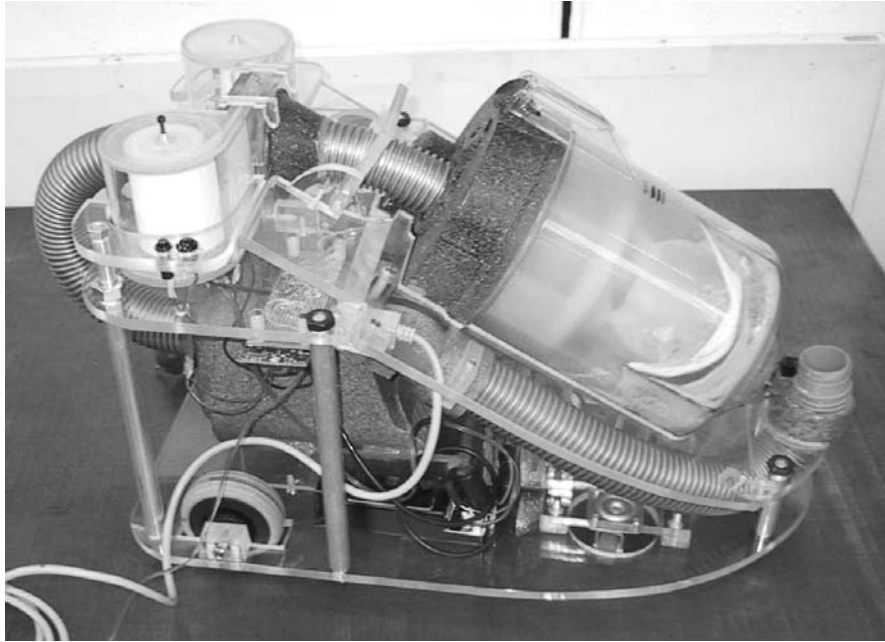


Fig. 2.24. Function prototype of the vacuum cleaner

The filter tape has been improved in such a way that a completely mechanical solution was found. This includes the measurement of the difference pressure before and after the tape and the forwarding of the tape (Fig. 2.25). The implementation of this improved filter tape will be carried out in an interdisciplinary team of product developers and industrial designers.

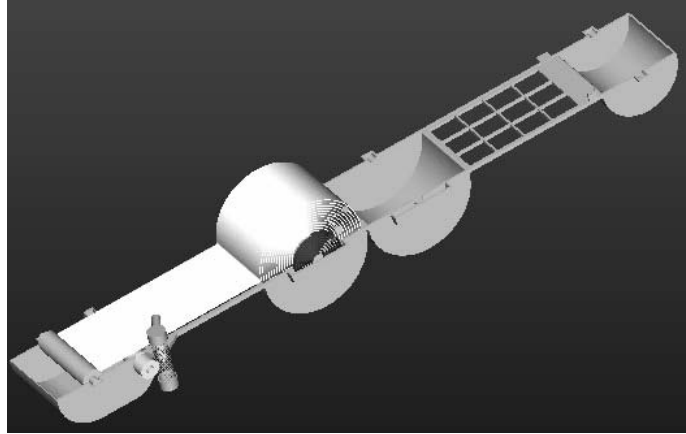


Fig. 2.25. Function prototype of the filter box

Dust Sensor to Support Users during Vacuuming

To support the user in vacuuming areas only once, a function to measure the cleanness of the floor is implemented (Weger et al. 2001). This function is based on an infrared particle sensor in the tube close to the cleaner head (Fig. 2.26).

This could support the user in saving energy due to the availability of accurate information about the cleanness of the floor. The function consists of a feedback device that informs the user of current cleanness levels. Based on this information, the user can rapidly and precisely identify dirty floor areas and respond immediately by moving forwards.

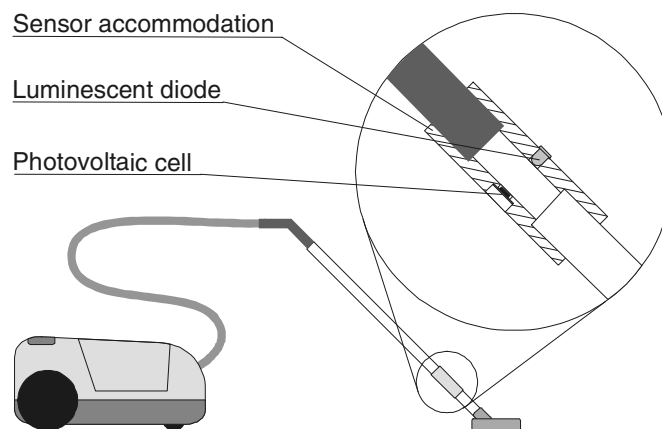


Fig. 2.26. Arrangement of the measuring set

A first prototype of a feedback device has been developed. A blinking red light indicates that dust particles are passing through the tube. The signal turns green if the amount of dust particles remains below a certain level. The light is located on top of the cleaner head, and therefore, is easily noticeable by the user (Fig. 2.27).

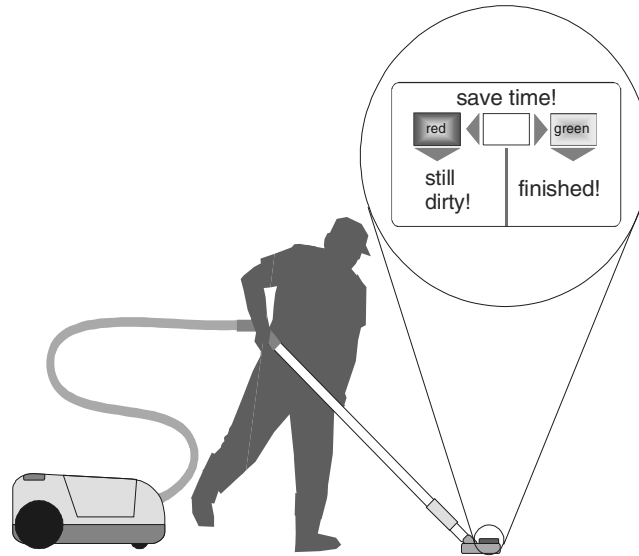


Fig. 2.27. Arrangement of the user feedback device at the cleaner head

The development of the feedback device needs to be carefully considered since design choices (e.g., acoustic, visual feedback, threshold value) may heavily influence user behaviour. Therefore, it is necessary to carry out empirical tests to ensure that pre-defined performance standards are met and no undesired side-effects crop up.

It was predicted that environmental impacts (e.g., due to increased energy consumption) can be reduced by increasing the user support. Based on the empirical tests, it will be determined to which extent this kind of feedback device reduces the environmental impact.

2.5 Conclusions

Throughout the systematic product development, it was possible to develop an environmentally friendly vacuum cleaner, which was also technically improved and should have a high marketability. At the time of print, the finishing touches were being put on the prototype of the vacuum

cleaner for further improvement. This project is executed in cooperation with industrial designers to give the environmentally friendly and marketable vacuum cleaner the cutting edge.

It is important to understand that for many methods and tools besides the results, the way to the results reveals new insights. Therefore, working in interdisciplinary product development teams and using group methods and tools are key success factors for the development of environmentally friendly products.

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