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CUSTOMER ORIENTED CONCEPT DEVELOPMENT IN MECHATRONIC PRODUCT DESIGN

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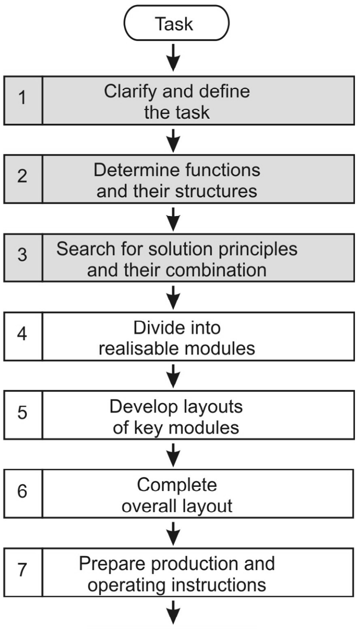
Keywords: customer orientation, quality function deployment, conceptual design, house of quality, house of concepts

1. Introduction

Due to the significant impact on the market success of products, many companies attach increasing importance to the enhancement of their customers' satisfaction. Customers' demands and their priorities have to be surveyed very carefully and the information gained ought to be regarded in all stages of product development. Thus, the developed products will meet the customer's wishes in the best possible way.
The challenge, therefore, is to systematically support the product development process to ensure customer orientation in every stage of product design. As most of the main properties (functions, behavior etc.) of a product are determined already by the design concept, it is crucial to ensure customer orientation already during the conceptual design phase. The present paper introduces an approach especially aimed to support this task.

2. Concept development in product design methodology

In the stage of conceptual design of the product development process, many essential decisions are made and the fundamental product concept is determined. Conceptual mistakes have large-scale impact on the following steps of product development. Thus, it is essential to put concept considerations on a solid basis. Furthermore, the concept determination should be traceable, consistent and well documented.
As mentioned in the introduction, costumer orientation is of capital importance, because it defines the direction of the product development efforts. Hence, market information has to be taken into account thoroughly during the whole design process. As the design concept of the product has fundamental impact on its market success, customer orientation is crucial especially during the conceptual design phase. Several design methodologies give assistance to the various phases of the design process. The VDI-guideline 2221 [VDI 2221] provides a "Systematic approach to the development and design of technical systems and products" and is a widespread approach at least in the German language area of Europe. Especially the steps 1 to 3 (shown in Figure 1) provide a general framework for conceptual design. Another well known design framework is the "Design methodology for mechatronic systems" mentioned in VDI-guideline 2206 [VDI 2206]. According to the so called "V-model" depicted in Figure 2, conceptual design is carried out in the step called "system design".
As one can see, both methods use customer information as an initial starting point, but none of them explicitly provides support to continuously assure and enhance customer orientation during all design phases, particularly during conceptual design.



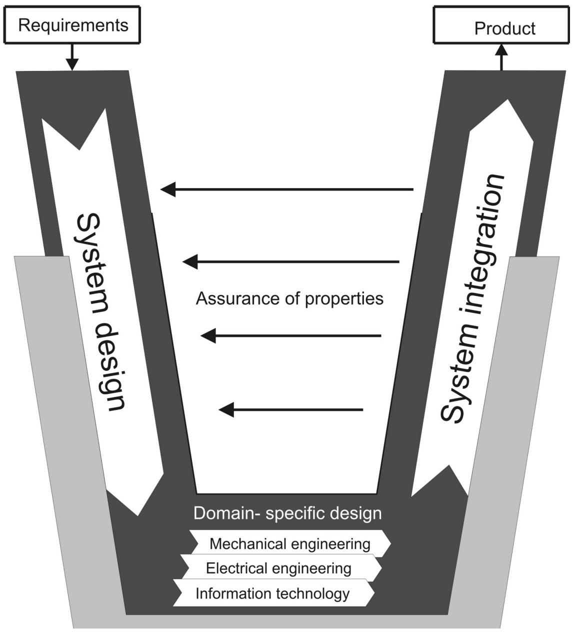


Figure 1. VDI 2221 design approach and Figure 2. VDI 2206 design approach

3. Quality Function Deployment

Quality Function Development (QFD) is an overall concept that aims at an enhanced consideration of the customer's voice in every step of the product design process. QFD is a matrix-based approach to improve the customer's perception of the ratio between benefit and cost of a product. Due to the orientation on the voice of the customer, QFD leads to fewer changes in product development projects. Furthermore, the method promotes a high integration of the various highly specialized company departments during the product development process.

QFD was developed in Japan in the late 1960's by Yoji Akao [Akao 1992] and was advanced further in the 1980's by Bob King [King 1994]. It has been used successfully by Japanese manufacturers of consumer electronics, home appliances, integrated circuits, construction equipment, synthetic rubber, textiles, agricultural engines and in the service industry, before American and European manufacturers started to use it within product development projects [Matzler 1998, Shin 2000]. Many further developments of QFD have been presented since then [Chan 2002]. One wide spread approach is the concept of the ASI (American Supplier Institute) [DGQ 2001]. It is a simplification of the extensive Japanese approaches and therefore easier to use. Instead of up to 30 matrices in the approach of King [King 1994], the ASI-approach (see Figure 5) uses four matrices for the design stages "Product Planning", "Part Planning", "Process Planning" and "Production Planning". Due to the appearance of the matrices, they are called "Houses of Quality" (HoQ). The output of one HoQ is used as the input of the next one. Explanations in more detail can be found in the corresponding literature, e.g. [DGQ 1994].

The first House of Quality chart (HoQ I) is devoted to "Product Planning" and shown in Figure 3. It includes "Customer Attributes" (①, "what to do") and their relative "Importance Rating" (②), "Engineering Characteristics" (④, "how to do it"), the "Relationship Matrix" (⑦) between "Customer Attributes" and "Engineering Characteristics", the "Correlation Matrix" (⑥) among "Engineering Characteristics", "Direction of optimization" (⑤) of "Engineering Characteristics", "Market Competitive Assessment" (③) and "Technical Competitive Assessment" (⑧).

The development of the HoQ data comprises several steps, the results of which are documented in the according fields shown in Figure 3. An Example of a HoQ I for a squirt gun is shown in Figure 4 in excerpts. The HoQ I aims at "Product Planning", which means to translate the customer wishes and their priorities ("voice of the customer") into a description of the product in a technical, quantifiable manner ("language of the engineer"). Thus, the priorities of the Engineering Characteristics can be derived. Corresponding to the numbers in Figure 3, the different steps for the development of a HoQ I are described below.

- **Step 1:**Identify customer needs. This step is crucial for the success of the product and has to be accomplished very carefully. It is very important to discover not only explicitly expressed needs but also unexpressed needs (e.g. exciting needs according to Kano [Matzler 1998]).
- **Step 2:** Structure the needs and prioritize them.
- **Step 3:** Analyze customer perception of the fulfillment of customer needs. Therefore the current product (when existing) is compared to those of the competitors.
- **Step 4:** Identify Engineering Characteristics. In this step the QFD team tries to translate the customer needs into Engineering Characteristics. The team has to identify the Engineering Characteristics which affect and fulfill the customer wishes.
- **Step 5:** Determine the optimization direction of the Engineering Characteristics. Which direction of changing the Engineering Characteristics would lead to an improved perception of benefit for the customer?
- **Step 6:** Identify the correlations of the Engineering Characteristics with themselves (in the so called ”roof-matrix”).
- **Step 7:** Develop the relationship matrix. For this purpose the QFD-team considers, how strongly the customer needs are influenced by the different design characteristics.
- **Step 8:** Compare Engineering Characteristics of the current product (when existing) with competing products.
- **Step 9:** Calculate the importance of the Engineering Characteristics.

$$weight\ of\ characteristic = \sum_{over\ all\ customer\ needs} weight\ of\ customer\ need \times relationship\ with\ characteristic \qquad (1)$$

- **Step 10:** Determine the target values of the Engineering Characteristics.

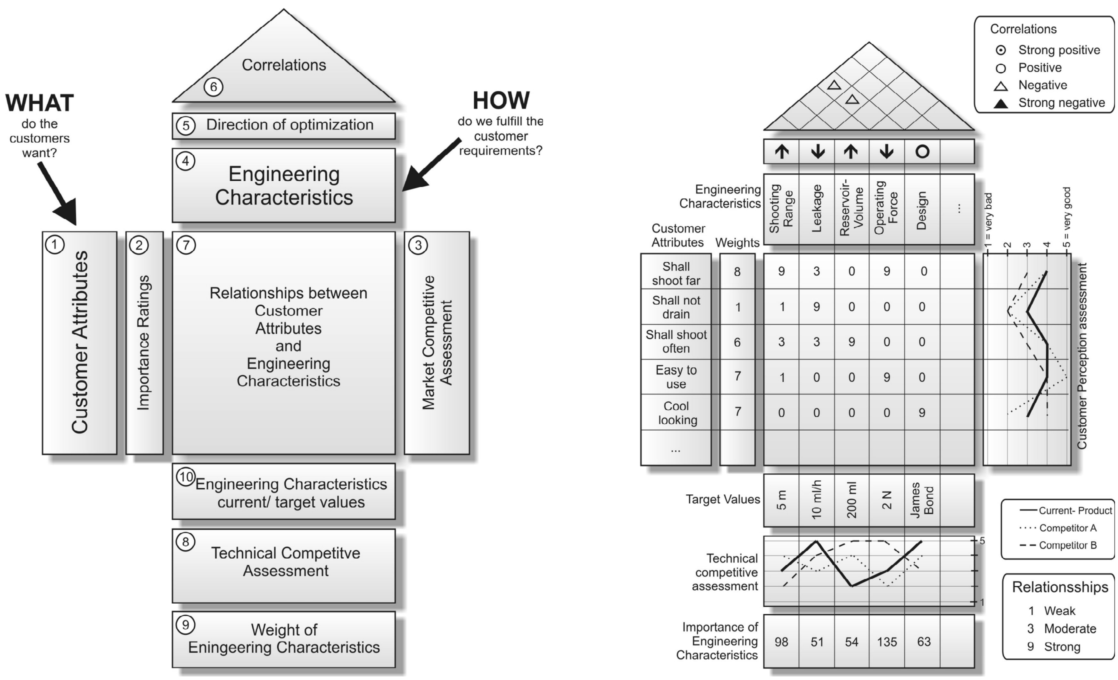


Figure 3. HoQ I Overview and Figure 4. HoQ I Example

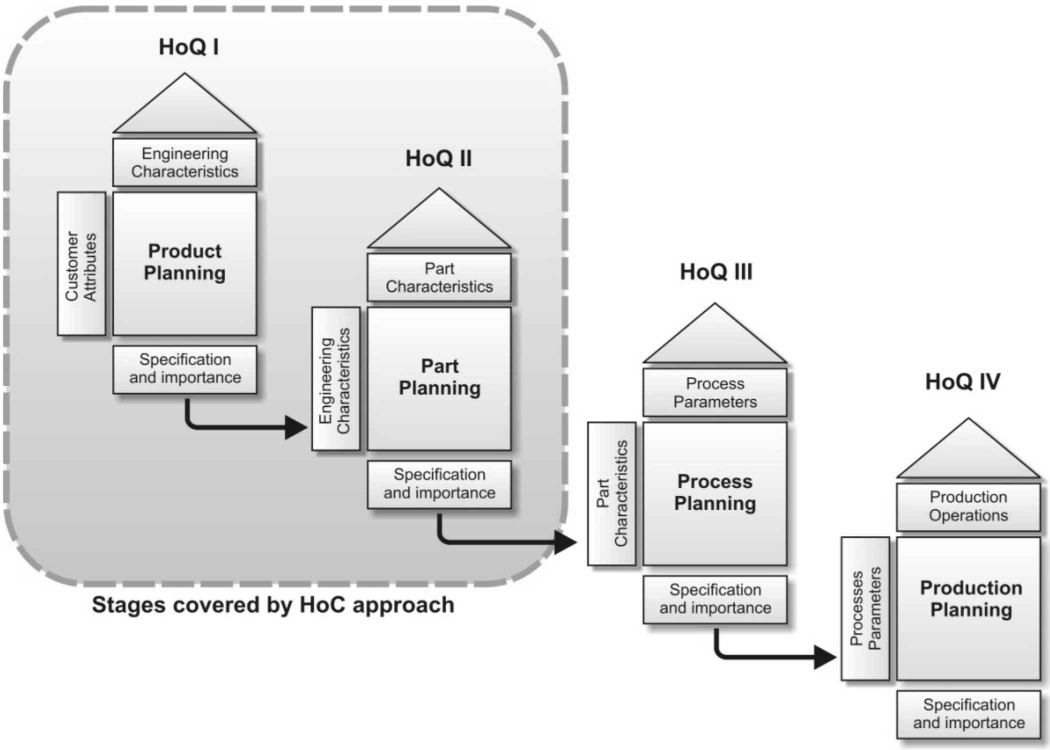


Figure 5. The ASI QFD Approach

Following the QFD approach through different stages of the product design process, as shown in Figure 5, ensures the orientation on customer needs and priorities. Thus, the probability of market success can be increased and the development process can be accelerated. The cooperation of teams from different company departments is encouraged, and thereby synergistic effects can be gained. Nevertheless, several important steps in conceptual design, such as concept creation and evaluation, are not explicitly addressed by QFD.

4. The House of Concepts (HoC) as a method to enhance customer orientation in the conceptual design phase of the product development process

4.1 Introduction and basic considerations

The name of the presented new approach "House of Concepts (HoC)" follows the term "House of Quality (HoQ)" in the QFD methodology. The House of Concepts is a further development of the QFD approach and aims at the development of product concepts on various hierarchical levels. Accordingly, the creation as well as the analysis, evaluation and selection of concepts are methodically supported. Due to a multi-stage process, decision-making is split into multiple steps. In the HoC, the contribution to the customer benefit can be determined for each concept alternative. The HoC approach is compact and illustrative and enhances comprehensibility. As shown in Figure 5, the HoC approach covers the first two of the four HoQs in the ASI QFD process. In addition, it offers steps especially helpful in supporting the conceptual design stage. In the following list the most important characteristics of the HoC approach are summed up:

- Systematic approach for concept creation, analysis, evaluation and selection
- Integration of Kano's model of customer satisfaction [Matzler 1998] into concept description
- Consideration of different product operating modes (load cases, operating scenarios)
- Support of synthesizing solution concepts by application of a morphological matrix (see chapter 4.2)
- Analysis of the impact of each concept on the degree of fulfillment of customer needs
- Multi-stage hierarchical concept finding

4.2 The HoC Methodology

Similar to the HoQ, the HoC consists of different matrices which should be processed in a certain sequence of steps, as shown in Figure 6. Steps 1 to 7 are devoted to problem analysis and task formulation. Here the wishes of the customers are translated into the properties of the product. Thus, the Kano model of customer satisfaction is applied. Not only the end customers, but also other company divisions and all kinds of stakeholders can be considered as customers. Moreover, the relationships and correlations between customer wishes and product properties are examined. Also different product operating modes and load cases can be taken into account.

In step 8, solution concepts are created. According to the actual hierarchy level under consideration, technology concepts, concept specifications, or contributions of sub-systems to the fulfillment of customer whishes are considered. Similar to a morphological matrix, several solution ideas for each product function can be gathered and documented. Thereby ideas emerging from executing steps 1 to 7 certainly shall be taken into account, too. Several overall solution concepts can be found from the combination of different partial solutions in the morphological matrix.

In steps 9 to 12, the various overall solution concepts are evaluated with respect to assessment criteria acquired by the customer-based data generated in steps 1 to 7.

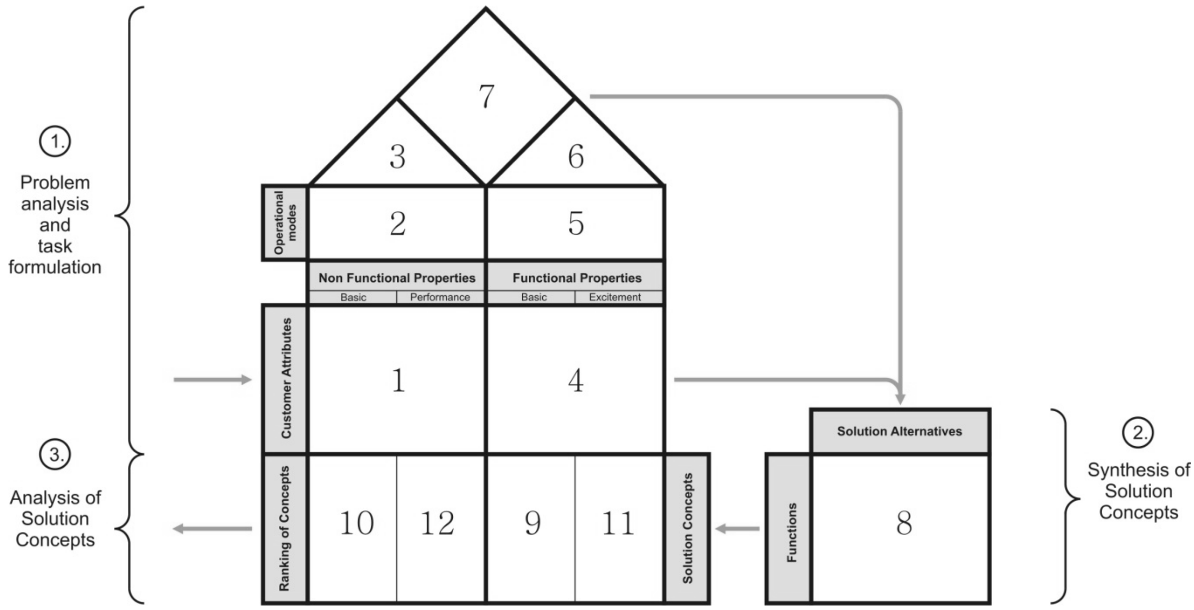


Figure 6. Overview of the House of Concepts (HoC)

4.3 Multi-stage hierarchical concept finding

The HoC is processed on different hierarchical levels, first of all, independently from a specific concept, afterwards more and more in dependence on selected solutions in order to evaluate different alternative concept versions. Hence, the HoC offers the possibility of a multi-stage concept creation. Decisions and considerations from one hierarchy level can be passed to and used in the next lower one. This multi-stage procedure of problem-solving can contribute to the reduction of complexity. After every cycle of the HoC approach, a basis for a well founded decision for the selection of one or more concepts is provided. In the presented example of a washing machine, three hierarchy levels were examined (Figure 7):

1. HoC 1 - Development and selection of technology concepts
2. HoC 2 - Specification of the main product properties
3. HoC 3 - Analysis of the contributions of each sub-system to the degree of fulfillment of customer wishes

The HoCs have to be slightly adapted on each hierarchy level, but the underlying procedure remains the same. Depending on the considered product, more or fewer hierarchy levels can be useful in concept creation. For product-improvement-projects, the hierarchy level "Choice of technology concept" may be dropped, whereas this hierarchy level may be essential for the development of new products. Similarly to the QFD method, the described approach shall not be understood as a fixed procedure, but can rather be seen as an adaptable way according to the design situation.

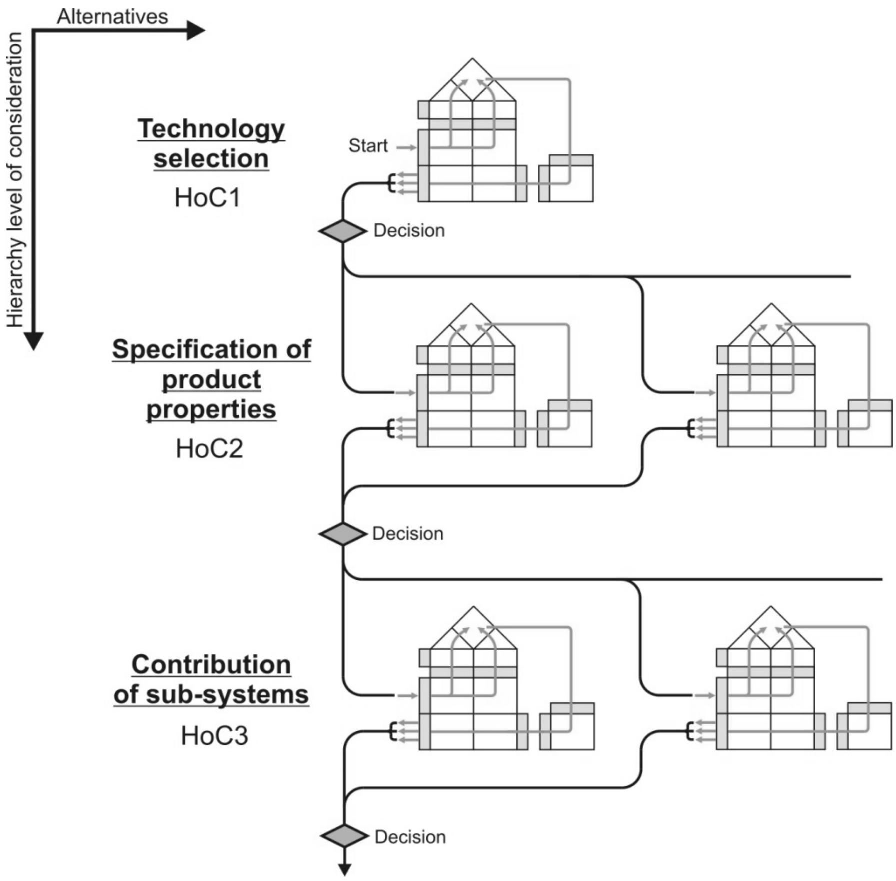


Figure 7. Hierarchical concept development

5. Application: Washing Machine

In the following, the presented approach of the HoC methodology shall be illustrated by the example of a washing machine.

5.1 HoC 1: Development of technology concepts

The object of this first HoC is to find a technology concept for a machine that can clean textile laundry. Therefore, different technologies are examined and their expected customer relevant benefit is evaluated. This information can be mirrored against the company's effort for development, production and marketing of the product.

First of all, the targeted market segment has to be defined and customer wishes as well as their priorities are investigated. Afterwards, the main product properties are considered. Product properties can be divided into "Functional Properties" ("FPs", e.g. "dry laundry"), which are the functions of the product, and "Non Functional Properties" ("NFPs") [Hubka 1984, Vajna 2009]. NFPs include function specifying properties (e.g. "amount of remaining moisture after drying laundry") and other NFPs (e.g. "mass" or "size"). Following Kano's model of customer satisfaction, these properties are assigned to one or more of the following categories: "Basic NFPs", "Performance NFPs", "Basic FPs" and "Excitement FPs". Subsequently the relationships and correlations between these properties and the customer wishes are estimated (steps 1, 3, 4, 6 and 7 in Figure 6). Steps 1 and 4 are shown in Figure 8 in excerpts. From these steps the importance of the product properties can be calculated. As a next step, product operational modes are defined, and the significance of the product properties (functional and non-functional properties) for each mode is considered (steps 2 and 5 in Figure 6).

Relationship: 1=weak 3=moderate 9=strong

No.	Max. row relationship	Weight	Customer Wishes versus Non Functional Properties	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
			Max. column relationship	9	9	9	9	9	9	9	9	9	9	9				
			Relative weight	13	6	8	7	10	5	6	8	4	15	7				
			Absolute weight	171	81	100	90	126	63	72	100	48	190	90				
			Direction of optimization	▲	▲	▲	▲	▲	▲	▲	x	▲	x	▼				
			Target values	Stain brightening scale X	40 - 60 %	5 - 7 kg cotton	average life cylce 3 years	40dB - 55dB washing, 60dB - 75dB drying	easy and single-handed	intelligible without instruction manual	installation size (fitted kitchen)	modern and serious	No leakage in lifetime	30l - 40l for standard washing				
				Washing Quality	Residual moisture after drying	Laundry Capacity	Machine durability	max. noise level	Simple Handling (Laundry in and out)	Handling (program choice)	Size	Design (Color, Surface)	Leakage prevention	Water Consumption				
1	9	19	Cleans laundry well	9														
2	9	9	Clothes are dried		9													
3	9	10	High capacity			9					1							
4	9	10	High lifetime of machine				9						1					
5	9	14	Silent operation					9										
6	9	7	Easy to operate						9	9		3						
7	9	10	Can be integrated in fitted kitchen			1					9							
8	9	3	Looks good							3		9						
9	9	20	Water never leaks										9					
10	9	10	Low cost of operation											9				
11	9	9	Clothes are not creased															9

Relationship: 1=weak 3=moderate 9=strong

No.	Max. row Relationship	Weight	Customer Wishes versus Functional Properties	Store laundry	Clean laundry	Dry laundry	Load and unload laundry	Control cleaning operation	Choose cleaning program
			No.	1	2	3	4	5	6
			Max. Column Relationship	9	9	9	9	9	9
			Relative weight	8	33	29	9	18	3
			Absolute weight	171	688	598	184	381	73
1	9	19	Cleans laundry well		9			3	
2	9	9	Clothes are dried			9		9	
3	9	10	High capacity	9	3	3	3		
4	9	10	High lifetime of machine		1	1	1	9	1
5	9	14	Silent operation		9	9		3	
6	9	7	Easy to operate				9		9
7	0	10	Can be integrated in fitted kitchen						
8	0	3	Looks good						
9	9	20	Water never leaks		9	9			
10	9	10	Low cost of operation		9	9		3	
11	9	9	Clothes are not creased	9	9	9	9	9	

Figure 8. Exemplary illustration of Steps 1 and 4 of the HoC 1 (in excerpts)

In step 8, several technology concepts for each of the main product functions are searched and listed. Thus, a morphological matrix is created, which supports the creation of several overall product concepts, for example the widespread products “classic front loading washer”, “classic top loading washer” or the novelty “ultrasonic concept” or the “silver ion” concept. Steps 9 to 12 (shown in Figure 9 in excerpts) aim at a customer oriented evaluation of the concepts.

Relationships: ☺=achievable ?=possibly achievable x=not achie

No.	Requirements achievable	Solution Concepts versus Basic Non Functional Properties	Size	Leakage prevention	Environment-friendliness
		No.	1	2	3
		Requirement achieved	OK	OK	OK
		Relative weight	8	15	
		Direction of optimization	x	x	▼
		Target values	installation size (fitted kitchen)	No leakage in lifetime	As little water pollution as possible, legal requirements
1	OK	1. Classic front-loading washer (EU)	☺	☺	☺
2	OK	2. Classic top-loading washer (USA)	☺	☺	☺
3	?	3. Two tubs and blow-dryer	?	☺	☺
4	?	4. Classic front-loading washer (EU) with squeezer	☺	☺	☺
5	?	5. Classic top-loading washer (USA) with squeezer	☺	☺	☺
6	?	6. Two tubs + squeezer	?	☺	☺
7	OK	7. Ultrasonic + Centrifugation	☺	☺	☺
8	OK	8. Ultrasonic + blow-dryer	☺	☺	☺
9	?	9. Ultrasonic + Squeezer	?	☺	☺
10	OK	10. Classic front-loading washer (EU) + Steam	☺	☺	☺
11	OK	11. Plastic chips	☺	☺	☺
12	?	12. Ionized water	☺	☺	?
13	?	13. CO2 detergent	☺	☺	?
14	X	14. Silver ions	☺	☺	X

Relationships: 0=very bad to 10=very good

No.	Max. row relationship	Score	Rank	Solutions Concepts versus Performance Non Functional Properties	Washing Quality	Residual moisture after drying	Laundry Capacity	Machine durability	max. noise level
				No.	1	2	3	4	5
				Max. Column Relationship	8	9	9	9	9
				Relative weight	13	6	8	7	10
				Direction of optimization	▲	▲	▲	▲	▲
				Target values	Stain brightening scale X	40 - 60 %	5 - 7 kg cotton	average life cylce 3 years	40dB - 55dB washing, 60dB - 75dB drying
1	9	436	1	1. Classic front-loading washer (EU)	8	7	9	9	3
2	9	364	9	2. Classic top-loading washer (USA)	7	6	9	9	2
3	9	384	6	3. Two tubs and blow-dryer	8	9	3	6	2
4	9	402	4	4. Classic front-loading washer (EU) with squeezer	8	3	5	9	7
5	9	370	7	5. Classic top-loading washer (USA) with squeezer	7	3	5	9	6
6	9	387	5	6. Two tubs + squeezer	8	3	3	9	7
7	9	289	13	7. Ultrasonic + Centrifugation	1	7	9	2	3
8	9	310	12	8. Ultrasonic + blow-dryer	1	9	9	2	2
9	9	260	14	9. Ultrasonic + Squeezer	1	3	5	2	9
10	9	366	8	10. Classic front-loading washer (EU) + Steam	8	7	9	2	3
11	9	418	2	11. Plastic chips	5	7	9	5	3
12	9	361	10	12. Ionized water	7	7	9	1	3
13	9	340	11	13. CO2 detergent	7	7	9	2	3
14	9	416	3	14. Silver ions	7	7	9	5	3

Relationships: ☺=achievable ?=possibly achievable x=not achievable

No.	Functions achievable	Solution Concepts versus Basic Functional Properties	Store laundry	Clean laundry	Dry laundry	Load and unload laundry	Control cleaning operation	Choose cleaning program
		No.	1	2	3	4	5	6
		Function achieved	OK	OK	OK	OK	OK	OK
		Relative weight	6	31	22	8	17	17
1	OK	1. Classic front-loading washer (EU)	☺	☺	☺	☺	☺	☺
2	OK	2. Classic top-loading washer (USA)	☺	☺	☺	☺	☺	☺
3	OK	3. Two tubs and blow-dryer	☺	☺	☺	☺	☺	☺
4	OK	4. Classic front-loading washer (EU) with squeezer	☺	☺	☺	☺	☺	☺
5	OK	5. Classic top-loading washer (USA) with squeezer	☺	☺	☺	☺	☺	☺
6	OK	6. Two tubs + squeezer	☺	☺	☺	☺	☺	☺
7	?	7. Ultrasonic + Centrifugation	☺	?	☺	☺	☺	☺
8	?	8. Ultrasonic + blow-dryer	☺	?	☺	☺	☺	☺
9	?	9. Ultrasonic + Squeezer	☺	?	☺	☺	☺	☺
10	OK	10. Classic front-loading washer (EU) + Steam	☺	☺	☺	☺	☺	☺
11	?	11. Plastic chips	☺	?	☺	☺	?	☺
12	?	12. Ionized water	☺	?	☺	☺	?	☺
13	?	13. CO2 detergent	☺	?	☺	☺	?	☺
14	?	14. Silver ions	☺	?	☺	☺	?	☺

Figure 9. Exemplary illustration of Steps 9, 10 and 12 of the HoC 1 (in excerpts)

Therefore the possible fulfillment of the basic properties is examined first (step 9 and 10). After that the fulfillment of the performance NFPs and excitement FPs is evaluated (steps 11 and 12). For the evaluation criteria the weights of the properties obtained in steps 1 and 4 are used. Additionally, the company's expected effort for each concept is estimated. Thus, it is possible to compare the estimated product (concept) performance to the estimated effort of each concept.
For the consideration of the results it is useful to put the acquired data into a chart. In the diagram shown in Figure 10, the different evaluation dimensions are plotted for the washing machine example. From this it becomes visible which concepts are the most promising ones and should therefore be progressed. By this means, the concept decision can be made, at the same time indicating the transition onto the next lower hierarchy level.

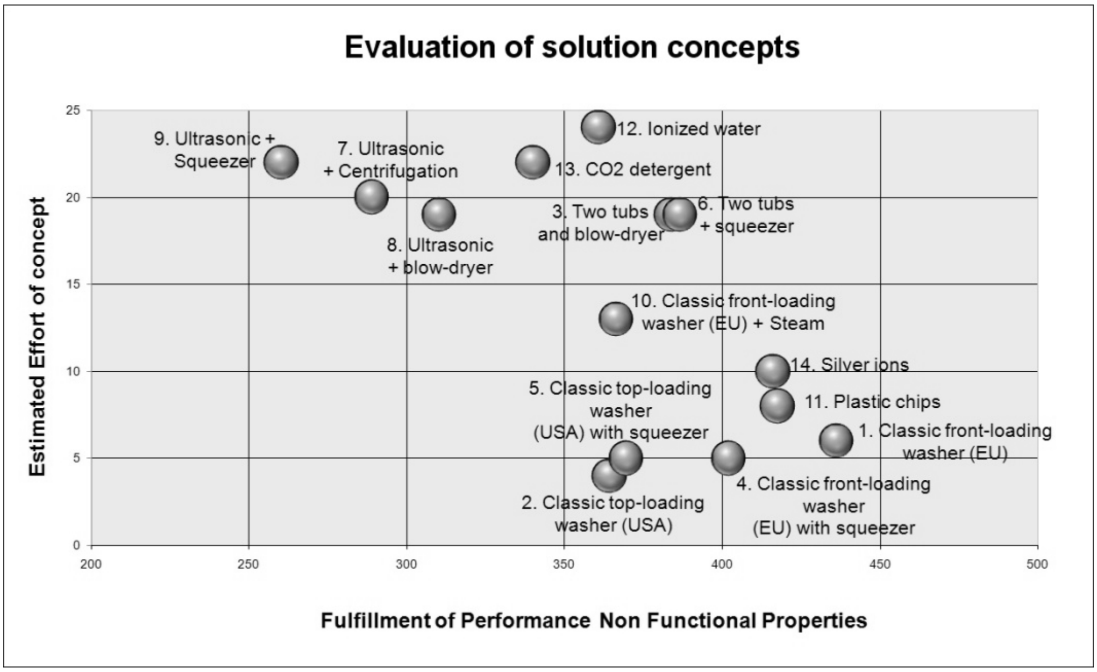


Figure 10. Results from the HoC 1: Evaluation of technology concepts

5.2 HoC 2: Specification of the main product properties

After the selection of a technology concept on the basis of the information gained in the HoC 1, the specification of the main product properties is searched for in the HoC 2. In the HoC 1 some main parameters were already determined in a certain range, but now, different product concepts with a specific quantification of their properties are created and evaluated. In the washing machine example, five different product concepts are considered. The HoC 2 is processed similarly to the HoC 1, but from a more concept specific view.
Similarly to the HoC 1, it is useful for the decision making to plot the created information in a diagram as it is shown in Figure 11. As might be expected, the concept ”simple model", which contains very easily achievable NFPs and fulfills no excitement FPs at all, comes off badly in the evaluation of the performance NFPs as well as in the fulfillment of excitement functions. However, the expected effort for this concept (in Figure 11 shown as bubble area) is obviously the lowest. In the opposite, the concept "luxury model" (very ambitious quantification of NFPs and a variety of excitement FPs) does very well in the evaluation of the performance NFPs, as well as in the fulfillment of the excitement functions. However, the expected effort of this concept is the highest. The comparison of the concept variants ”standard model", ”performance model" and ”excitement model" show a very interesting result. These three concepts reveal almost the same expected effort, but offer the possibility in aiming at very different market segments. The ”standard model" represents an average model, whereas the "performance model" especially aims at performance-oriented customers, who are not interested in

additional gimmicks. On the contrary, the ”excitement model” could target customers who are interested in prestigious excitement functions („My washing machine is able to do …“).
Which concepts finally shall be pursued, depends on the question which market segment should be served. Thus, the HoC 2 offers a valuable contribution to accurately position products on the aimed market segments.

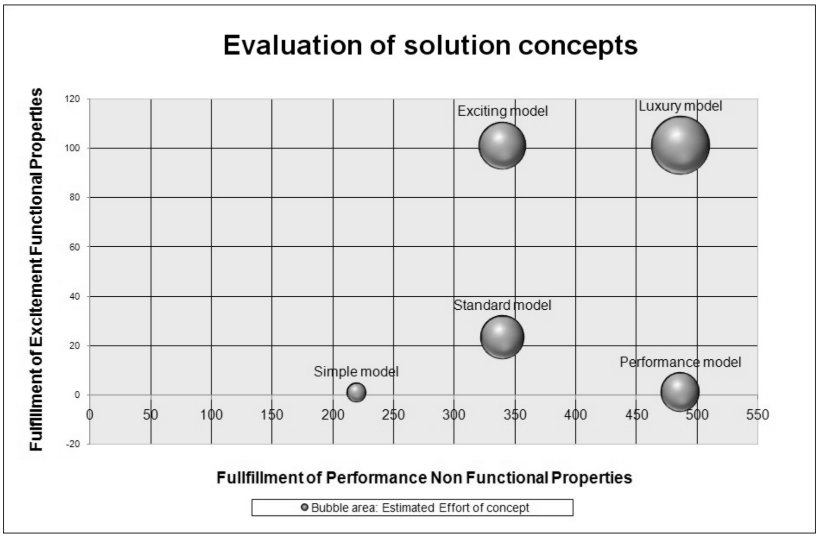


Figure 11. Results from the HoC 2: Evaluation of specific concepts

5.3 HoC 3: Analysis of the contribution of the product sub-systems on the degree of fulfillment of the customer wishes

After choosing the technology in HoC 1 and the specific main properties in the HoC 2, the HoC 3 aims at finding priorities for an effective product realization. Therefore, the sub-systems and components of the product are considered. For that reason, each contribution of the different sub-systems to the main engineering properties of the product and furthermore to the customer wishes and their satisfaction is examined.

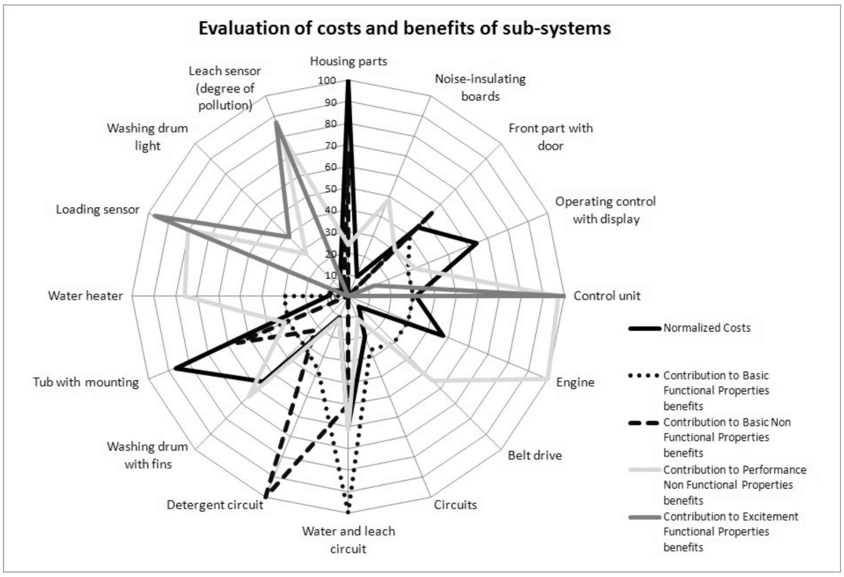


Figure 12. Results from the HoC 3: Evaluation of sub-systems

The acquired information from the HoC 3 is pictured in the radar chart shown in Figure 12. Thereby the five different criteria “Normalized costs”, “Contribution to basic FPs benefits”, “Contribution to basic NFPs benefits”, “Contribution to performance NFPs benefits”, and “Contribution to excitement

FPs benefits" are depicted for each assembly. For each criterion the largest contribution of all sub-systems is normalized at a value of 100, so that the same scale can be used.

With this kind of chart, a lot of information can be summarized within one figure. For each of the five criteria it can be recognized, which sub-systems have a major and which have a minor contribution. On the other hand, when looking at a single assembly, it can be discovered, to which extent the different criteria are affected by this device.

Regarding this information, several strategies can be formulated and may serve as a basis for further activities. Depending on the aims of the project, the important sub-systems for the achievement of the goals can be identified and focused on in the further product development process.

6. Conclusions

Especially in early product design stages, customer orientation is mandatory for product success. Hence, this aspect should be emphasized there. A method aiming at this goal is the QFD approach, which, however, does not focus on conceptual design, at least not to the desired extent. Hence, a new approach, namely the House of Concepts (HoC) is introduced offering assistance in enhanced customer orientation particularly during conceptual design, and supporting systematic concept development on different levels of abstraction. Thus, the HoC approach contributes to position products exactly in the targeted market segments.

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References

Akao, Y., "Quality Function Deployment – Wie die Japaner Kundenwünsche in Qualität umsetzen", verlag moderne industrie, 1992.

Chan, L. K., Wu M. L., "Quality Function deployment: A literature review", European Journal of Operational Research 143, pp 463-497, 2002.

DGQ, Deutsche Gesellschaft für Qualität e.V., "QFD – Quality Function Deployment", DGQ Band 13-21, 2001.

Hubka, V., "Theorie technischer Systeme", Springer Verlag Berlin Heidelberg, 1984.

King, B., "Doppelt so schnell wie die Konkurrenz", gfmt verlag, Gesellschaft für Management und Technologie AG, 1994.

Matzler, K., Hinterhuber H., "How to make product development projects more successful by integrating Kano´s model of customer satisfaction into quality function deployment", Technovation Vol. 18(1) pp 25-38, 1998.

Shin, J. S., Kim, K. J., "Complexity reduction of a design problem in QFD using decomposition", Journal of Intelligent Manufacturing 11, 339-354, 2000.

Vajna, S., Weber, C., Bley, H., Zeman, K., Hehenberger, P., "CAx für Ingenieure: Eine praxisbezogene Einführung", Springer Verlag Berlin Heidelberg Germany, 2009.

VDI, Verein Deutscher Ingenieure, VDI-Gesellschaft Entwicklung Konstruktion Vertrieb, "VDI 2206 – Entwicklungsmethodik für mechatronische Systeme", VDI Richtlinien, Beuth Verlag Germany, 2003.

VDI, Verein Deutscher Ingenieure, VDI-Gesellschaft Entwicklung Konstruktion Vertrieb, "VDI 2221– Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte", VDI Richtlinien, Beuth Verlag Germany, 1993.

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