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QFD – A LINK BETWEEN CUSTOMER REQUIREMENTS AND PRODUCT PROPERTIES

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ABSTRACT
The method QFD consists of several consecutive phases, in which every phase uses a correlation matrix. To ensure a structured procedure, as well as to illustrate the connection between requirements and properties, this matrix will be expanded to include the House of Quality (HoQ).In this paper the QFD method is used to link and transform customer requirements to product properties of profile structures manufactured by linear flow splitting. The product properties consist of external and internal properties. For this interrelationship of requirements and properties a QFD investigation with two phases is accomplished. In phase one the interrelationship of standardised customer requirements with external properties is investigated. The QFD-Number, a results for the importance of every external property in order to affect and meet certain standardised requirements, is used as weighting factors in the HoQ of the second phase. The second phase QFD links the external properties over internal properties. Internal properties are those that can be adjusted by the designer during a design process. The link from internal to external properties and finally standardised requirements plays an important role during the design process.

Keywords: QFD, standardised requirements, internal properties, external properties

1 INTRODUCTION
In the Collaborative Research Centre 666 (Sonderforschungsbereich 666) methods, processes and machinery facilities are to be developed in order to optimize the function and the load of bifurcated structures with an integral sheet metal design [1]. In many cases the use of bifurcated integral profile structures offer the realization of desired requirements on a limited space with the smallest amount of mass. Linear flow splitting, a newly created massive forming process, enables the forming of branched sheet metal products in an integral style. To design these products one has to consider the variety of feasible process chains as well as the huge amount of technological and market influences on product geometry and material.
For the optimization of profile structures it needs intense cooperation between the designer and mathematicians, to develop a new proceeding for an algorithm-based product development. In the first partial project of this Research Center – which is the main focus of this paper- the transformation from customer requirements and market requirements into product properties is one aim. For this transformation, methods such as Quality Function Deployment (QFD) could play an important role [2]. The method can be used during the whole product development process with the major goal of translating customer requirements into product-specific properties. Critical properties can be found at an early stage of the product development. Therefore a QFD investigation consisting of two phases is carried out. The first phase is QFD with the interrelationship of requirements to external product properties and the second phase relating the external product properties to internal product properties.

2 THE QFD METHOD
Quality Function Deployment (QFD) is a method of quality planning developed by Yogi Akao [2] in Japan in the late 60's and advanced further in the 80's by Bob King [3]. According to Danner [4], QFD is a holistic, interdisciplinary and universal planning and communication system designed to support the coordination of all business activities for producing and improving market driven products.

This method can be employed at every stage of product development for both technical and non technical products, in order to translate customer requirements and wishes into technical and product

specific properties. The goal is to make products that truly match customer wishes and requirements and to identify critical developments at an early stage.
In all QFD studies, the structured collection and interpretation of customer requirements is a basis of studies to improve quality. For this purpose, a House of Quality (HoQ) is used where customer requirements are set against manipulable, technical parameters that determine quality [5].

2.1 The strcuture of the QFD method

The QFD method is composed of several phases building on one another. In each phase, a relationship matrix [6] is provided. Its results serve as a template for the next phase Figure 1.

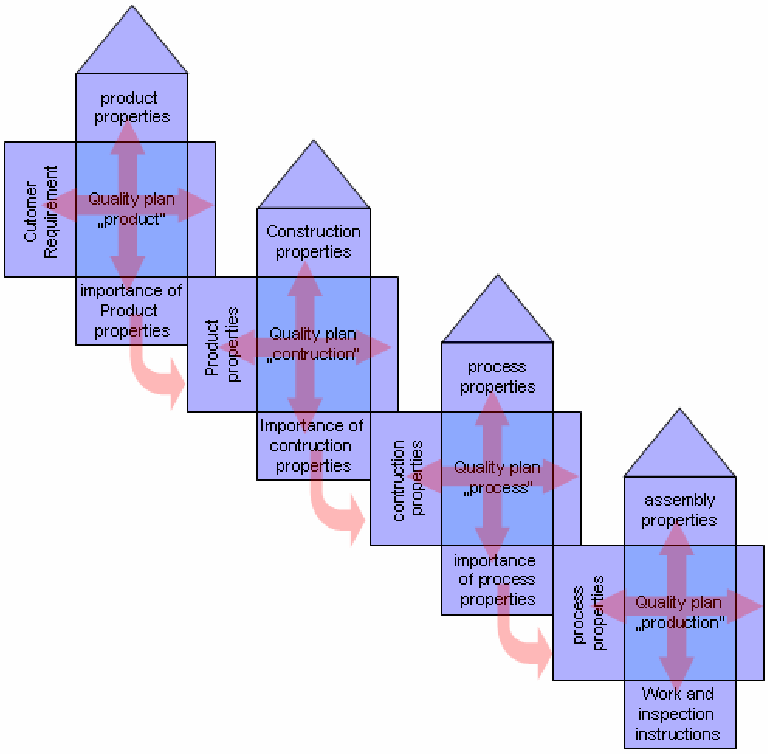

Figure 1. Four phases of the QFD

Yogi Akao has drawn up eight important quality planning criteria (quality, technology, cost, reliability) that he brought together in a correlation matrix and created a sequence plan for carrying out a QFD. To overcome problems that can arise when using the QFD method, Bob King complemented the correlation matrix of Yogi Akao by introducing a few additional aspects (concepts, support methods, process development).
To ensure an orderly correlation matrix procedure and to illustrate it graphically, the matrix becomes a House of Quality (HoQ). This HoQ is composed of several rooms that are dealt with one after the other. Customer requirements are methodically translated into technical properties with the help of the HoQ element illustrated in Figure 2. In this process, the requirements drawn up for customers are set against the technical properties (external properties) by using a matrix in which their dependencies can then be entered. The external properties must be manipulable parameters that influence the quality of the implementation of the determined requirements. Room 2 and room 6 allow for more space for a concrete form and weighting.
Furthermore, the HoQ offers the possibility to set product comparisons against customer requirements from the customer's point of view (room 5). The roof of the HoQ (room 7) illustrates the interdependency between external properties themselves and serves as a basis for the estimation of constructive realisation difficulties of individual requirements that have to be registered in (room 8). A weighting of values of these properties leads to a final prioritisation (number of external properties) of external properties that are entered in (room 9) as results. Room 10 and room 11 are here not being considered.

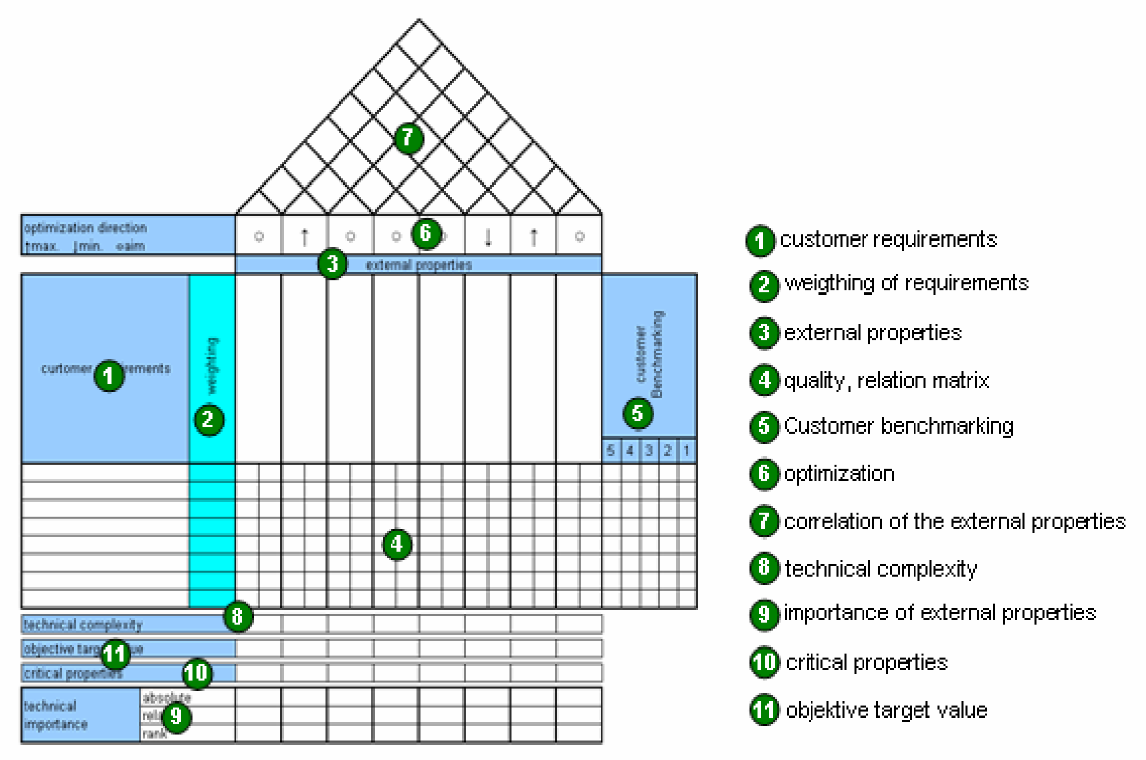

Figure 2. House of Quality (HoQ)

2.2 The QFD procedure

To draw a qualitative conclusion regarding a usable interrelationship between customer requirements and product specific internal properties determined i.e. suggested by the product manufacturer, QFD studies were carried out in two phases Figure 3 in our research.

Phase-1: Interrelationship between standardised customer requirements and external properties

Phase-2: Interrelationship between external properties and internal properties.

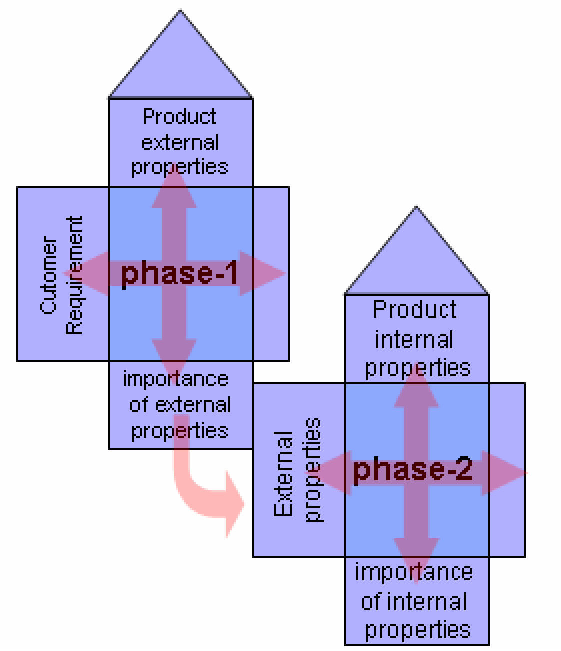

Figure 3. Two phases of the QFD studies

Phase 1 consists of analysing the quality chart in which customer wishes i.e. requirements are entered opposite to quality criteria. In our case, the external properties are used as quality criteria. To conduct a QFD study, it is necessary to weight the requirements. The weighting should be carried out separately and then implemented in room 2. In room 9 of phase 1, the weighting of the requirements to be examined and the external properties are calculated.
In phase 2, external properties are set against product specific internal properties. Weighting factors from room 9 of phase 1 are then implemented as weighting factors in room 2 of phase 2.
By interrelating customer requirements to external properties and external properties to internal properties, it is possible to draw a qualitative conclusion regarding the relationship between vaguely expressed customer wishes i.e. requirements and the external and internal properties of the sheet metal product. In this way, a standard relationship network between customer requirements and internal properties can be created.

2.3 Standardising customer requirements

"Standardised requirements are requirements that can be understood and interpreted in the same way, whether by manufacturers or by the customers. For this reason, they can be called unambiguous. Designers know exactly what customers expect when customers exclusively employ terms of standardised requirements in their descriptions of the desired product."
To be collected, standardised requirements have to be defined for the real, manufacturable product. The larger the collection, the larger the standardised requirements and the easier it is to create i.e. generate new products. The standardised products we use in our research centre (Collaborative Research Centre 666), are defined by components that are manufactured by us.

3 1ST PHASE QFD, THE PROCEDURE OF INTERRELATING STANDARDISED CUSTOMER REQUIREMENTS TO EXTERNAL PROPERTIES

To interrelate customer requirements to external properties in phase 1 Figure 4 i.e. in the first HoQ for a specific product, the following steps are necessary in our approach:

1- Determining standardised customer requirements
2- Weighting standardised customer requirements
3- Determining external properties
4- Interrelating the weighted requirements to external properties
5- Assessing the relationship matrix between the weighted requirements and external properties

In the CRC 666, we deal with integral sheet metal constructions with bifurcated structures. In the following sections, a component (product) from this field will be analysed.
We shall focus on the trapeze profile that is manufactured with the help of linear flow splitting.
As trapeze profiles are constructed in a consistent way, e.g. in the container walls, they are more stable, because common deformations of the external walls are reduced.

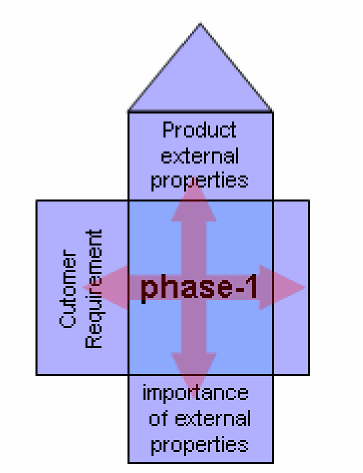

Figure 4. 1st Phase QFD

Trapeze profiles could for instance be used in shipbuilding as a ship's hull or in automobile construction as a side impact protection. In shipbuilding, corrosion resistance is a must, while in

automobile construction, stiffness and damping features of construction components play an important role.
The trapeze shaped component profile Figure 5 is constructed by using two linear flow splitting and two roll bending processes. By means of laser welding, it is closed at the internal and external flange end and then laser welded with another component, so that the joined individual components become one plate Figure 6.

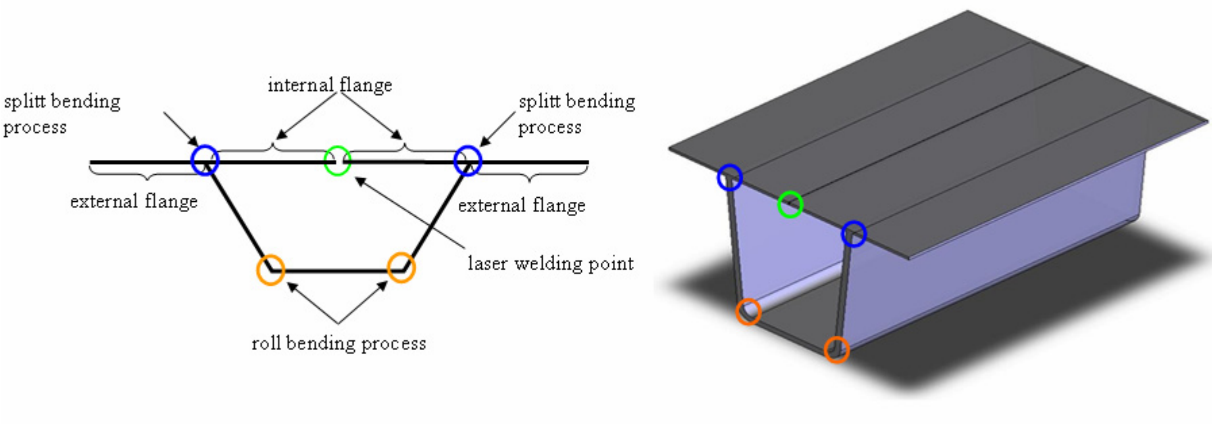

Figure 5. Manufacturing processes for one assembly

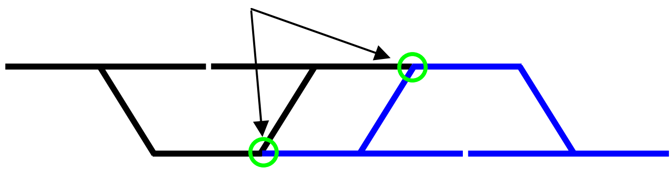

Figure 6. Joint between to assembly

Due to the limited manufacturing possibilities of our linear flow machine, a few standards have to be observed regarding geometry and connection possibilities. At present, it is possible to construct a flange with a length of max.10 mm. Before the linear flow splitting process, the width of the sheet metal should not exceed 250mm. Because of the planned joining procedure (laser welding) there are other restrictions, as the laser head is relatively large and must be very close to the work piece and because the flange can only be joined from the outer side. In addition to that, the material has to match the selected joining procedure. This restriction and the requirements of linear flow splitting result in more or less standardised requirements. They can be assumed as such, as they cannot be manufactured yet.

3.1 Determining standardised requirements

In phase 1, the customer requirements that are to be analysed must first be determined.
In accordance with the example of the trapezium shaped component, customer requirements for the 1st HoQ of phase 1 that can be gathered from the standardised requirements for sheet metal profiles are selected. To guarantee clarity, only a few customer requirements are selected for the HoQ.
The following terms have been taken over as customer requirements: costs, assembly, reliability, safety, stability, and environmental damage.

3.2 Weighting standardised customer requirements

To weight standardised requirements, associations i.e. the closeness between terms used for requirements have been examined. The associated terms i.e. requirements can serve both the designers to specify lists of requirements and the customers to specify their wishes and requirements as precisely as possible.
To work out a list of requirements with the customer, a network of terms can be very helpful where the relationship between the terms is recognizable. Figure 7 shows us an extract from such a network of terms, i.e. requirements.

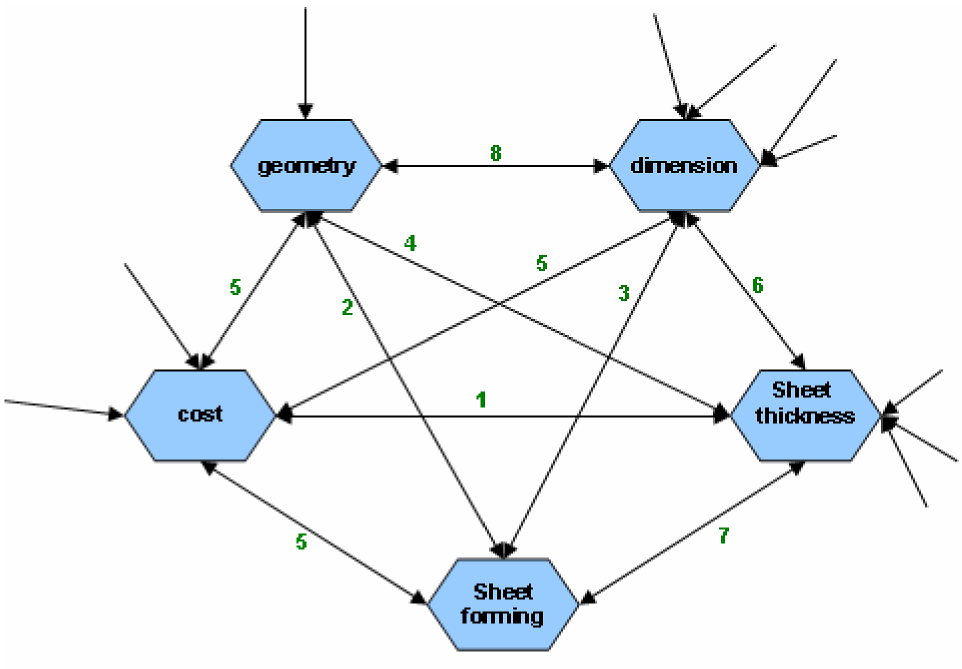

Figure 7. Network of closeness between terms

The determined closeness is needed to calculate the distance between the terms. This distance – also referred to as the Euclidian distance – is used during the Cluster analysis to divide objects according to specific criteria [7]. The Euclidian distance serves to determine the similarity between objects according to their properties. When all properties are identical i.e. when their numerical values are equal, the distance is 0, and the objects are identical. To determine the Euclidian distance for weighting the terms themselves

- the closeness between two different terms
- and the closeness between both two different terms and the rest of terms of the sum that is examined are of importance.

To calculate the weighting for the 1st HoQ, the closeness between the terms that is to be analysed is calculated first. Then, the Euclidian distance is calculated. The calculated weighting of individual terms i.e. standard requirements is also entered in Room 2 of the HoQ Figure 8.

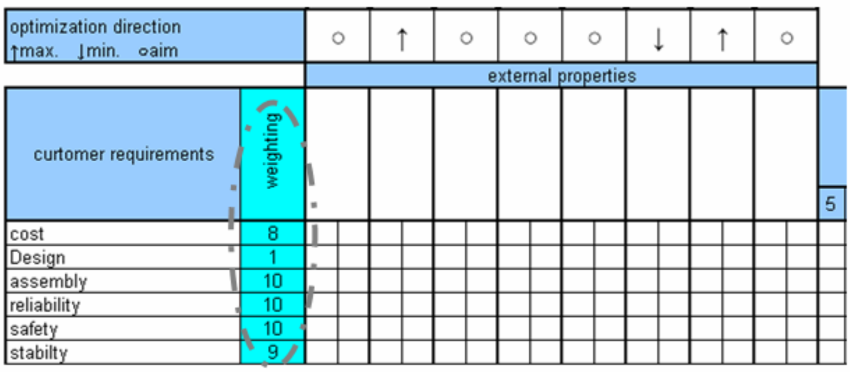

Figure 8. Weighting of customer requirements

3.3 Determining external properties

First, technical product properties are listed, that are suited to fulfil the analysed and weighted customer requirements. To guarantee more clarity, it is helpful to focus on generic terms for product properties, so that perhaps sometimes unnecessary aspects can be excluded. For this purpose, a list of possible product properties was drawn up where the suitable properties are selected in a second step. Large catalogues can be found in literature [1], [8], [9], [10] with terms that serve as a basis for independent search. These catalogues are however not complete and consequently, they must be adapted and complemented in most problem cases.

curtomer requirements	weighting	external properties															
		dimension		use		beding force		eigenfrequency		function		weight		corrosion resistance		deformation	
cost	8																
Design	1																
assembly	10																
reliability	10																
safety	10																
stabilty	9																

Figure 9. External properties

In accordance with these catalogues, a list of properties Figure 9 can be drawn up for the trapeze profile Figure 5. The next step consists of dividing up the found terms in external and internal properties, and identifying generic terms. The following properties are selected as external properties to interrelate to standardised requirements: application, bending force, natural frequency, weight, corrosion resistance, deformation. External properties are then registered in room 3 of the 1st HoQ.

3.4 Interrelating weighted requirements to external properties

First, the optimisation direction is determined in a next step. Here, three different symbols are used:

a) max: the property value must be enlarged
b) min: the property value must be reduced.
c) Objective: the property value must attain a specific objective value or objective zone

While a specific objective value is desirable for the "natural frequency" of a trapeze profile, the property for "application" has to be increased, to cover a wide spectre of application areas. For reasons of cost and manufacturing of lightweight construction, weight should be minimised as much as possible.

The next step is dealing with the relationship matrix (room 4) Figure 10. Here, the relationship between customer requirements and external properties is illustrated in numerical values. If there is no relationship, the field remains empty. Weak relationships are marked with 1, medium ones with 2, and strong ones with 9.

As some of the properties influence each other, the next step is to look at the interaction between the selected external properties. By using a correlation matrix all listed external properties are interrelated to one another. In using suitable symbols, it can be shown how one property influences another. Here, a conflict of objectives can arise, if by improving one property another is negatively influenced. On the other hand, there is harmony of objectives if there is a positive correlation between the modifications of two product properties. If there is no relationship, there is neutrality of objective.

optimization direction ↑max. ↓min. ○aim		○		↑		○		○		○		↓		↑		○	
		external properties															
curtomer requirements	weighting	dimension		use		beding force		eigenfrequency		function		weight		corrosion resistance		deformation	
cost	8	3	24	1	8	3	24	1	8	1	8	3	24	3	24	3	24
Design	1	3	3	3	3	3	3	3	3	1	1	3	3	1	1	3	3
assembly	10	9	90	3	30	0	0	0	0	9	90	3	30	1	10	1	10
reliability	10	0	0	3	30	9	90	9	90	9	90	0	0	9	90	9	90
safety	10	1	10	9	90	9	90	9	90	3	30	3	30	9	90	9	90
stabilty	9	3	27	9	81	9	81	9	81	1	9	1	9	9	81	9	81

Figure 10. Relationship matrix

Subsequently, attention is paid to the technical difficulty to fulfil and translate external properties. Here, an assessment scale between 1 and 10 is used with 1 standing for “easily attainable” and 10 for “almost unattainable”.

3.5 Assessing the relationship matrix between the weighted requirements and the external properties.

In a last step of phase 1 Figure 11 i.e. of the 1st HoQ, the assessment of the relationship matrix is calculated. The weighting of customer requirements based on the closeness of individual terms is multiplied with the value of the relationship matrix. Then, an addition is carried out in all columns. In this manner, the technical importance of external properties is clearly expressed as an absolute value. The properties with the highest values fulfil the listed customer requirements best, and should therefore be prioritised in a subsequent phase of the QFD method.

technical importance	absolute	154	263	351	335	249	103	359	361
	relativ	7%	12%	16%	15%	307%	5%	17%	17%
	rank	7	5	3	4	6	8	2	1

Figure 11. Importance of external properties

4 2ND PHASE QFD

The second phase QFD Figure 12 links the external properties over internal properties. Internal properties are those that can be adjusted by the designer during a design process in order to meet certain requirements. In the second phase of the QFD the importances of the external properties from the first phase HoQ are used as weighting factors in this HoQ.

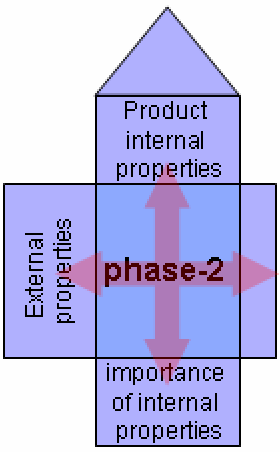

Figure 12. 2nd Phase QFD

The relationship matrix finally connects the external properties with the internal properties. The determined technical importance of internal properties shows the designer, with which adjustable internal properties external properties are achieved, and therefore over the first phase which requirements and demands are met.

4.1 Determining internal properties

The next step of the 2nd HoQ is the determination of the products internal properties. By realizing certain internal properties the external properties and therefore finally requirements are influenced. This means designers have to choose internal properties in such a way that the required external properties are possibly met. So which properties could be possibly adjusted and directly influenced by the designer? In a study of internal properties of profile structures a limited set of internal properties were identified such as:

- Geometry
- Sheet thickness
- Material

- Manufacturing Process

All those internal properties and their values can be directly influenced by the designer in order to meet the required goal.

4.2 Interrelation of external and internal properties

Same as in chapter 3.3 the external properties are interrelated to the internal properties. The weighting factors for the external properties, room 2 of the second phase HoQ, are taken from the calculated result of room 9, the importance of the external properties, out of the first HoQ. The procedure of the second HoQ is similar to the one of chapter 3.4.
As already known from the first phase in the next step the relationship matrix (room 4) is completed. In this matrix the relationship between external properties and internal properties is illustrated in numerical values. The calculated result of this matrix is the importance of every internal property. From this investigation it is possible to get first insights into the relationship of properties. A demonstrative study has shown that material and geometry are the most important internal properties in order to influence external properties and finally meet requirements.
Finally the correlation between internal properties, if they affect among themselves, is checked by using a correlation matrix. This study will give us a feeling for those internal properties that can be adjusted and have great effect in order to meet a certain external property and therefore finally the standardised requirements.

5 SUMMARY

The QFD method offers new ways of structuring properties to create profile structures and gives insight into the dependencies of internal-external product properties and standard requirements. This is a attempt to use method of quality planning and adjust it to our conditions. One can gain insight into the dependencies of product properties relating to requirements and value. To specify those dependencies and give an exact interrelation of e.g. internal and external properties, physical models have to be considered to obtain a more qualitative connection between properties.
A first approach for a computer supported QFD has been done and further work on the implementation of the QFD into the design process of profile structures has to be done.

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