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TIDY UP DESIGN METHODS – AN APPROACH USING ELEMENTARY DESIGN METHODS

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1. Introduction

Design research offers a huge amount of design methods to improve efficiency and effectiveness of design work. However, in fact, a major amount of them does not leave the hemisphere of academia. Most design methods do not have a long-term impact nor in education either in practice [Birkhofer et al. 2005]. In addition, a substantial amount of methods seems to be only derivations or aggregations of previous published ones. In total, the world of design methods for a potential user in design practice appears rather heterogeneous and even obscure. Further, the application of design methods is rarely supported by advices how to adapt them to a specific design situation. The inflexibility and even rigidity of design methods are major obstacles hindering a widespread application in industry [Jänsch 2007].

Triggered by the vision of a limited set of elementary design methods representing basic prescriptive procedures, a corresponding research program was initiated at TU-Darmstadt. The objectives were to extract method-inherent basic procedures by analysing current design methods to evaluate these so-called *elementary design methods* by re-assembling them to known design methods and to create specific sequences of elementary methods according to a specific task and design situation. In total, the approach aims to tidy up the world of design methods [Birkhofer et al. 2002a], which seemed to be a most demanding, even utopian goal regarding previous attempts of various authors.

2. State of the art

A wide range of research work intends to capture the basic nature of design methods or to improve application by giving advices. Some approaches structure design methods according to specific characteristics like generalised steps of problem solving [Lindemann 2005] or specific objectives [Jones 1970]. Some approaches like the Process oriented Method Model (PoMM) [Birkhofer et al. 2002(b)] or the Basic Structure of Design Methods from Dobberkau [Dobberkau 2002] focuses on how to describe the variety of methods more generally to see similarities and differences. More often one can read approaches linking methods to design phases [VDI 1993, Pahl et al. 2003], or typical applications [Wach 1993]. Several attempts [Zanker 2000, Walter et al. 2003] in the past define elementary design methods as basic prescriptive procedures. Doing so, researchers wished to reduce the huge amount of published design methods to a limited set of basic (elementary) methods that represent the "petri dish" of design methodology.

Nevertheless, there is no consensus within the community about the preference of a specific approach. It seems to be a remarkable gap between the challenging demands of the individual researcher creating his own structure of design methodology and the perceptible benefits of these approaches for the research community.

3. Methodical approach

This contribution presents an approach to define elementary design methods, which differs substantially from previous ones. This contribution presents the way of analysing and reasoning as well as the results of the project [Walter 2007, Birkhofer 2007] describes in detail.

3.1 Basic recognitions

Regarding a presentation of the second House of Quality (HoQ) of a Quality Function Deployment (QFD) one can recognize its vector and matrix based structure (figure 1).

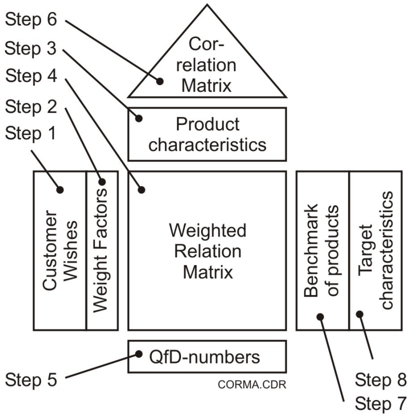


Figure 1. Second House of Quality (HoQ) of Quality Function Deployment (QFD)

Same as other methods like Morphological Box, Requirements List, Evaluation Charts or Design Structure Matrix the HoQ links vectors or matrices either to themselves or to other vectors resulting in new vectors or matrices. Beginning at the left side of the HoQ in figure 1 a user has to follow the procedure:

List customer wishes in the first column (vector of customer wishes)

1. Link them to a vector of weights (vector of weights)
2. List product characteristics
3. Link the customer wishes to product characteristics (central matrix)
4. Connect weight of customer wishes with product characteristics to a vector of QFD-numbers
5. Link product characteristics to themselves (correlation matrix or roof of HoQ)
6. Connect customer wishes to product properties
7. Connect product characteristics to target characteristics

In fact, the QFD may be reduced to a sequence of operations with vectors and matrices.

3.2 Elements, operations and elementary methods

Analysing nearly 90 currently used design methods, the vector- or matrix-approach became obvious. It is based on the phenomenon of semantically defined elementary methods, which may be created by applying syntactically defined operations on specific elements (vectors, matrices).

3.2.1 Elements

Elements are information-items, which are processed and/or regarded in design methods. Typical elements, which occur repeatedly in design methods, are:

- Processes
- Functions
- (Physical) Effects
- (Working) Principles
- (Real) Objects (like parts, components, units)

- Properties
- Characteristics and
- Values.

Of course, other types of elements may occur in specific design methods, but the eight named above represent a vast majority of elements currently used. Processes, functions, effects, principles and objects represent specific product models [Sauer, 2006] or products whereas properties, characteristics and values describe them according to the theory of technical systems [Hubka 1973]. In some applications a vector of elements degenerates to a single scalar, which should be seen as a kind of specialization.

3.2.2 Operations

Analysing up to 90 design methods, again a limited set of (five) basic operations was found:

- *"List"* is a special operation listing a set of elements in a sequential order (column or line). In fact, it is a kind of assigning, as these elements have to be taken from somewhere (catalogues, experience, textbooks…) and/or are assigned to a numbered sequence.
- *"Assign"* links two lists of elements belonging together. Concerning its semantic, it is "more" than the operation *list*, as the elements are not only listed but also put into a specific relation.
- *"Divide"* separates generic elements into sub-elements, which means, that the number of elements in the subdivided list is larger than the number of the generic elements.
- *"Merge"* may be seen as a kind of abstraction, which aggregates at least two sub-elements into a generic one. Therefore, this operation reduces the number of elements in the merged list.
- *"Connect"* is the most complex operation because it addresses hereby all types of functions between two elements. The operation especially covers logical, mathematical or heuristical relations between elements and results in a transformation of the original elements creating new information

The results of the operations "*Assign*", "*Divide*" and "*Merge*" are vector-oriented or matrices-oriented structures, the result of the operation "*Connect*" is a value-imposed matrix. Same with the elements, the limitation on five basic operations represents no final border, but the current status got by analysing about 90 design methods until now.

3.2.3 Elementary methods

It is now the linking of two specific elements with operations resulting in a scalar, vector or matrix which we call an elementary method. An elementary method represents a basic semantic unit and represents new information for the user not known before applying the method. Typical elementary methods are e.g.

- "weighting of evaluation criteria" which results in weighted criteria
- "comparing solutions with each other" which results in a ranking of solutions

Regarding figure 2 both lists of "*Solutions*" form the input, the operations "*Assign*" and "*Connect"* represent the procedure, and the (new) output is the matrix of weighting factors.

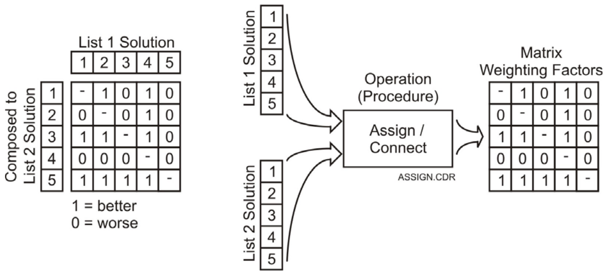


Figure 2. The definition of elementary methods shown at the paired comparison (left: the conventional method; right: the illustration of the related elementary method)

Altogether, the number of elementary design methods is based on just seven elements and five relations. This approach has cut out to be the beginnings of a precise definition and an almost complete set of elementary design methods.

4. Evaluation

Based on the elementary-methods-approach, current design methods now appear as containers [Birkhofer et al. 2001], structured by a sequence of different elementary methods representing their "*functional genomes*". In the meantime, about 40 design methods were traced back to a sequence of elementary methods. Figure 3 demonstrates a QFD of a mechatronic sensor in detail and figure 4 its functional genome.

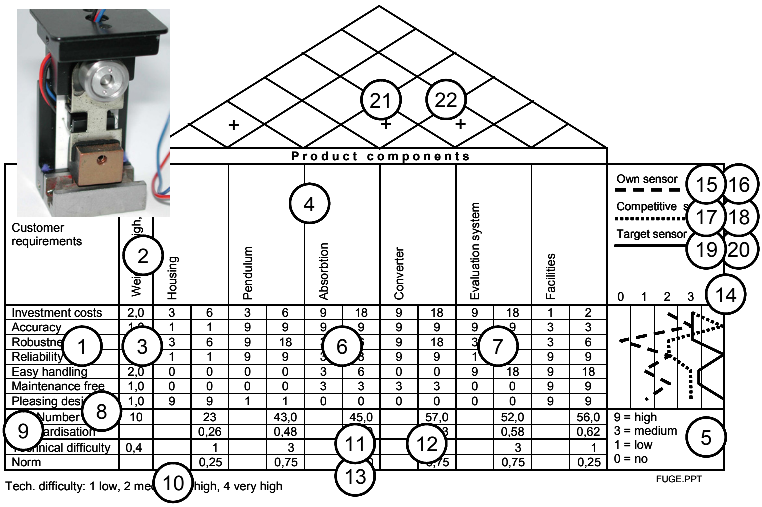


Figure 3. Quality Function Deployment (QFD) for a mechatronic sensor numbering the related elementary methods

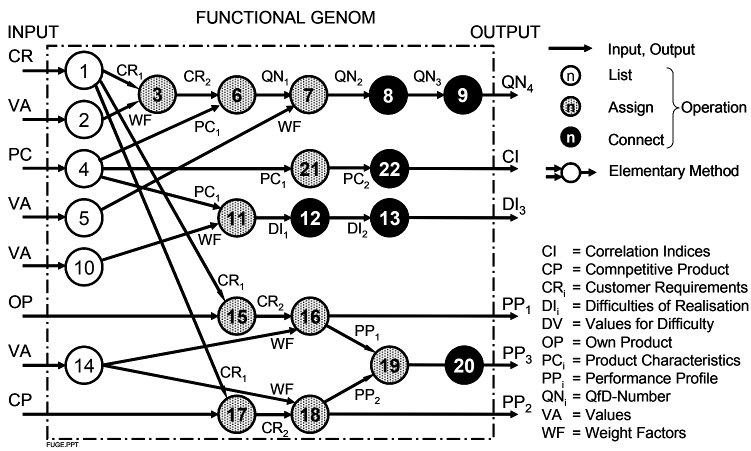


Figure 4. Functional Genome of the QFD according to figure 4 composed by elementary methods

Regarding figure 4 some specialties in regard to operations and elementary methods attract attention:

- The very first operations on left hand side are "*List"*-operations, which create the starting point of following procedures
- In the centre we see throughout a number of "*Assign*"-operations which link the input elements in specific, goal-oriented relations.
- Right hand side the assigned listed are processed and new information is created
- The HoQ uses 4 "*List"*-operations to define value-lists (no. 2, 5, 10 and 14) and 5 "*Assign"*-operations (no. 3, 7, 11, 16, 18) linking elements with weight factors, which indicates the assessing-character of this method
- Surprisingly no "*Divide"*-and "*Merge"*-operation are used in HoQ. In consequence the very nature of HoQ is not to structure information but to process it.

Detailed investigations have shown that also graphically oriented design methods, like "functional decomposition" or calculation methods like "calculation of the lifetime of a shaft under external loads" according to DIN 743 [DIN 2000], represent a multiple transformation process from a given input into the desired output according to the list approach. The only prerequisite to structure a design method into elementary methods is the one, that this method may be described in a presentation with scalars, vectors and matrices and related operations. It is already obvious at this time, that structuring design methods on a well defined basis and with a simple applicable procedure may increase the understanding of the working principles of this method substantially and create a huge scope for development in terms of flexibility.

5. Application and benefits

Even if the elaboration of the approach is still in progress, the results so far are promising for design research as well as for design practice.

5.1 Classification of design methods

The major part of the analysed design methods until now belong to the design phases "Clarification of task" and "Conceptual design". However, it is already obvious that most current design methods as well may be reduced to a limited set of elementary methods. It was already proven with methods from other design spheres like QFD, FMEA, Eco-Indicator, Design for Experiments, Cost Calculation Methods and Value Analysis. Based on this fact, it is easy to see the "parents" as well as the "children" of a design method by comparing the shared genomes. Just the same, it should be easy to detect similarities and differences between different design methods by comparing the particular genomes. Ongoing work is dedicated to an algorithm-based approach of comparing different "genomes" using an artificial language.
In addition one may now assess the level of difficulty of a given design method. If elementary methods are assessed due to their origin level of difficulty, than the level of difficulty for a given method may be estimated according to the equitation

$S = \sum (A_i \cdot s_i)$ *with* S = level of difficulty of a complex method
A_i = Number of a specific elementary method occurring in the sequence
s_i = level of difficulty of a elementary method
i = Index for each of the 5 elementary methods

As a first result, about half of the analysed design methods were calculated (table 1).
This estimation does not take into consideration the amount of work to carry out a specific application. Rather it indicates how difficult it is to capture the method.

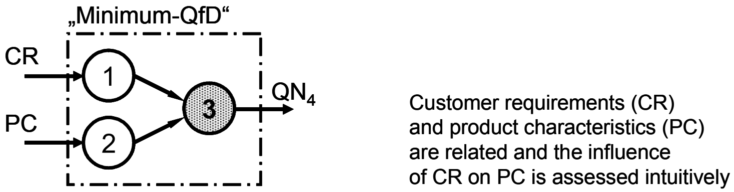
5.2 Flexible adaptation of design methods

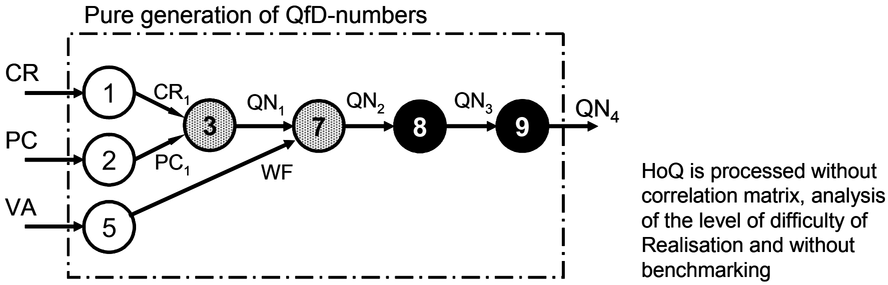
Using the genome-concept of a specific method seems to be quite easy to change it to fit a specific design situation. Knowing the whole range for reducing and enlarging a given design method may be directly used for a flexible adaptation of methods to a specific design environment. In this sense, a "Minimum-QFD" is nothing else than an elementary method, which directly links product components to customer wishes according to the related importance. Designers discussing or elaborating design preferences quite often use this method intuitively, but nobody count it to the QFD-family, where it belongs to in fact!

Table 1. Rough estimation of the level of difficulty of some design methods

Design Method	Level of difficulty
Use of Checklists	2
Use of Design Catalogues	3
Morphological Box	3
Intuitive Evaluation of Solutions	4
Compatibility Analysis	5
Functional Decomposition	7
Goal conflict analysis	7
Weighted Paired Comparison	9
Selection list	9
Eco-Indicator 95	11
Requirement List	13
Function Costs Analysis	14
Kano-Analysis	17
Quality Function Deployment	22
Systematic Product Evaluation VDI 2225	34
Failure Mode and Effects Analysis (FMEA)	41

Each stage from a Minimum-QFD over the standard one to an extended QFD is in the end nothing else than a question of reducing or enlarging the genome. Figure 5 demonstrates three examples of a specific reduction, mixture and enlargement of HoQ-subgenoms according to a specific design task.
As the research work on elementary methods is ongoing, it is hard to evaluate the benefit for education and training at this time. Nevertheless, one has to be aware of the promising perspectives for a deepened insight into the working principles of a design method and in consequence for its professional use which means flexibility and performance of methodical work.





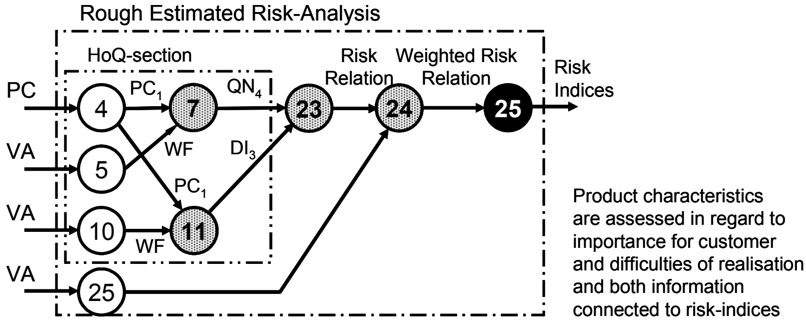


Figure 5. A set of different QFD with its genomes reduced for creating specific outputs

5.3 Automated generation of an appropriate design method and its description

Conversely, the characteristics of a specific design project may be compared with the prerequisites of elementary methods. If the available input, the desired output and the design environment or situation are known, there may be a vision that a "Method Creating Tool" will create or at least suggest an appropriate method automatically. This vision is partly realised in the so-called "*Dynamic Process Generator*" of the *pinngate*-navigator [Weiß 2006], which creates process chains automatically out of a set of given process modules, if inputs and outputs are defined. Combined with the standardisation of method description in the PoMM-approach [Birkhofer et al. 2002(b)] a powerful tool may be developed in future, to support design practice substantially with a design environment specific *Method Creator*.

6. Conclusion

The elementary method-approach in order to defining elementary methods has proven powerful in systematising existing and creating adapted design methods [Birkhofer et al. 2002a]. The clear definition of elements and operations and the obvious derivation of the elementary methods reduce or even avoid interpretation problems arising from different views and meanings. The remarkable success of the approach so far shows that it most likely satisfies a specific element of human communication. It seems that the linking of elements with relations is a commonly used and powerful procedure to transmit information from one person to another.

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