PROPERTIES AND CHARACTERISTICS AND ATTRIBUTES AND… - AN APPROACH ON STRUCTURING THE DESCRIPTION OF TECHNICAL SYSTEMS

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1. Motivation

The methodology of designing technical systems is published in numerous books and articles and well established in curricula of university design departments. In spite of a reasonable success in teaching and learning design methodology a main obstacle seems to be the huge variety in terminology, meanings and interpretations hindering researchers as well as practitioners to find their way around different design-schools and to select the appropriate approach for an actual design task [Birkhofer 2006]. This irritates all the more as already since about 25 years the fundamental work of Hubka [Hubka 1983] defines quite properly a Theory of Technical Systems (TTS) as a basis for founding design methodology. Hubka specifies properties of the technical system (TS) as all features belonging to the object [Hubka 1996]. Properties are classified into external and internal properties. External properties are the outbound and perceivable properties of a TS and are caused by internal properties. In addition other authors like Andreasen, Weber, Eder, Hosnedl contributed to Hubkas approach substantially in enlarging, detailing and focussing the view on TTS. Weber [Weber 2005] distinguishes between characteristics and properties of a product. Characteristics describe the structure, shape and material of a product and can be influenced by the designer in a direct manner, whereas properties describe the product's behaviour. Nevertheless a commonly agreed set of terms and related concepts is still missing and as "far as the eyes could see" there is a substantial lack of serious efforts to consolidate the structure and description of TTS. Based on different attempts within the context of meetings and conferences organized by the Design Society this contribution tries to capture one of the almost numerous ropes of the consolidation topic by focussing on a universally valid way how to describe TTS. Triggered also by an intensive discussion within the Special Interest Group (SIG) "Applied Engineering Design Science (AEDS)" on properties, characteristics, values, attributes and related terms this contribution does not struggle with terms only but initially tries to clarify the meaning behind.

2. Methods used for clarifying terms and meanings to describe Technical Systems

Unlike creative design, which is stimulated by visual ideas and mental concepts [Lindemann 2003], systematic design is founded on models a part of them are TTS-models. According to Hubka & Eder [Hubka 1996] Technical Systems are understood here as an entirety of (product representing) objects and processes and the relations between them.
TTS models enable researchers e.g. to analyse existing technical systems and to create design catalogues or databases with solution elements. Designers may use models e.g. for

structuring existing products and processes and for creating new ones by variation techniques. In fact an awareness of such models and their conscious application may be seen as one key-element for successful design. Looking at numerous examples [Birkhofer 2004] it's evident that the conscious use of TTS-models and related design methods also forces creativity and may lead to substantial innovation.

A key-role for modelling TTS plays the term "Eigenschaften". The German term "Eigenschaften" is used in this contribution further on to neutralise specific and maybe one-sided views and to avoid intellectual prejudices. Numerous types and classifications of "Eigenschaften" exist in literature and the legitimate question, which of them are true or correct has to be seen as a wrong question. Each classification of "Eigenschaften" is linked to concepts or models behind and serves or at least should serve a specific purpose. In this paper "Eigenschaften" are analysed and categorized for highlighting their role for design science and design methodology and to deepen the understanding of the synthesis character of design.

This contribution is based on product and process models used at Technische Universität Darmstadt, which have proven well in design research as well as in design application. These models allow to separate different types of "Eigenschaften" in regard to specific views. A stepwise approach of clarification should guide readers and listeners from one level of abstraction to another one. The types and definitions are first illustrated on a current and easily understandable example and afterwards treated in a generalized way. The authors hope that this way of presenting may lead to a more impartial content-related discussion about "Eigenschaften" as a fundamental part of Design Science.

3 The example profile manufactured by new forming process

A multi-chambered profile which is being used as a heat exchanger delivers a universal example. Our approach will be explained with this demonstrator heat exchanger profile. Heat exchangers are widely used in industry both for cooling and heating large scale industrial processes. In many industrial processes there is waste of energy or a heat stream that is being exhausted. Heat exchangers can be used to recover this exhausted heat and use this heat for heating a different stream in the process [Kakac 2002]. This practice saves a lot of money in industry as the heat supplied to other streams from the heat exchangers has to be generated otherwise from an external source which is more expensive and more harmful to the environment.

An innovative production technology to manufacture such a profile, called linear flow splitting and linear bend splitting, create the foundation of the Collaborative Research Centre 666 (CRC 666, German: Sonderforschungsbereich 666, SFB 666) of the Technische Universität Darmstadt. Linear flow splitting and linear bend splitting allow branched profiles to be formed using sheet metal in integral style without joining, laminating material or welding the semi-finished part. They are new massive forming processes for the production of bifurcated profiles in integral style. The semi-finished part is a sheet metal plane, which is transformed at ambient temperature by a specific tooling system consisting of obtuse angled splitting rolls and supporting rolls. The fixed tool system forms the translatory moved work piece in discreet steps up to a profile with the final geometry. Using a subsequent forming process, new multi-chambered structures with thin-walled cross-sections can be made from sheet metal (Figure 1).

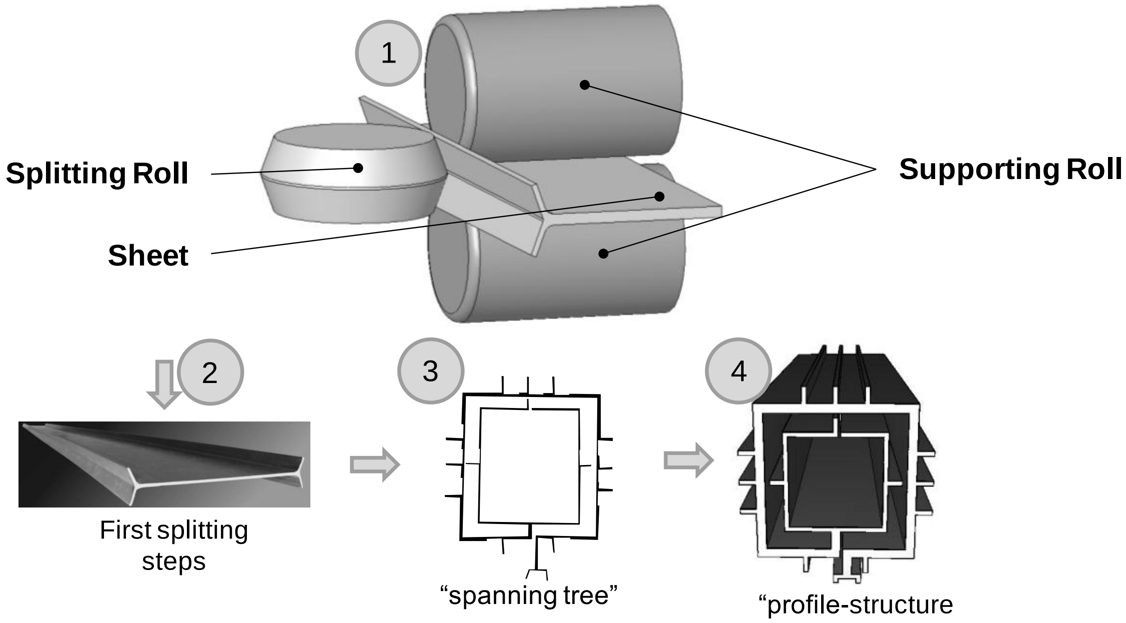


Figure 1. Manufacturing a multi-chambered heat exchanger

Using renewed linear flow splitting and linear bend splitting at the end of the flange and forming of the profiles, numerous new possibilities for chambered profiles optimizing lightweight design arise [Groche 2006]. Figure 1 shows such a profile with 12 free flanges which are used for a better heat conduction and five chambers to channel hot and cold liquids or gas. To produce those multi-chambered profiles, a continuous production line was established at TU Darmstadt. It consists of several linear flow splitting tool systems, roll forming tool systems, high-speed-cutting (HSC) and laser welding systems in one production line. In comparison with the bar extrusion process, e.g., the continued processing of linear flow split profiles offers the possibility to integrate features into the profile using milling or drilling procedures. An application possibility can be an increase of the surface area inside the profile to optimise the heat flow between the chambers.

4 General remarks to describe Technical Systems

An important aspect to describe Technical Systems (TS) is the theory of its "Eigenschaften". Every TS can be described or identified by its "Eigenschaften", it is designed only because certain "Eigenschaften" are desired, used and valued [Hubka 1996]. Every TS carries its "Eigenschaften" whether they have been knowingly designed.

4.1 The distinction between Identification and Description

There are two ways to capture a product like the heat exchanger of figure 1:

1. Identification is based on a formal term (name, number, symbol) linked to the product. Looking in a catalogue of a plumbing shop the heat exchanger might be found under the identification-number H3-OOU 64F, which indicates a specific type and size. The material is specified by ZStE500 which indicates a certain type of high strength steel, specified in the SEW 093 material worksheet (Stahl-Eisen-Werkstoffblatt). Both identifications are abstract names coding geometry and material in a way, only experts with related knowledge get a vision about form, size, structure and material.
2. Description is a way, to illustrate a product by characterising its "Eigenschaften". The heat exchanger has a length of 2.45 meter, is separated in 5 sub-channels, has a grey colour and is made from structural steel sheet with a thickness of 3 millimetres. Everyone with a sufficient awareness of such "Eigenschaften" can now imagine the product or at least its concept.

Whereas identification is heavily used in technical standards and catalogues, description is the most common way in human communication to illustrate objects, processes, situations or even abstract concepts like love or truth. An identification is a placeholder for a product, product part or material which also can be defined descriptively by its “Eigenschaften”. For design and design methodology purposes the concept of description by “Eigenschaften” is a most powerful one which enables the formalisation of description and is starting-point for any variation-technique and mathematical optimisation routine.

4.2. The formalism of a description

Description of a TS by “Eigenschaften” is done always in the same way. The length of the heat exchanger is 2.45 meter, it links the value 2.45 meter (in German “Wert”) to the attribute length (in German “Merkmal”). Attribute and a related value form what we call “Eigenschaft” [Birkhofer 1980] and it is related in our case to the object heat exchanger. This concept of description is truly generic, even if we break often this strict rule in daily use in some sloppy way. If we say: “The heat exchanger is grey” exactly we mean: “The colour (attribute) of the heat exchanger (object) is grey (value).

Once again: The definition of “Eigenschaften” as a set of an attribute and a related value (with or without dimension) related to an object or to anything else is fundamental for design science and design methodology. Products differ if at least one “Eigenschaft” differs which means that either a new “Eigenschaft“ can be seen (a heat exchanger without cooling rips) or another value for the same attribute creates a new product (a heat exchanger with the length of 1.6 meter). Comparing “Eigenschaften” is the basis for the powerful theory of similarities and also enables systematic variation of products by changing values for given attributes.

5. The distinction between independent and dependent „Eigenschaften“

This chapter explains the different types of “Eigenschaften” in order to describe objects. Object is used hereby as a generic term for all product representing models like functions, working principles, prototypes or even as the most concrete model the product by itself.

5.1 Independent “Eigenschaften”

5.1.1 The independent „Eigenschaften“ of a Technical System (3D-CAD model)

Looking at a TS (3D CAD-drawing) of a heat exchanger one can recognize a lot of “Eigenschaften” some of them are highlighted in figure 2.

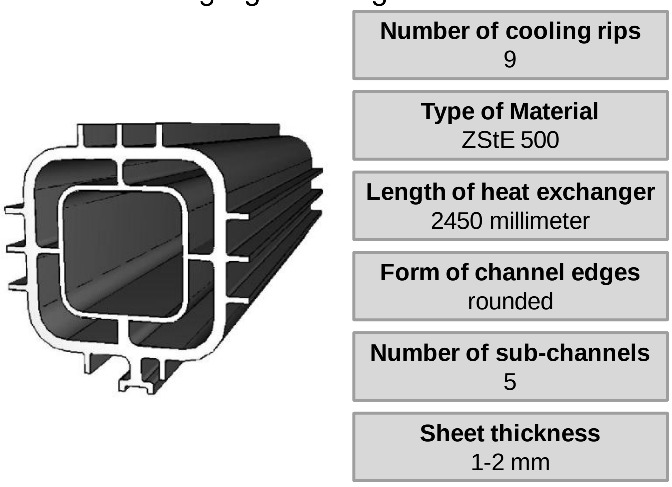


Figure 2. Example “heat exchanger” – independant “Eigenschaften”

All these „Eigenschaften“ are geometrical or material properties. Geometrical properties can be macro-geometrical ones like form, number, arrangement and size of specific elements like profiles or profile-features. Even micro-geometrical product elements like surfaces, surface

roughness or grains of metallic may be described in such a way. In fact 3D-CAD is a very powerful tool, but originally limited on modelling and visualizing geometry. A designer working in 3D-CAD can't give any input but only geometrical ones and he can assign certain materials to its model. The material itself is specified by certain material "Eigenschaften", e.g. the sheet metal ZStE 500 has a certain density or elastic limit.
These "Eigenschaften" directly fixed by the designer working on a product-model e.g. 3D-CAD we call independent "Eigenschaften". They are the constituents of a specific model and distinguish different models.

5.1.2 The dependent „Eigenschaften" of a Technical System (3D-CAD model)

When establishing independent "Eigenschaften" during the design process e.g. on our 3D-CAD model, we indirectly design a lot of dependent "Eigenschaften". Dependent means that these "Eigenschaften" depend on the determination of independent "Eigenschaften". Figure 3 shows a set of relevant dependent "Eigenschaften" of a heat exchanger a designer has to design in order to fulfil certain required "Eigenschaften".

Heat recovery 80 %
Max. air volume flow 330 m³/h
Weight 37 kg
Max. deflection 9 mm
Heat resistance 0,9*10^{-3} K/W
Ease of maintenance easy

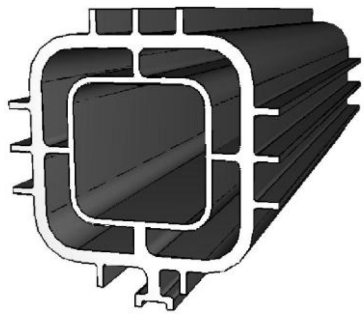


Figure 3. Example "heat exchanger" – dependent "Eigenschaften"

In order to change the dependent "Eigenschaft" heat resistance the designer is only able to determine independent "Eigenschaften", which have a direct effect on the heat resistance (figure 4). To minimize the deflection of a heat exchanger attached to the workshop roof the designer has to design a "stiff" geometry, providing more support fixings at the roof or choose a "stiff" material.

5.1.3 The link between dependent and independent "Eigenschaften"

The example in 5.1.2 has shown that the link between independent and dependent "Eigenschaften" is of fundamental importance for the design process and therefore has to be analyzed. This knowledge of "Eigenschaften" and their relation is often stored in scientific literature (e.g. guidelines, textbooks). These sources of information consist e.g. of texts, formulas, graphs and tables. Even a physical model like the heat resistance model consists of a heat transfer formulas, an explaining text and a illustration provide more insights to the problem. This model links the heat resistance of the profile to the geometry, as well as to the material properties of the heat exchanger itself. This specific knowledge enables one to decide which independent "Eigenschaften" to concentrate on in order to create the required dependent "Eigenschaft". To represent the dependencies of "Eigenschaften" a network structure is introduced [Wäldele 2006]. In this network structure, called the property-network, the dependencies are clearly defined, coming from dependent to the independent "Eigenschaften" of a product.

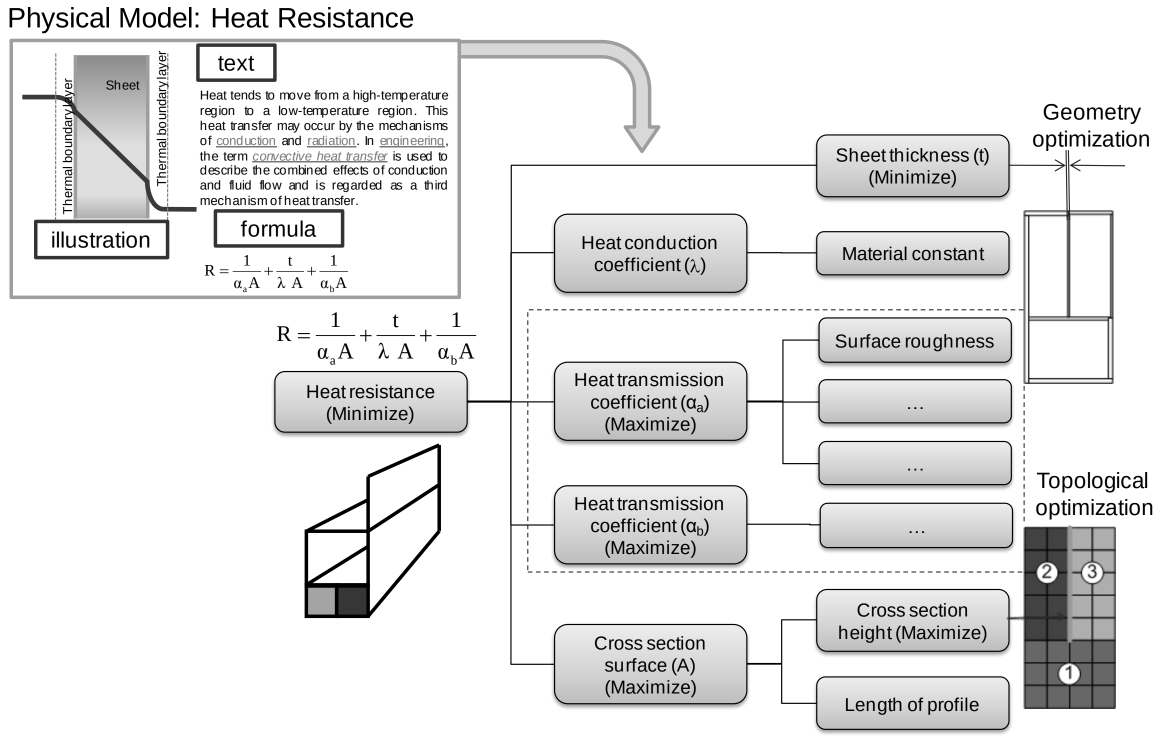


Figure 4. Dependencies between the dependent "Eigenschaft" "heat resistance" and independent "Eigenschaften"

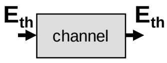
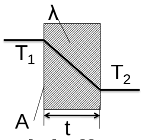
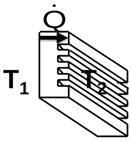
Dependent "Eigenschaften" can always be traced back to independent "Eigenschaften". This means that dependent and independent "Eigenschaften" always have a certain relationship to one another. Not only must a designer know which individual parameters influence a dependent "Eigenschaften", he must also know which "setscrews", and therefore independent "Eigenschaften", he must adjust to achieve his desired external properties [Wäldele 2007].

5.1.2 The independent „Eigenschaften" of product models in general

The previous chapter highlighted „Eigenschaften" regarding geometric product representation within a 3D-CAD. In design methodology more product related object models are known and used. A common approach in systematic design is the approach of the product model pyramid [Andreasen 1987, Ehrlenspiel 2007]. The dissertation of Sauer [Sauer 2005] separates each model in its (constituent) elements and its structure. This approach is valuable, because it clearly demonstrates basic similarities within the "composition" of different product representing models.
Elements and structure of each partial product-model can be described completely and clearly by their independent "Eigenschaften".

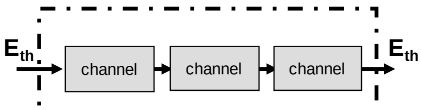
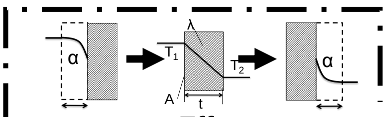
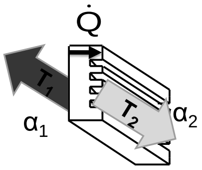
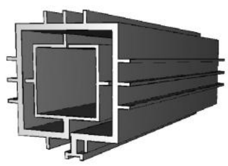
- The type of a model-element may be described by „Eigenschaften" like type, number, form or size of its subelements (figure 5)
- The Type of an model-structure may be described completely and clearly by „Eigenschaften" concerning the type and number of model-elements and relational „Eigenschaften" concerning logical, topological or geometric relations between the elements (figure 6)

By the way, that's why the „Eigenschaft" function e.g. cannot be assigned to an independent "Eigenschaft". Function is an independent "Eigenschaften" within the functional model, but a dependent "Eigenschaften" e.g. within the model of working principles. Obviously the number of independent "Eigenschaften" of each models is quite limited, in fact the number of model-variants is infinite due to the huge amount of values for each of its "Eigenschaften" as well as due to the unlimited number of combinations of elements.

Model-elements			Independent „Eigenschaften“
 **Subfunction**	Type of function	**defined by**	• Type, number and order[1] of variable (Input / output variable) •Type of operation
 **(Sub-)effect**	Type of effect	**defined by**	Type, number, size, order and arrangement[1,2] of • Effect-elements (m, c, d, I, A, ρ…) • Effectunits(F, M, U, v, I, p…)
 **Working principle**	Type of working principle	**defined by**	Type , number, size, order and arrangement[1,2] of • Working surface • Working space • Working motion
 **Component**	Type of component	**defined by**	• Type, number, measurement and arrangement[2] of partical surface • Material

[1] topological relation
[2] geometrical relation

Figure 5. The independent “Eigenschaften” of elements of product models

Model-structure			Independent „Eigenschaften“
 **Function structure**	Type of the Function structure	**defined by**	Type, number and order[1] and system boundary of the subfunctions
 **Effect structure**	Type of the effect structure	**defined by**	Type, number, size, order and arrangement[1,2] of the sub-effects
 **Working structure**	Type of working structure	**defined by**	Type , number, size, order and arrangement[1,2] of the working principles
 **Construction structure**	Type of the construction structure	**defined by**	Type, number and arrangement[2] of the components

[1] topological relation
[2] geometrical relation

Figure 6. The independent “Eigenschaften” of the structure of product models

5.2 Dependent Eigenschaften

5.1.2 The dependent „Eigenschaften“ of product models in general

Heat exchangers are widely used in industry both for cooling and heating large scale industrial processes. Industrial processes usually reject surplus heat. In the right circumstances, heat recovery techniques can make effective use of this heat by using various equipment or systems. This surplus heat may arise as hot exhausts from ovens or furnaces. Using the heat of hot exhausts saves a lot of money in industry as the heat supplied to other streams from the heat exchangers would otherwise come from an external source which is more expensive and more harmful to the environment. The type and size of heat exchanger used can be tailored to suit a process depending on the type of fluid, its phase, temperature, density, viscosity, pressures, chemical composition and various other thermodynamic properties.
These types of “Eigenschaften“ depend (not only, but also) on the geometry the designer has directly fixed in his 3D-CAD model. It’s the same with numerous other “Eigenschaften“ like weight, inertia moment, strength, stresses, heat resistance, corrosion resistance or glance. The entirety of these “Eigenschaften“ resulting from the initially fixed geometric (and material-) “Eigenschaften“ and other influences (see chapter 5.2.1) we call dependent “Eigenschaften”. Once again these dependent “Eigenschaften” may be assigned to elements (figure 7). as well as the structure of each model (figure 8).

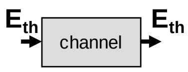
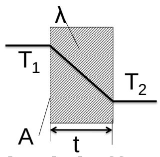
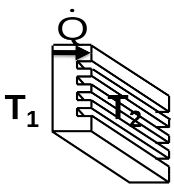
Model-elements	**Dependent „Eigenschaften“**
 **Subfunction**	• Effort of realisation • Importance of function • Function costs •…
 **(Sub-)effect**	• Time dependency (Drift, Offset…) • Duration of effect • Energy supply • Position dependency •…
 **Working principle**	• Kinematics • Efficiency • Power dissipation • Type of lubrication • Risk of abrasion •…
 **Component**	• Handling • Design /impression • Manufacturing costs • Lifetime • Scratch resistance •…

Figure 7. Some dependent “Eigenschaften” of elements of product models

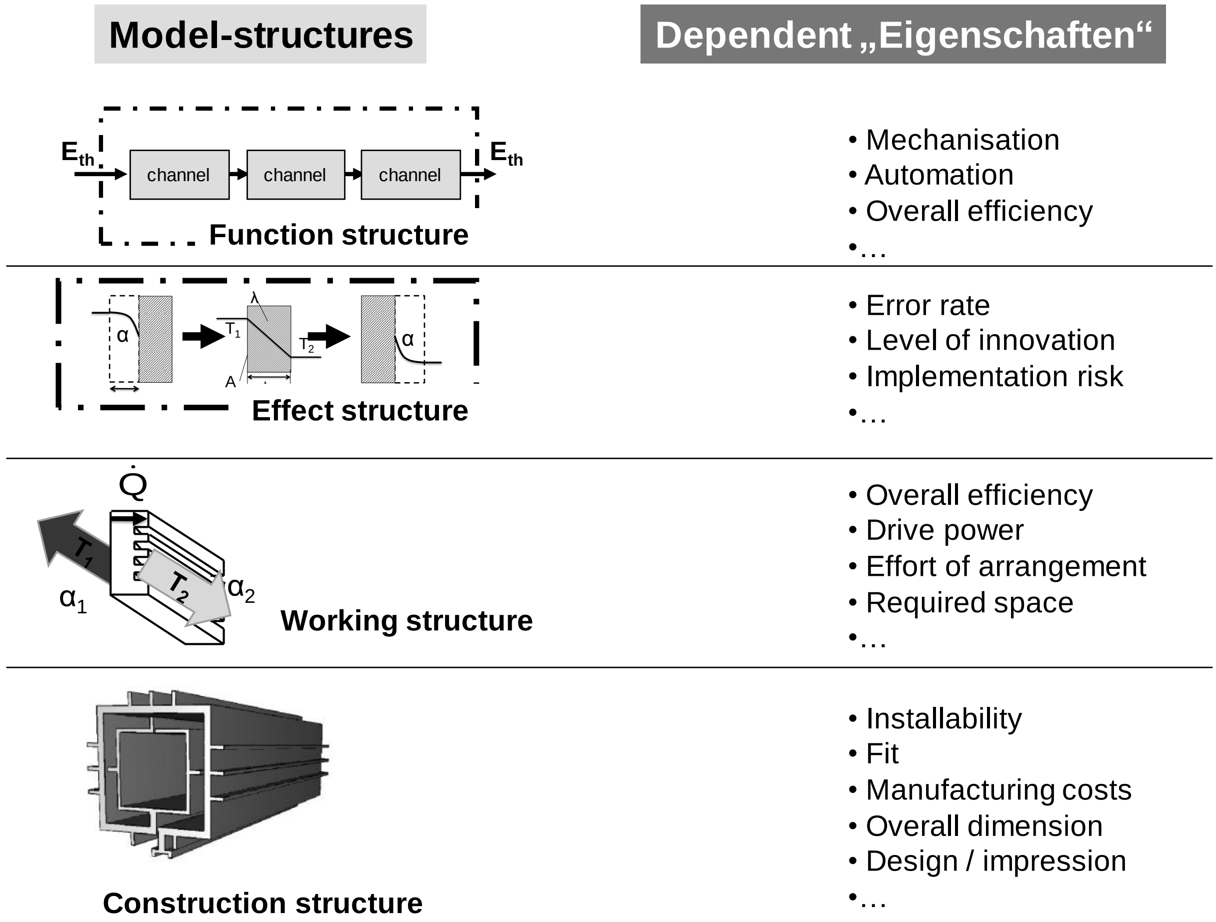


Figure 8. Some dependent "Eigenschaften" of the structure of product models

Dependent "Eigenschaften" are also related to models, but not in such an exclusivity as the independent ones. For the heat exchanger e.g. the bending resistance may be of interest in the working principle model as well as in the geometrical model. Of course each product model aims on an specific area of independent „Eigenschaften" (which means each model serves for a specific purpose), but these areas are overlapping.

5.2.2 Process influences on dependent „Eigenschaften"

If we put a load on the heat exchanger like its deadweight or an external weight of assembled tubes we can see or measure a deformation –a deflection- of the heat exchanger. Regarding different dependent "Eigenschaft" shown in figure 3 it is obvious, that e.g. the deflection of the heat exchanger is not only caused by geometrical and material "Eigenschaften", but is also determined by external loads and the location of supports. Same as heat flow between the channels. The heat recovery is not only dependent on the geometrical and material "Eigenschaften" but also on the temperatures of the fluids, their flow velocity and environmental factors like atmospheric pressure or humidity. Any object gets functionality and creates benefit only if it is part of a process. A heat exchanger deposit in space near the Andromeda-nebula has no functionality at all and is absolutely useless. But if we connect it in a factory in Germany to an exhaust air outlet and a fresh air inlet and open the valves, then in this process it serves a purpose and has a value for the user.
To get onto the trail of such object and process influenced dependent „Eigenschaften" is quite a challenging task and much more complicated as to detail the independent „Eigenschaften" of an object. Well settled models like the Life-Cycle-Model and the Process-Model support substantially to get a holistic overview as well as a direct access to the related "Eigenschaften".

A further differentiation within the area of dependent „Eigenschaften“ may be done in regard to dependent “Eigenschaften“ caused only by the model-inherent independent “Eigenschaften“ and not by process elements in addition. In the case of geometrical and material related models different primary independent “Eigenschaften“ may be connected to higher aggregated secondary, tertiary and so on “Eigenschaften”. The cross-section area A between the channels as active surface for the heat transfer is the product of its cross-section heights and lengths of the profile without any influence of a process. Other examples of such dependent “Eigenschaften“ influenced only by independent “Eigenschaften“ of the model are volume, mass, moment of inertia or electric and thermodynamic capacity and resistance. These type of higher aggregated “Eigenschaften“ mostly defines artificial “Eigenschaften“ used within design processes e.g. for calculating deflection of a bar or stresses within a part. Such a higher aggregation of primary “Eigenschaften“ saves time for calculation and enables designers to recognize specific characteristics and estimate suitability of a specific object for its use.

5.2.3 Some remarks to the modelpyramid and its implications for design science an practice

The model pyramid with its partial models is well defined to its purpose for design practice. It supports designers to proceed stepwise from given or targeted processes in the use phase to geometric and material related definition of parts, components and products. The function-, effect- and working principle-model contain process related quantities like forces, current or hydraulic pressure and object related ones like density, elasticity or dilatation. Simonek [Simonek 1974] called the former one “Funktionsgrößen” and the later ones “Konstruktionsgrößen”.
On each level of model the product is concretised, which means more and more product “Eigenschaften” were added until the final state of design, the complete product representation in form of drawings and part lists is achieved. A central challenge throughout this stepwise approach is the alignment of dependent “Eigenschaften” with requirements. Once a level of modelling has been completed and the next lower level has to be worked out, all the previously defined “Eigenschaften” have to be retained, which of course is an idealistic view and sometimes neglected in real design work. They live so to say “hidden” in the later product models.

5.2.2.2.1 The Life-Cycle Model

The Life-Cycle-Model of the CRC 392 (Sonderforschungsbereich 392) [Abele 2005] consists of material processing, production, product use and recycle/disposal (figure 9).

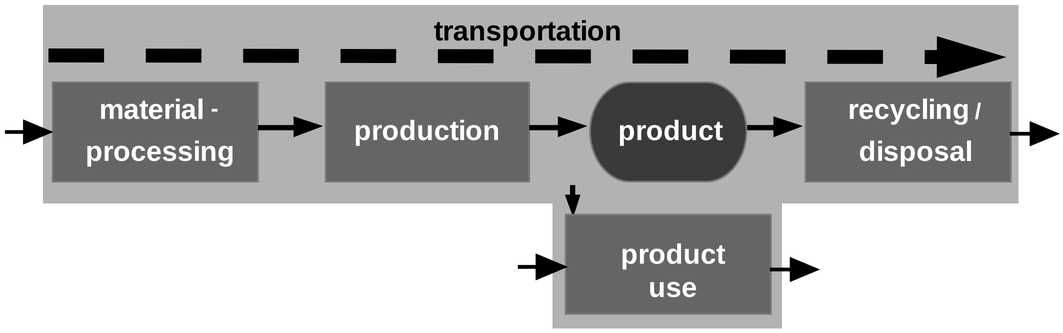


Figure 9: Product Life-Cycle-Model

The earliest life cycle phase material processing includes all steps from the extraction of resources (e.g. iron ore) to the production of semi-finished products, which is in our case the coil of steel sheet which is then processed in a continuous production line. The production of the heat exchanger covers all technical processes needed to manufacture the final product starting with the semi-finished product. The manufacturing processes in the continuous production line of CRC 666 consist of linear flow splitting and linear split bending as new

innovative processes, but also roll forming, drilling, high-speed-cutting (HSC) and laser welding processes. The output of this life cycle phase is the distributed product, the profile structure used as heat exchanger.
At the end of the product's life cycle the product becomes waste and loses its functionality. During this last phase the product is recycled or disposed.
A remarkable difference and a most important one for understanding design is the different role of a product in the use phase in relation to the other phases of life-cycle:

- In the use phase the product is an operator used to "transform" (as Hubka calls it) an object like a lawn or a shaft or a used battery from one state into another one. In our example the heat exchanger exchanges the heat in between the hot process air and cold fresh air. The operand in the case is the air and the operator the heat exchanger.
- In the other phases the product and its components and parts are operands, which are produced, manufactured, assembled, disassembled or disposed. In these cases the operators are machines, tools or workers. In our heat exchanger example during the production life phase the continuous production line can be seen as the operator. The semi-finished product sheet metal is being transformed in several subsequent manufacturing processes (e.g. decoil, linear flow splitting, roll forming, welding and cutting) to the final product.

5.2.2.2.2 The Process Model

The process model of Heidemann [Heidemann 2001] has proven well to visualise and structure processes of the life cycle of a product. It characterizes a process as the temporal transfer of an object from an initial state to a final state. Depending on the life phase of the product "heat exchanger", it can be seen as operand or operator. In the case of linear flow splitting, sheet metal as a semi-finished part is transformed into a bifurcated profile, which then is processed in further manufacturing processes. Figure 10 shows the transformation of the object's properties from the initial state to the final state. The most obviously modified property is the shape of the sheet metal, and therefore the geometrical measurements, e.g. sheet metal thickness, flange length, flange width. On the first glance, the process model reveals that the description of linear flow splitting needs to be differentiated into processes and objects. The sheet metal is regarded as an object transformed into a bifurcated profile, which represents a second object. The process is the cold forming of the sheet metal by inducing compressive stress

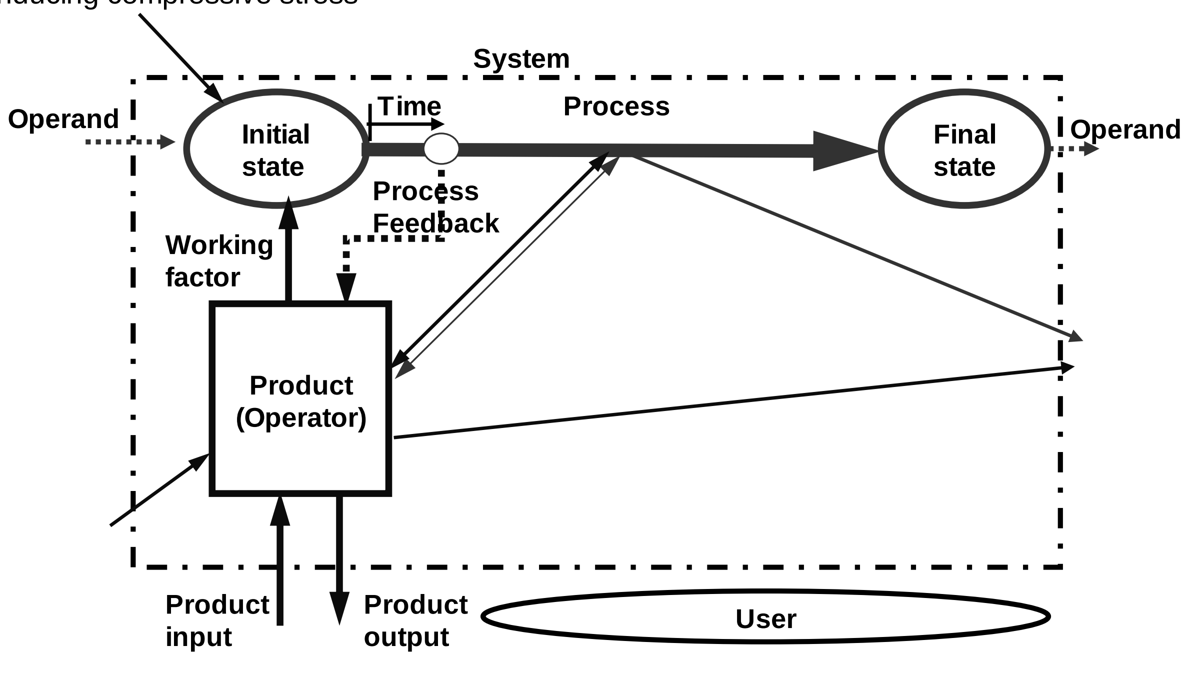


Figure 10. Extended process model [Heidemann 2001]

5.2.2.2.3 Dependent „Eigenschaften“ of a product in the operator role (use phase)

The role of a product as an operator, which serves a special purpose in the use phase is the standard role, every designer has in mind first when he is designing. A heat exchanger should exchange heat between liquids or gas, should guide these fluids without any leakage, should support his own weight and so on.
Dependent “Eigenschaften“ in such an “active” product role may be detected by applying the process model with the product (or its components) as an operator. Figure 11 demonstrates the systematic deduction of influencing factors and influences working in the process of heat transfer within a heat exchanger.

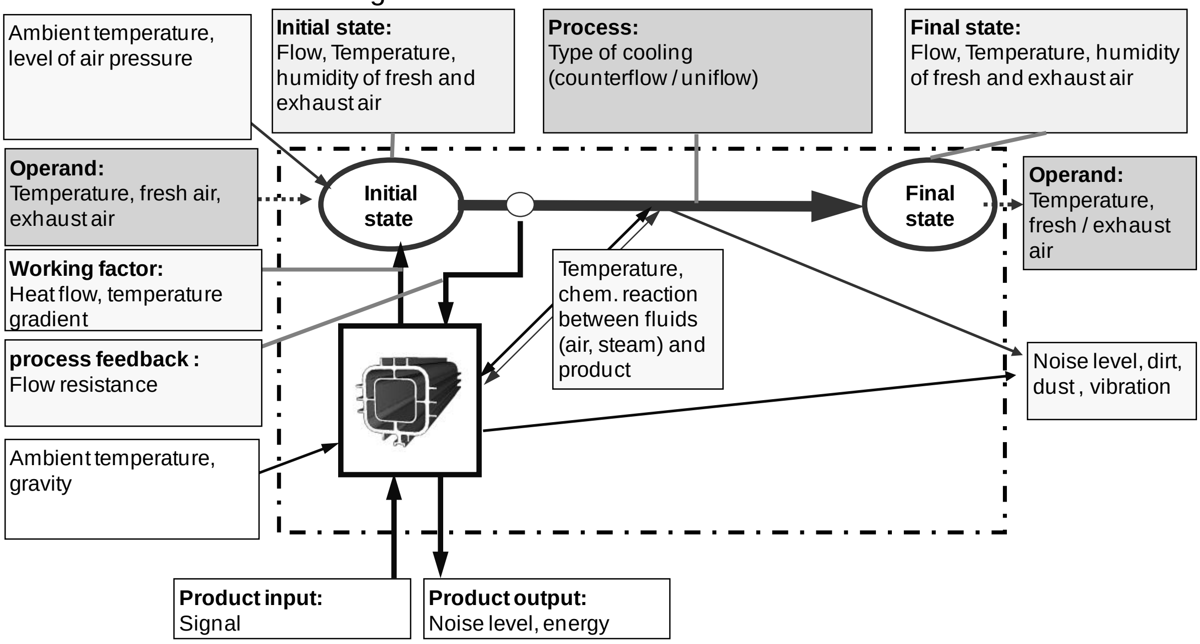


Figure 11: Process model of a heat exchanging process with influencing factors and influences (only examples)

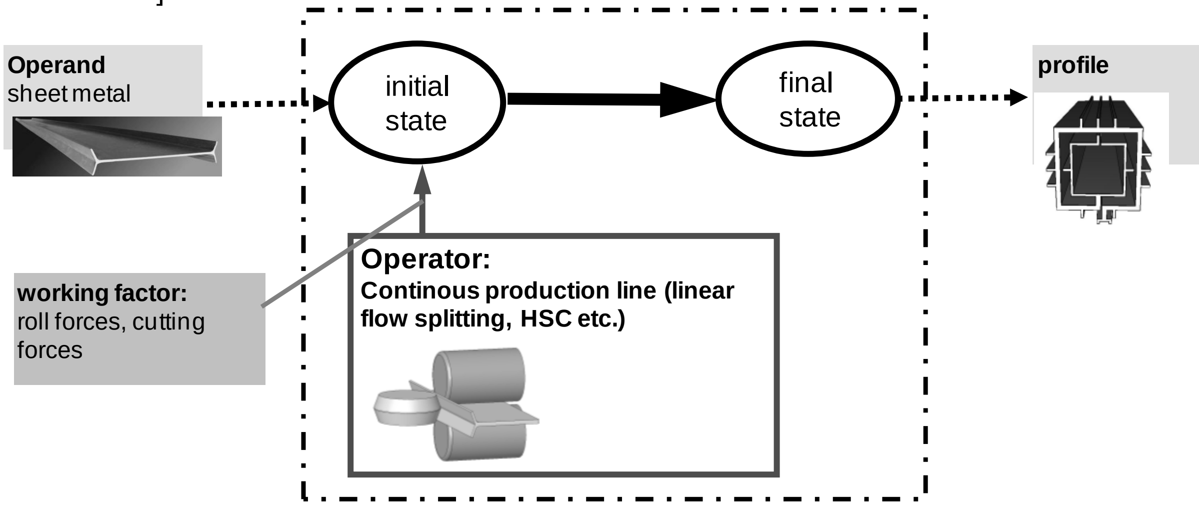
Influencing factors and influences may also be described by “Eigenschaften”, a remarkable amount of them are dependent “Eigenschaften” and normally are called product “Eigenschaften” (figure 11).
Figure 11 should demonstrate, that a well defined process model is the key for a systematic search for dependent “Eigenschaften”.
There are further and well established proposals to structure dependent “Eigenschaften“ further on e.g. in mechanical, thermo dynamical, fluid dynamical or electrical “Eigenschaften”. Also the mode of operation, the external loads or the load spectrum are used to highlight influences on product “Eigenschaften” due to their importance for proper design. Nevertheless all these classifications are formulated for practical reasons and do not affect the fundament of design methodology.
Maybe an analogon to the classification of environmental effects may separate dependent “Eigenschaften” of a product in the operator role in a more general way. Dependent “Eigenschaften” may be called

- local, if they refer to the specific purpose the product serves like stress, load spectrum or the mode of operation
- regional, if they refer to influences, which occur normally in the environment of the product, but are not specific for it like climatic conditions or influences of neighbouring systems.
- global, if they result from influences common for all products on earth like gravity and its resulting acceleration.

Even if the borders between these categories are fluent this may support understanding and increase efficiency of modelling.

5.2.2.2.4 Dependent „Eigenschaften“ of a product in the operand role (all phases without use phase)

Dependent “Eigenschaften” in such a “passive” product role within a process may also be detected by applying the process model. The passive role means, that the product, its components or parts will be transformed by themselves. Figure 12 shows a process of the life-phase “production”. The operand in this case is the sheet metal being “transformed” to a profile structure. The operator is the continuous production line with e.g. linear flow splitting stands which consists of components like the splitting roll, the support roll, and so on, and is steered by parameters like the incremental splitting depth and the position of the splitting and supporting rolls. The linear flow splitting machine represents the operator (or product) in the process model which affects the process using the working factor roll force in y-direction [Hirsch 2007].



Firgure 12. Product as operand being transformed by manufacturing processes

Another main focus in this view is the initial and final state of the product caused by external influences like work or environmental influences (e.g. temperature, corrosion, wear). A sound concept for modelling the changes of a product in the use phase by internal influences (e.g. wear, friction) and external influences (e.g. corrosion, temperature of the environment) also in the way of a passive product. During use the product is not only an active operator but also a passive operand and we know the often intensive interaction between products and processes. But for simplification and in regard to the purpose of this contribution the original process model should be used here without any changes

5.2.2.2.5 The fairytale of product “Eigenschaften”

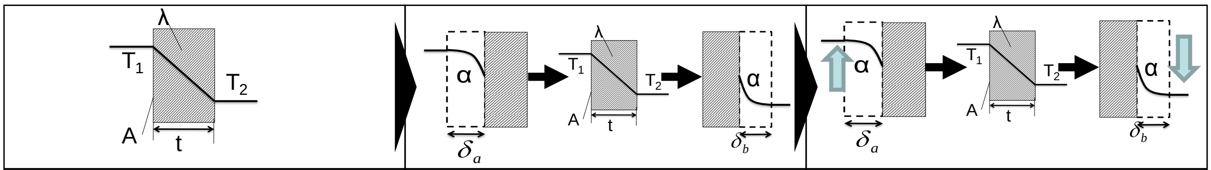
The previous chapters demonstrated, that the majority of dependent „Eigenschaften“ are caused by (independent) „Eigenschaften“ of the product and „Eigenschaften“ of the process and its influencing factors. All the more the fact is remarkable, that apparently everybody ignores the junction term “and” and call them product “Eigenschaften”!
Its obvious, that manufacturing costs of a shaft e.g. result from the semi finished part we need and from the costs for manufacturing caused by turning and grinding machines, tools and the energy needed. Nevertheless we are accustomed to “glue” the “manufacturing costs” onto the shaft like a paper-based label.
Same with the use phase, where everybody regards e.g. the running costs of a car as product costs although we know, that running costs depend heavily from the price of crude oil, the relation between offer and demand of gasoline and the current situation on world trade market, all influences far away from indepedent “Eigenschaften” of a car like a Golf from Volkswagen.
Nobody can imagine how many misunderstanding, faults and deficits in design related methodology have been caused by this simplification.

6 Some insights using “Eigenschaften” in design science and practice

6.1 Product modelling on different levels of granularity

So far the application of models of the model-pyramid to represent specific „Eigenschaften“ of the product was addressed in general. In detail however modelling a product may not only be done on different product models coming from abstract to concrete but also on different levels of granularity inside one product model itself. An asynchronous motor e.g. may be regarded in total as an energy transformer, a functional description sufficient for modelling a complex drive unit. More in detail a designer of electric drives may model such a motor as a complex structure of sub-functions to get more insight into the functionality and to find out new techniques to control torque and speed. Transferred to our heat exchanger profile, one could model the heat resistance between channels very simple as heat conductivity of a sheet metal plate without regarding the thermal boundary layer (figure 13, left). Going more into detail heat resistance can be modelled also regarding the thermal boundary layer of the fluid (figure 13, middle) and the impact of fluid flow considering the Nusselt-Number(figure 13, right).

Therefore choosing the appropriate level of granularity for modeling products is not a question of truth or correctness but once again of the purpose, the designer aims by doing it.



Heat resistance $R = \frac{t}{\lambda A} = \frac{1}{\alpha A}$	Heat resistance $R = \frac{1}{\alpha_a A} + \frac{1}{\alpha A} + \frac{1}{\alpha_b A}$	Heat resistance $R = \frac{1}{\alpha_a A} + \frac{1}{\alpha A} + \frac{1}{\alpha_b A}$
Heat transfer coefficient $\alpha = \frac{\lambda}{t}$	Heat transfer coefficient $\alpha_i = \frac{\lambda}{\delta_i}$	Heat transfer coefficient $\alpha_i = Nu \frac{\lambda}{\delta_i}$ Nusselt-Number $Nu = C\, Gr^m\, \mathrm{Pr}^n$

Figure 13. Levels of granularity of “heat resistance”

6.2 The drive for creating holistic models representing independent and dependent “Eigenschaften”

Coming back to 3D-CAD it is a truly powerful tool, but in its core it represents geometry. A first step to enlarge the field of application of 3D-CAD and to represent also product behaviour was done when animation techniques were integrated enabling the demonstration of kinematics and to analyse collision between parts. Progress in CAx-techniques is dedicated continuously enlarging the “behavioural part” of the original geometrical model to FEM, Digital Mock Up – models and Virtual Reality and even Augmented Reality.

The deflection under load as a dependent “Eigenschaft” of a heat exchanger is simulated with FEM. The deflection is not only dependent on geometry and the assigned material but also on “Eigenschaften” like external loads or the earth gravitational force. Imagine this profile being used on the moon there would not be such huge deflection and in space there would not be a profile’s deflection at all of due to gravity.

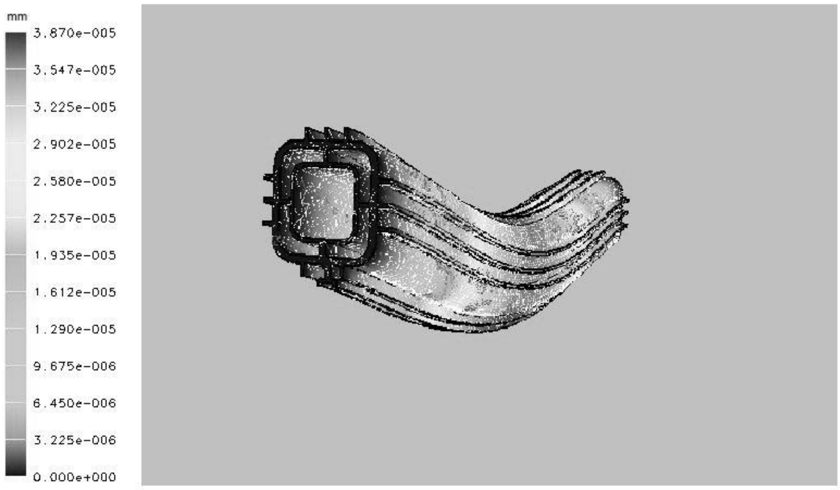


Figure 14. Deflection simulated by FEM of 3D-CAD

6.3 The benefit of modelling "Eigenschaften" in design practice

For design practice in a certain stage of the design process the question may be:

1. Which requirements are focused in this stage of design work?
2. Which model represents the requirement-correlating dependent "Eigenschaften" best?
3. Which operations (change, eliminate, integrate, connect) within the model can or should be done in regard of the independent, model-inherent "Eigenschaften", to create a maximum of correspondence between dependent "Eigenschaften" and requirements.

These questions occur permanently in design practice even if product models are chosen often unconsciously and their use is mainly dominated by external facts like the use of related tools in a company.

If we limit just for a short moment the work of designers only on 3D-CAD modelling of geometry and assigning material to parts in a part list, then design as a whole may be seen as the appropriate fixing of independent "Eigenschaften" in that way, that all generated dependent "Eigenschaften" fulfil the requirements and limitations of a given design task best. This idea is the key for understanding the very nature of design and the challenges and difficulties related to design work. Designers work becomes quite more complicated if one take the whole variety of product and process related models into account.

Considering the incredible amount of knowledge in regard to the relations between independent and dependent "Eigenschaften" needed, in regard to the lack of concrete and detailed knowledge in many cases and the huge amount of contradictions within this body of knowledge it's a near-miracle that designers succeeded in so many cases.

7 Conclusion

In this contribution, examples have shown that the terminology and the knowledge of "Eigenschaften" is of fundamental importance for design science and the description of TS. Our Approach tried not to struggle with terms and to focus a universally valid way how to describe TS and to clarify the meaning behind used terminology. Besides the terminology different models of products (e.g. function model) and processes (e.g. extended process model) have been discussed and brought in line with the used terminology.

Apart from the heat exchanger example, the concept of dependent and independent "Eigenschaften" may prove as a basis for structuring design knowledge in general. An algorithm-based design, which is the objective of CRC 666, requires a highly formalized "Design Language" based on the terms and definitions of Design Science. However, the effort to "motivate" designers to use this exactly defined "Design Language" in their daily work is problematic.

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