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THEORY OF TECHNICAL SYSTEMS (TTS) – EXISTING APPROACHES AND CHALLENGES

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ABSTRACT
Considerations on the nature of artifacts (technical products or systems) have always been part of Design Theory and Methodology. In this context it is quite interesting to investigate the role of so-called artifact concepts or theories (Theories of Technical Systems, TTS) in different approaches to Design Theory and Methodology and reason about challenges of TTS in the future.
One trigger to do so are big changes in industrially relevant products and systems during the last couple of years, e.g. with regard to their complexity, "multi-disciplinarity" (mechatronic products, Product/Service Systems) and variability. Finally, in the field of computer support for design processes (CAx) a big discussion about product models and product modeling is ongoing which is entirely separate from TTS considerations.

Keywords: Theory of Technical Systems, Design Theory and Methodology, Product Modeling

1 INTRODUCTION
Considerations on the nature of artifacts (technical products or systems) have always been part of Design Theory and Methodology. If formalized in a scientific manner – as has been described in [1], [2], [3] and [4] – we speak of a comprehensive "Theory of Technical Systems" (TTS).
In this context it is quite interesting to investigate the role of artifact concepts or theories in different approaches to Design Theory and Methodology: Quite amazingly, in some of the even well known approaches, TTS is only considered implicitly or even not mentioned at all.
On the other hand, the last couple of years have brought big changes in industrially relevant products and systems, e.g. with regard to their complexity, "multi-disciplinarity" (mechatronic products, Product/Service Systems) and variability.
Moreover, in the field of computer support for design processes (CAx) a big discussion about product models and product modeling is ongoing which is entirely separate from TTS.
Against this background, this contribution shall try to

- investigate the role of TTS in (different approaches to) Design Theory and Methodology and
- reason about challenges of TTS in the future.

Before going into details it should be noted that the term "systems theory" is very broad indeed:

> "Systems theory is an interdisciplinary field of science. It studies the nature of complex systems in nature, society, and science. More specifically, it is a framework by which one can analyze and/or describe any group of objects that work in concert to produce some result." [5]

Depending on the point of view and the purpose of the respective approach, it has a lot of different derivatives – [5] lists almost 50 different types of systems theory. Some aspects relevant and often quoted in engineering are general/philosophical [6], decomposition- and behavior-related ("systems engineering"), dynamics- and control-related ("cybernetics", "physical systems theory", [7]), communication-related, etc. All these approaches are basically independent of Design Theory and Methodology; it would have been interesting to include at least some of them in this study, for the time being prevented by limited time and space.
However, general knowledge derived from these approaches is incorporated in practically all schools of Design Theory and Methodology, e.g. how to draw borders in order to delimit a (technical) system against its environment, how to define input/output relations across system borders or how to decompose systems hierarchically (all approaches having it on the parts level, many also on more abstract levels such as functional decomposition).

This contribution will focus on more specific questions of: What are the elements and relations in different approaches which make them specifically relevant and useful for product development/design? Particular attention will be paid to the interdependencies between system models and development/design process models in different sources.
The contribution is an extended and refined version of a paper which was presented and discussed at the AEDS 2008 workshop (Applied Engineering Design Science) in Pilsen, Czech Republic [8].

2 EXISTING APPROACHES TO TTS

In this section some approaches to TTS in the context of Design Theory and Methodology are briefly presented and commented on, with a summary given at the end, section 2.6. Their selection is, to a certain degree, subjective, but tries to capture well-known and/or related concepts. Time and space permitting, more approaches could and should be studied, e.g. Andreasen's Theory of Domains [9] and what came of it over the years [10], Gero's so-called Function-Behavior-Structure Theory (FBS) [11], [12] or the Concept-Knowledge Theory (C-K) of Hatchuel & Weil [13]. Additionally, a deeper study of existing concepts for data structures CAx-systems would be interesting, but could just not be accommodated in this contribution.

2.1 Hubka/Eder/Hosnedl: Design Science

Hubka was one of the first authors who developed an elaborate, design-related Theory of Technical Systems (TTS), first published in [1]. It is also noteworthy that Hubka's approach to TTS, together with his considerations about design processes [14], became an integral part of Hubka's and Eder's Design Science, [2], [3], which led to the most recent concepts published by Eder & Hosnedl [4].
In a much simplified overview, the Design Science of Hubka/Eder/Hosnedl consists of:

- Considerations on the ***objects*** being designed and their properties (i.e. TTS),
- statements and recommendations about the ***process*** of and useful operations in designing (i.e. Design Methodology), and
- a concept of how to structure of design-related ***knowledge***.

This paper shall focus on the TTS part. Again simplified, the core of the Hubka/Eder/Hosnedl approach to TTS has the following constituents[1]:

1. A general transformation process model which serves to define the purpose of the technical system to be or being designed, fig. 1, and which is adaptable to the different system life-phases,
2. a model which refers to the kinds of structures of the technical system as they are successively established according to the stages of the design process (purpose, internal process, functions, organs, components – not shown as a figure here) and
3. a structure of (system) properties which define and describe a technical product or system after it has been designed, fig. 2.

The elaboratedness of the Hubka/Eder/Hosnedl approach to TTS is the reason why it is presented first in this paper and why all other approaches (described in the next sub-sections) are finally "measured" against it by investigating the existence of the listed constitutive elements.

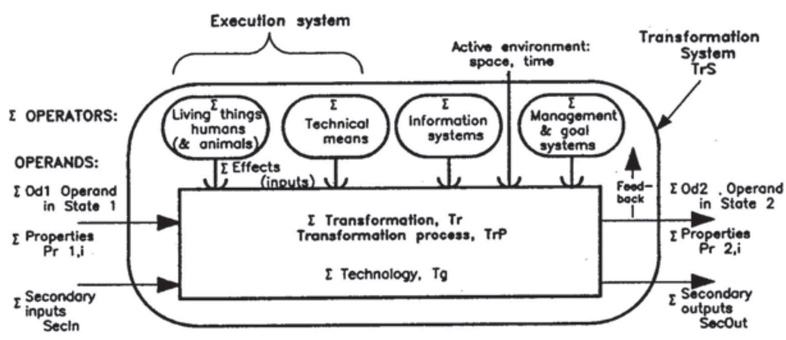


Figure 1: General model of transformation processes according to Hubka & Eder [3]

[1] Here: All references and figures taken from [3] in order to remain consistent.

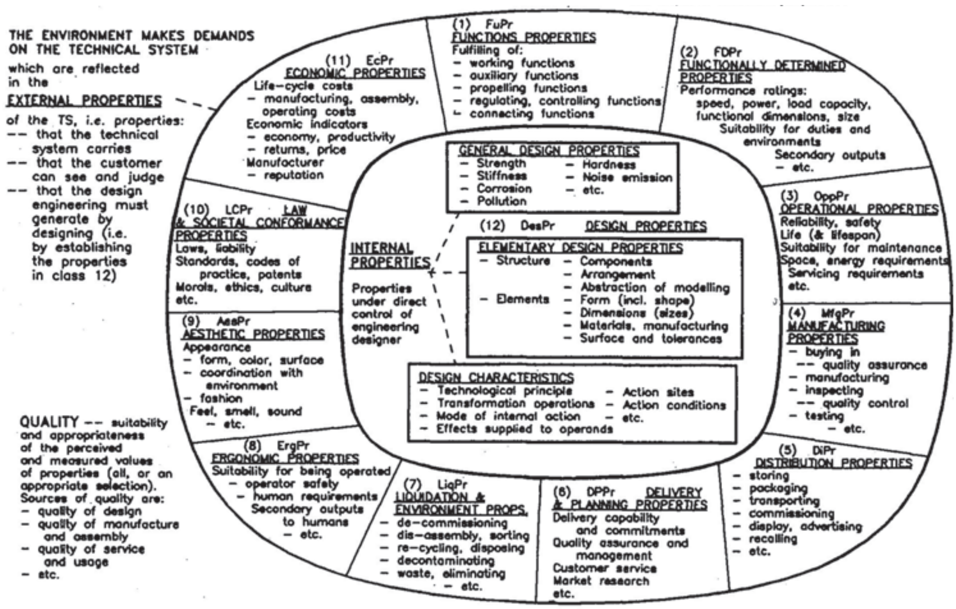


Figure 2: Properties of technical systems according to Hubka & Eder [3]

2.2 East German School: Hansen

Friedrich Hansen can be regarded as one of the most prominent (and also very early) representatives of the former East German school of Design Theory and Methodology. Hansen's first publications on Design Methodology date back to 1953; a first small booklet on "Systematic Design" (as Design Methodology was called at that time, in German: *Konstruktionssystematik*) was published in 1955 [15], this one very much aiming at practice rather than academia. A more comprehensive (and also clearly more science-related) book of the same title was published in 1966 [16].

All these publications covered the design process (i.e. Design Methodology) and had no notion of TTS. This changed in 1974 when Hansen presented his approach to Design Science (in German: *Konstruktionswissenschaft*), [17]. Similar to Hubka and Eder, Hansen's concept of Design Science consists of:

- Considerations on the ***objects*** being designed and their properties (i.e. TTS) and
- statements and recommendations about the ***process*** of and useful operations in designing (i.e. Design Methodology).

If we again focus on the TTS part, Hansen's basic approach is strictly "top-down":

A "system" is generally defined as a clearly delimited part of reality which:

- has relations to its environment (in German: *Umwelt*, **U**),
- has a structure (**S**) and
- has a function (**F**).

"There is a meaningful relation between these three system properties[2]. Always the function is determined by the structure and depending on the environment." [17]

The properties of a system (vector **P̲**) can be formally expressed by the following equation:

$$\underline{\boldsymbol{P}} = \{\, \boldsymbol{U}, \boldsymbol{F}, \boldsymbol{S} \,\} \tag{1}$$

Based on that, Hansen distinguishes ***technical*** from other systems by defining and describing environments (**U**), structures (**S**) and functions (**F**) specific for them.

Of course, also the interrelationships between **U**, **S** and **F** are studied. Core issues in engineering design are the relations between function and structure, more exactly the ***sets*** of functions and the ***sets*** of structures. These are explained graphically (fig. 3) as well as formally (eq. (2) and (3)). In both repre-

[2] Literal translation, well knowing that the term "property" might be ambiguous in our context.

sentations the double-tipped arrow denotes that the mapping from function to structure is always multivalent, while the single-tipped arrow when reasoning from structure to function stands for a univocal relationship.

$$\text{Analysis:} \quad \mathbf{S} \longrightarrow \mathbf{F} \tag{2}$$

$$\text{Synthesis:} \quad \mathbf{F} \twoheadrightarrow \mathbf{S} \tag{3}$$

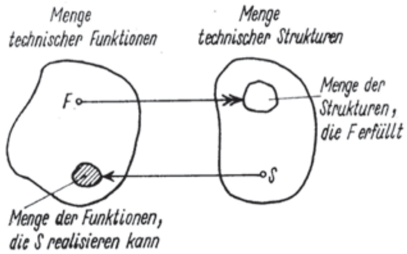


Figure 3:
*Relations between function (**F**) and structure (**S**) according to Hansen [17]*

2.3 West German School(s): Pahl/Beitz, Rodenacker, Roth, Koller, VDI-Guidelines

Since the late 1960ies several scientists in West Germany worked in the field of Design Theory and Methodology and published their results in books which have been extremely influential and have seen several editions until this day, e.g. Rodenacker [18] to [19], Koller [20] to [21], Pahl and Beitz [22] to [23], Roth [24], [25]. Based on these works and, as far as they were agreed, combining their results the VDI (Verein Deutscher Ingenieure, (West) German Association of Engineers) brought out a series of guidelines which today consists of VDI 2221 [26] as the general framework and VDI 2222 and VDI 2223 [27], [28] dedicated to particular phases of the design process.
The book of Pahl and Beitz ([29], [30], [31]) and the VDI-guideline 2221 [32] are since a long time also available in English, which made these approaches belong to the most widely spread concepts world-wide.
There are differences between the mentioned approaches; but with respect to our topic – basic concepts of TTS – they are not that big. In terms of TTS concepts, the author of this contribution interprets the West German approaches as follows:

- All books have sections on (technical) systems theory which mainly refer to quite general issues (delimitation of systems against their environment, hierarchical decomposition).
- With view to contents, all authors structure their system models along the overall procedure of the design process. Fig. 4 shows this based on [26] and [32], respectively, fig. 5 illustrates the stream of (stage-related) system models (and their decomposition parameters such as element and relation types) by an example taken from [30].

2.4 Suh: Axiomatic Design

N.P. Suh presented an approach to Design Theory and Methodology which is completely different from the "European" concepts described above [33], [34]. His Theory of "Axiomatic Design" is intensively discussed in the academic as well as the practical world of product development/design, especially in the USA.
The basic concept of Axiomatic Design is that designing is ("just") seen as a mapping process from the "functional space" into the "physical space", or, more specifically: mapping a given set of functional requirements (**FR**s, "what we want to achieve") into a defined set of design parameters (**DP**s, description of "how we want to achieve it"), fig. 6.
This is also clad into quite an elegant mathematical formalization (mapping between two vectors $\underline{\mathbf{FR}}$ and $\underline{\mathbf{DP}}$ via the so-called design matrix $\underline{\underline{\mathbf{A}}}$) which shall not be explained here.
Based on this concept, Suh formulates two axioms about good designs and develops a number of corollaries and theorems from them in order to support practical development/design processes. The strongest axiom is the independence axiom: "An optimal design always maintains the independence of **FR**s" or "in an acceptable design, the **DP**s and the **FR**s are related in such a way that a specific **DP** can be adjusted to satisfy its corresponding **FR** without affecting other functional requirements".

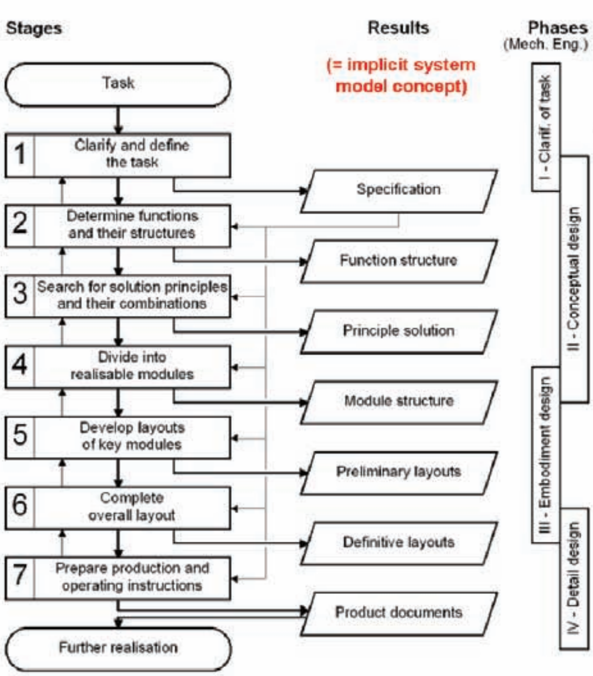


Figure 4:
Implicit concept of modeling technical systems along the (results of the) stages of the design process according to VDI 2221 [26], [32]

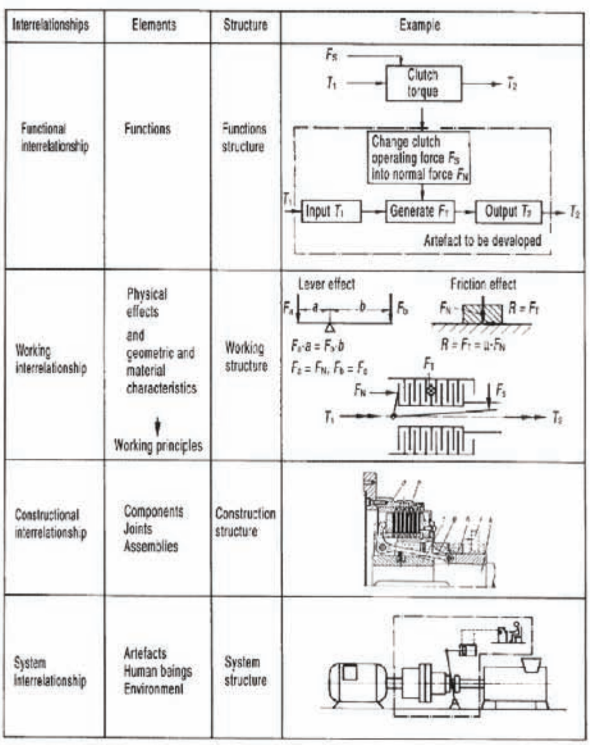
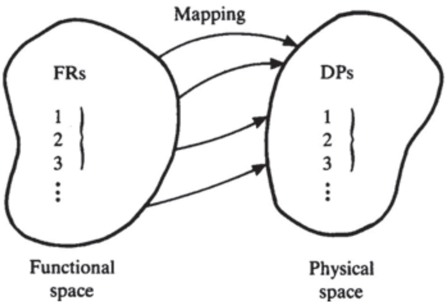


Figure 5:
Example for the stream of system models and their constituents along the design process [30]

Figure 6:
Design as mapping
functional requirements (**FR**)
to design parameters (**DP**)
according to N.P. Suh's
Axiomatic Design approach [33], [34]



2.5 Weber: Characteristics/Properties Modeling

Since some years, the author of this paper develops and propagates an approach called CPM/PDD:

- Characteristics-Properties Modeling (CPM) as the ***product/system*** modeling side and
- based on this, Property-Driven Development (PDD) explaining the ***process*** of developing and designing products.

The approach shall not be explained in detail here, most recent publications – each one stressing different conclusions from the basic approach – are [35], [36], [37], [38].

The CPM/PDD approach is mainly based on the distinction between characteristics (in German: *Merkmale*) and properties (*Eigenschaften*) of a product[3]:

- The characteristics (formally denoted $\mathbf{C}_i$) describe the structure, shape, dimensions, materials and surfaces of a product (in German: *Struktur und Gestalt*, *Beschaffenheit*). They can be directly influenced or determined by the designer.
- The properties ($\mathbf{P}_j$) describe the product's behavior (e.g. function, weight, safety and reliability, aesthetic properties, manufacturability, assemblability, environmental friendliness, cost, etc.). They can not be directly influenced by the developer/designer.

The characteristics are very similar to what is called "internal properties" in the Hubka/Eder/ Hosnedl approach to TTS (see sub-section 2.1) and what in Suh's theory of Axiomatic Design (see sub-section 2.4) is called "design parameters". The properties as defined in the CPM/PDD approach are related to the "external properties" of the Hubka/Eder/Hosnedl considerations and to the "functional requirements" according to Suh.

To be able to handle characteristics and properties – literally thousands of them in complex products – and to keep track of them in the development process they have to be structured. Fig. 7 shows the existing propositions, on the left side for the characteristics, on the right side for the properties.

Fig. 7 also introduces the two main relations between characteristics and properties:

- ***Analysis:*** Based on known/given characteristics of a product its properties are determined (its behavior is analyzed), or – if the product does not yet exist – predicted. Analyses can, in principle, be performed by experiments (using a physical model/mock-up, a prototype or – after manufacturing – the actual product) or "virtually" (by calculation and/or using digital simulation tools).
- ***Synthesis:*** Based on given, i.e. required, set of properties the product's characteristics are established and appropriate values are assigned. Synthesis is the main activity in product development/ design: The requirements list is mainly seen as a list of required properties and the task of the designer is to find appropriate solutions, i.e. an appropriate set of characteristics to meet the requirements.

[3] The English terminology "characteristics" and "properties" used in the CPM/PDD approach originally goes back to M.M. Andreasen of the Technical University of Denmark. It has been debated frequently and controversially. The German terms "Merkmale" and "Eigenschaften" are less of a problem, because they have a certain (nevertheless also not entirely universal) tradition in the German engineering design and machine elements literature. Despite these debates, the originator of the CPM/PDD approach for the time being decided to stick to this terminology, because he has practical objections against calling all parameters relevant in product development/design "properties" (e.g. "internal and external properties" as in the Hubka/ Eder/Hosnedl approach, see sub-section 2.1):

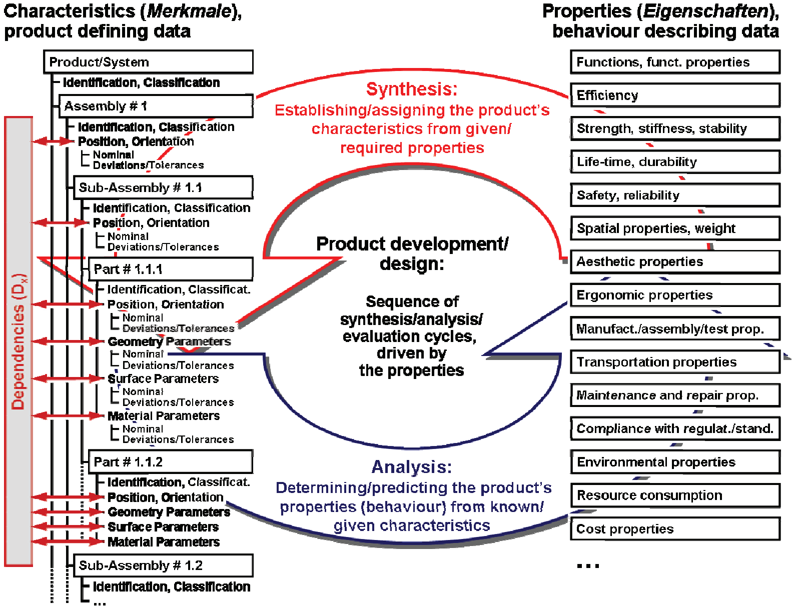


Figure 7: Characteristics-Properties Modeling and Property-Driven Development (CPM/PDD); basic structure of characteristics (left) and properties (right); analysis and synthesis as the two main relations between the two; product development/design as sequence of synthesis/analysis/evaluation cycles, driven by the properties

Based on this, a scheme for product development/design processes is presented: Product development/ design is seen as an activity that consists of synthesis-analysis-evaluation cycles and which is controlled by the properties. More exactly: At any time in the process evaluating the "gap" between "Ist"-properties (as-is-properties) and "Soll"-properties (= requirements) drives the process. During the process (in every synthesis step) ever more characteristics of the product are established and their values assigned; in parallel (by means of the analysis steps) ever more and ever more precise information about the product's properties/behavior is generated.

In total, the CPM/PDD approach is strongly influenced by the considerations of Hubka/Eder/Hosnedl on properties, but also by Suh's – however implicit – ideas and by experiences from the so-called Feature Technology, i.e. a CAx topic [39]. New is:

- The structuring of characteristics and properties is put into the ***center*** of considerations, in terms of product/system modeling (TTS) as well as in terms of process modeling (methodology).
- There is no a-priori preference among the properties (i.e. "external properties" in the terminology of Hubka/Eder/Hosnedl), all are seen as equal and equally important. Therefore, in the CPM/ PDD approach there is no strict stage model of the product development/ design process, e.g. starting from function and then doing the rest. As stated in [37], [38], the question of which properties are relevant and how they are structured as well as the sequence of cycles of the product development/design process entirely depend on the application (branch of industry, company).

2.6 Summary of the Different Approaches and Some Conclusions

The findings about the different approaches to TTS can be summarized as follows (in an extremely compressed form shown in table 1):

- The Hubka/Eder/Hosnedl approach to TTS (section 2.1) is the most comprehensive in existence; no other approach has all three elements:
  1. A general transformation process model,
  2. a model of how to successively establish the relevant structures of the technical system along the stages of the design process, and
  3. a structure of (system) properties.

- Hansen's approach to TTS (section 2.2) focuses on structuring system properties, i.e. the no. 3 issue of the Hubka/Eder/Hosnedl concept. There is some, but not a very strong relation to Hansen's (earlier!) considerations on the product development/design process (no. 2 issue according to Hubka/Eder/Hosnedl). If read carefully (not covered in this contribution) there is also a concept similar to, but not identical with the transformation process (no. 1 issue) of the Hubka/Eder/ Hosnedl approach (called *"Grundprinzip"* of a design).
  With hindsight, Hansen's approach to TTS is closely related to much later propositions, e.g. from Suh and Weber (see sub-sections 2.4 and 2.5). It delivers interesting and relevant, for its time even unique contributions to TTS. Seen from today's perspective, however, it remains a little "fuzzy" in some details, even displaying some unsolved overlaps when explaining core terms such as environment, function and structure.
- With regard to TTS, the West German school(s) of Design Theory and Methodology (section 2.3) mainly relate(s) to the no. 2 issue of the Hubka/Eder/Hosnedl approach to TTS, i.e. considerations on the contents and constituents of system models defined by the stages of the process. The no.1 issue (transformation process defining requirements of the technical system) is not addressed, but also not rejected. The no. 3 issue (general structure of system properties) does not exist.
  In this approach the process concept clearly governs the product/system modeling approach: The system concept is justified via the process concept. Or even more pronounced: There exists, in fact, no TTS separate from Design Methodology.
- In N.P. Suh's Axiomatic Design approach (section 2.4) TTS or product modeling issues are not explicitly addressed – even less so than in the West German school(s). The collection of known and defined functional requirements (maybe formalized as a vector **FR**), design parameters (**DP**) and relations between the two (**A**) could, however, be seen as an implicit TTS concept.
  Interestingly, this is related to the no. 3 issue of the Hubka/Eder/ Hosnedl approach to TTS, i.e. the structure of system properties. Here, no.1 and no. 2 issues (transformation process defining requirements and system models based on design stages, respectively) do not exist. This corresponds with the fact that Axiomatic Design does not have a stage model of the design process; the "mapping" approach might even be seen as openly denying the necessity of having such a model at all.
- Weber's CPM/PDD concept (section 2.5) is clearly related to the no. 3 issue of the Hubka/Eder/ Hosnedl approach to TTS, i.e. providing a structure of system properties (or "characteristics" and "properties" in the CPM/PDD terminology). The no.1 issue according to Hubka/Eder/Hosnedl (transformation process defining requirements of the technical system) is not addressed, but again also not rejected. The no. 2 issue (considerations on the contents and constituents of system models defined by the stages of the process) can not exist in the traditional form (stage defines content) because all stage models are seen application-specific.

Table 1. Comparison of approaches to TTS as described in sections 2.1 to 2.5

	Hubka/Eder/ Hosnedl	**Hansen**	**Pahl/Beitz, ..., VDI**	**Suh (Axiom. Design)**	**Weber (CPM/PDD)**
Transformation process model	●	◗	○	✘	○
System structure according to design process stages	●	◗	●	✘	◗
Structure of (system) properties	●	●	✘	●	●
Relation system/process model	⇔	??	⇐	✘	⇒

● exists; ◗ exists in parts; ○ not explicitly mentioned, but possible; ✘ does *not* exist;
⇐ / ⇒ system model defines process model or vice versa; ⇔ system/process model simultaneously developed

Significant in the CPM/PDD concept is the fact, that modeling the product/system (i.e. TTS) clearly governs the process modeling approach (Design Methodology) which is, in a way, a complete reversal of argumentation compared to most other approaches. Or even more pronounced: The TTS approach could be completely separated from the Design Methodology side. Somewhat consequently, the whole approach also tries to build strong links to the field of computer-based product models and modeling [35].

3 PRODUCT MODELS AND PRODUCT MODELLING WITH COMPUTERS (BRIEF OVERVIEW)

An area related to TTS is product models and product modeling with computers, i.e. in CAx-systems. Relevant for product development/design are mainly CAD-, CAE- and PDM-systems[4]. It would require an own paper to discuss the present situation and future concepts in this area. Therefore, only some brief remarks on the links between TTS and product modeling will be presented – based on the author's experiences and views.

The discussion on products models/modeling has been led since the 1980ies, necessitated by the ever increasing role of computer support in practically all engineering and business phases (i.e. throughout all product life-phases). Until today the discussion is primarily IT-driven, with data structures, programming paradigms, IT technologies and system architectures as main topics.

Because of concentration processes on the side of the IT developers/suppliers during the last years along with "concentration on core competences" strategies on the side of the IT customers/appliers, the development in the whole area is at present strongly dominated by (a ***de***creasing number of) IT system suppliers rather than application experts. It is also IT-technology-driven rather that application-driven.

In the application field of product development/design[5] much could be improved. The author of this contribution sees the main bottleneck with the fact that CAx-systems for product development/design still have not moved much further than modeling geometry, parts structures and administrating parts-related data (e.g. coupling all information to part numbers). This is not denying the fact that inside the CAx-systems a lot of change has taken place, e.g. evolving from 2D to 3D modeling, adding parametric modeling functionalities, enhancing simulation capabilities both qualitatively and quantitatively, etc.; the basic paradigms, however, have remained fairly static.

While geometry is important and "parts-centeredness" is extremely useful for some areas (e.g. individual parts sourcing or manufacturing), many issues important for product developers/designers can not be assessed, let alone supported on this base alone (e.g. function, assembly, safety, maintenance, environmental issues, …).

In the terminology of the author's CPM/PDD approach this situation could be summarized as being able to capture the characteristics side well (or, in the terminology of Hubka/Eder/Hosnedl, the side of internal properties), but having severe lacks on the side of the properties (or external properties, respectively).

So why are these issues not covered systematically by the IT developers and suppliers? The author of this contribution has the opinion that exactly these issues are extremely difficult to cover ***and*** are quite application-specific, i.e. specific to particular branches of industry, maybe even particular companies (see some considerations in [37], [38]). Therefore, engagement in this field is hardly paying off for the developers/suppliers.

Another reason may be that – opposed, for instance, to computer science where we encounter a shift of paradigm and new techniques evolving every couple of years – there is no stable concept from science how products ***should*** be modeled – neither in general nor for a specific application context.

This is where – at least for the field of product development/design – Design Theory and Methodology, and in it TTS in particular, could and should come into place: Who else could and should tell the computer experts what to build their software on in terms of contents? However:

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4 CAD – Computer-Aided Design; CAE – Computer-Aided Engineering, used in the sense of calculation and simulation; PDM – Product Data Management.

5 Especially in the field of computer support, some authors even prefer to extend from traditional product development/design and integrate it with manufacturing and assembly planning. The result is often denoted with the term "product creation".

- Existing TTS concepts have not really shown any impact on CAx-development. Most intensively tried were (and still are) attempts to derive product model/modeling concepts based on the West German school(s) of Design Theory and Methodology (see sub-section 2.3); as these are primarily stressing the no. 2 issue of the Hubka/Eder/Hosnedl approach to TTS, i.e. structuring the contents and constituents of product/system models along the stages of the development/design process, the resulting product models were structured accordingly (similar to the example in fig. 5, but digitized).
- As none of these attempts and proposals were ever taken up and realized beyond a prototype stage, the author of this contribution wonders whether the base might be wrong (at least for computer-based product models/modeling) – maybe we should better start afresh, but based on another TTS concept
- Scientists from the field of Design Theory and Methodology do at present involve themselves even less in product model/modeling discussions than they did in the past [40] – with occasional exceptions, e.g. [35]. But how else could our findings gain any influence on these discussions?

4 CONCLUSIONS FOR FUTURE DEVELOPMENTS IN THE FIELD OF TTS

The review of the role of TTS in Design Theory and Methodology described in the previous section 2 brought some interesting insights, especially very different driving forces, constituents and dependencies. Based on these findings, this section attempts to draw conclusions for future developments in the field of TTS.

Of strategic interest to Design Theory and Methodology are the following issues:

1. In Design Theory and Methodology, do we at all need an "own" Theory of Technical Systems (TTS)? Or is the "theory of methodology of designing" the main (and possibly only) goal?
2. If we want an "own" TTS approach, what is its relation to the process side (Design Methodology)? Does TTS govern (at least parts of) design methodology (like in CPM/PDD, sub-section 2.5) or vice versa (like in the West German school(s), sub-section 2.3)? Or semi-detached approaches (like, in principle, the Hubka/Eder/Hosnedl approach, sub-section 2.1, and even more so Hansen's considerations, sub-section 2.2)?
3. What makes up a "good" TTS with regard to supporting development/design processes well (and maybe: with regard to fitting well to the use and development of computer support systems)?

Along with the more strategic questions listed above, the author sees necessities to re-visit and update TTS content-wise – with big challenges. Some (probably not all) issues are:

4. If we decide to invest research effort into TTS, of course a broad discussion on the terminology is required (see e.g. [41]). This would definitely be not easy (because you can not "just" change some words in a couple of approaches without considering the whole theoretical background).
5. Seen from today's perspective, all existing approaches covered in this contribution – including the author's own attempts (see sub-section 2.5) – are too exclusively "mechanical". What we would need is a sort of extended TTS which is able to also cover mechatronic products, maybe even Product/Service Systems (see e.g. [42], [43], [44]). The problem here is that a TTS structure based on the mechanical view of parts structure, geometry and material ***alone*** may be able to also cover electrical/electronic components, but can certainly not cover software and service components.
6. In this context: Which part of possible constituents of TTS (starting from the considerations of Hubka/Eder/Hosnedl, see sub-section 2.1) has the highest priority (or biggest needs): Transformation process model, structuring the technical system according to the stages of the development/design process, structure of system properties, others?
7. Finally, a content-related, but at the same time strategic question: Should Design Theory and Methodology via TTS involve itself more strongly in CAx development and application? If this question is answered with "yes" then again some extensions, maybe even modifications have to be expected.

The development and consolidation of TTS is, in the first place, an academic issue. But how is it related to practical engineering? Interestingly, the area most relevant for practice is the last one mentioned and, at present, the one where TTS is least engaged: providing a sound base for the development and application of software tools and architectures for the support of product development/design processes.

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