INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

TODAY'S REQUIREMENTS ON ENGINEERING DESIGN SCIENCE

Christian Weber[1], Herbert Birkhofer[2]

[1] Technical University Ilmenau, Department of Engineering Design, Germany
[2] Darmstadt University of Technology, Department of Product Development and Machine Elements (pmd), Darmstadt, Germany

ABSTRACT

In the last couple of years the question of how to consolidate and further develop the knowledge in the field of Engineering Design Science has come into the focus. In this context and based on some recent activities and discussions in this area the authors raise the question: What is required of a comprehensive Design Science from today's perspective? After some initial remarks on the present situation of engineering design practice and present concepts of the term "science", in its core section this contribution identifies different "stakeholders" who might pose these requirements (scientists, designers in practice, students, and tool/software developers) and tries to collect their views and needs (just like in product design where several "stakeholders" would pose their views and requirements on the product to be designed). The result is the proposition of a new systematic framework of activities within Engineering Design Science. The authors do not claim to present final solutions, but rather first ideas to spark off and intensify discussions amongst experts which might, eventually, lead to an agreed and joint approach to consolidate and further develop Engineering Design Science.

Keywords: Engineering Design Science

1 INTRODUCTION

Engineering Design Science has evolved over the last 40-50 years. The first mention of the term (in German: *Konstruktionswissenschaft*) goes back to Hansen [1], but it is today mainly connected to the names of Hubka and Eder [2], [3] whose concepts are based on much earlier studies on the theory of artefacts [4], [5] as well as the theory of creating them [6].

Besides the term "Engineering Design Science", the term "Design Theory and Methodology" has been used – with the relation between the two often being not very clear. With first dedicated activities during the late 1950s and the 1960s mainly in Europe (Czechia, Germany, Great Britain, Russia, Scandinavia, Switzerland), Design Theory and Methodology became an important and interesting research and teaching issue also in Australia, Canada, Japan, and the United States of America.

Today, the question of how to consolidate the knowledge in this area is imminent: Since 2005, this topic was intensively discussed in several of the Design Society's conferences and workshops, e.g. at the AEDS[1] workshops in Pilsen 2005 and 2006 and at the DESIGN 2006 conference (see e.g. [7]).

Thus, Design Science, or Design Theory and Methodology respectively, after evolving through experiental, intellectual and empirical phases, could finally reach a theory-based phase [8].

Against this background, this contribution discusses the question:

What is required of a comprehensive Design Science seen from today's perspective?

This question came up when the authors of this paper had to summarise the outcome of the workshop "Engineering Design Science – Consolidation and Perspectives", held at DESIGN 2006. In practically all approaches to Design Science, or Design Theory and Methodology respectively, the first step of the synthesis process is a thorough clarification of the requirements, because its results will not only support the process but also enable proper evaluation and selection of solutions. So, why did we never do it when "synthesising" a comprehensive science of designs and designing?

[1] AEDS: Applied Engineering Design Science, a Special Interest Group (SIG) of the Design Society which holds annual workshops in Pilsen, Czech Republic..

This paper tries to provide some (initial) reasoning about the question raised above. It is based on the authors' personal experiences and opinions. It does not claim to present final solutions, but rather first ideas to spark off discussions amongst experts.
In order to discuss the question raised, several "stakeholders" of Engineering Design Science are introduced and their views and requirements are discussed – just like in product design where several "stakeholders" (e.g. manufacturing and assembly engineers, sales people, customers, users, maintenance experts, etc.) would pose their views and requirements on the product to be designed.
Because our focus is basically the 21st century, at first (section 2) some considerations about changes in engineering design practice during the last 10 to 20 years are made.
The approach may seem critical at first glance: Shouldn't "science" be value-free, something "pure" and "absolute", beyond criteria of usefulness? Is it permissible to have expectations, even requirements of a science? Therefore, in another – very brief – section (section 3) prior to the core of this paper the summary of some considerations about the term "science" in general and about "Engineering Design Science" in particular are presented.

2 CHANGES IN ENGINEERING DESIGN PRACTICE

Engineering design is primarily seen as one phase in the product life-cycle which, due to being in a very early position and being responsible for the determination of the internal and external properties of the forthcoming product, has a dominating influence on all subsequent phases, such as manufacturing, assembly, sales, use, maintenance, replacement, etc. Besides this rather technically oriented view, engineering design is part of the business (-creating) process in a company which imposes various constraints in terms of human and technical resources, time and money. Finally, engineering design is a highly creative activity which is increasingly performed in teams – thus having many socio-cultural implications. A nice breakdown of all these views into manifold dimensions of "design is …" is given by Hubka and Eder [3] and will not be repeated here.
With respect to practically all of the aforementioned views on engineering design, quite radical changes have taken place in the last two decades (and are still ongoing):

- Mainly because of price and, subsequently, cost pressure, but also due to new requirements (e.g. environmental awareness and legislation) the consideration of all phases of the product life-cycle has become a much more tough and diverse matter, at the same time being brought up to the front of the process as much as possible ("front-loading"): Today DfM, DfA, DfE, DfC[2] etc. are both early and integrated activities in engineering design.
- More innovation is required (at least in "high-tech" countries) which means that market-lives of products and, subsequently, development time ("time to market") are decreasing. At the same time, risks (technical and economical ones) are increasing.
- Product complexity increases: Products become increasingly a multi-discipline/multi-domain affair (e.g. "mechatronic" products, i.e. intelligent combinations of mechanical, hydraulic/pneumatic, electric/electronic components with embedded information processing); they also have more (and more intensively interlinked) components than in the past. At the same time, the number of product variants is exploding („mass customisation").
- Information technology plays an increasing role in today's engineering design and all subsequent phases of product creation (in some industries even beyond): A multitude of CAX-tools[3] is available to support various activities; among them the concept of the so-called Digital Master (i.e. the one and only valid reference of the product at all times being a comprehensive digital model, usually based on a 3D representation) and an appropriate (digital) management of the vast data connected to it (via PDM/PLM) are the most influential. Interfacing of and interaction between CAX-tools is still sub-optimal, however, thus also hindering the flow of activeities along the design and overall product creation process.

---

[2] DfM – Design for Manufacturing. DfA – Design for Assembly. DfE – Design for Environment. DfC – Design for Cost. These and other considerations (Design for Ergonomics, for Recycling, ...) are often summarised by the term "DfX " (Design for X).
[3] CAD – Computer-Aided Design. CAE – Computer-Aided Engineering, usually used in the sense of calculation/ simulation. CAPP – Computer-Aided Process Planning. CAM – Computer-Aided Manufacturing. PDM/PLM – Product Data/Life-Cycle Management. ERP – Enterprise Resource Management. These and other tools are often summarised by the term "CAX" (Computer-Aided X).

- Business-creation increasingly involves service components besides the material product itself (“Product-Service Systems”), the development of the two sides being also intensively interlinked.
- All phases of the product life-cycle are today performed on a global scale, with partly dramatic changes in organisation and work distribution, both institutional (between different sites, between different companies) and regional (between different countries, continents, cultures). This also has a severe influence on the use of information and communication technologies in engineering design and in all subsequent phases of the product life-cycle.
- Somewhat opposed to some of the issues mentioned before (e.g. shorter market-lives of products), engineering design has to increase efforts in the field of sustainable development. This question is more a socio-political, even ethical issue than a purely technical one, it is also not (yet?) addressed full-heartedly by industry.

Many existing approaches to Design Science, or Design Theory and Methodology respectively, do not give answers to the questions and problems listed above. This is, of course, not their deficiency, as they were usually formulated years or even decades before the mentioned influences became relevant.

Seen from today’s perspective, however, a comprehensive and up-to-date Design Science will ***also*** be judged by the criterion whether it can provide answers to current questions and problems. This is the reason why this short summary was given before collecting requirements of a Design Science in the next section.

3 WHY “SCIENCE”? MAY WE HAVE REQUIREMENTS OF A SCIENCE?

Discussions on what is a “science” (and, consequently, what is not) have been going on roughly for 3,000 years, and the question is still not finally answered. Lenk [9] shows that the issue was taken up again during the last four or five decades (by the way: mainly, but not entirely because of human-made artefacts and technology with their related disciplines of science had to be accommodated). In [10] the authors went into this issue more deeply (with regard to Engineering Design Science), but in this paper will only summarise their conclusions:

The prevailing concepts of the term “science” all refer back to the term “knowledge”, with the additional requirement that, in order to form a science, knowledge has to be “accumulated”, “established”, “systematised” and “formulated”. It is, at the same time, quite open to different “branches”, “departments”, “distinct fields of investigation”, etc. where this might take place. It is often explicitly mentioned that “science” may well have both sides: collecting and systematising knowledge about “what is” (descriptive approach) as well as collecting and systematising knowledge about actions and skills that eventually interfere with the present “what is” state (prescriptive approach).

- Therefore, as a first statement: The existing concepts of “science” give no indication that it is wrong to strive for an Engineering Design Science which necessarily has to contain both aspects at the same time – the descriptive as well as the prescriptive side (see e.g. [2], [3]).
- Second statement: In the – often concurrently used – notion “Design Theory and Methodology”, the descriptive and the prescriptive aspects are split up. If seen as a unit and assuming close relations between the two parts, then “Design Theory and Methodology” is synonymous to “Design Science”. If seen separately and/or with the two parts having weak or missing links, then “Design Theory and Methodology” may become something different from “Design Science”.
- Third statement: The authors think that nothing contradicts having “stakeholders” pose requirements of a science – mainly in the sense that the borders of a particular “field of investigation” are defined and that criteria for “accumulation”, “establishing” and “systematisation” of knowledge are formulated.

4 “STAKEHOLDERS”, THEIR VIEWS AND REQUIREMENTS

In this core section of the contribution several “stakeholders” of Engineering Design Science are introduced and their views and requirements are discussed. Where appropriate, remarks on the present state of Engineering Design Science are added in order to show achievements and deficits, thus maybe giving hints for further work.

The groups of “stakeholders” considered are scientists, designers in practice, students (including PhD students), and tool/software developers.

4.1 Scientists:

The main interest of any type of "scientific community" is in collecting, systematising, structuring/ formalising, but also discussing, verifying/falsifying knowledge in the respective field of investigation. This can be translated to the following requirements of Engineering Design Science:

- Knowledge about the field (in our case engineering design) has to be "established" and "systematised". This requirement mainly addresses the "establishing" and "systematising" of a common terminology.
- Furthermore, Engineering Design Science has to formulate its hypotheses, conclusions, recommendations, etc. in such a way that by using scientific methods verification – or, as Popper put it [11] and as is recognised particularly in the so-called exact sciences[4]: falsification – is possible.
- Connected to the last point: What are scientific methods and procedures that could verify/ falsify elements of Engineering Design Science? How can we measure "truth" (or the opposite) especially with regard to its prescriptive elements?
- Engineering Design Science has to ***describe*** the objects in the field. In this particular case there are two different "objects" to be considered, the design***s*** (as artefacts) and the design***ing*** (as a rationally captured process to create artefacts):
  - What are the basic properties of (existing) technical products? What are basic relations between them? What is common to all types of products, what is specific for particular types? How to formalise and express ("model") all this?
  - How are design processes (i.e. the "set-up" of properties and their relations) actually performed? Can we find common procedures ("processes") and elements? Where do we find specific procedures and elements (and: specific to what – types of products, situations, people, companies, cultures, …)? How to formalise and express ("model") our findings?

As was discussed in section 3, "science" in general, besides describing "what is", may well have a prescriptive dimension. In Engineering Design Science in particular, this component has to be regarded indispensable. Therefore:

- Engineering Design Science should ***prescribe*** how to deal with objects not yet existing. Again, both types of "objects" have to be considered:
  - How to systematically predict and optimise properties of technical products/systems, especially when the products do not yet physically exist? How to relate product properties to business goals (e.g. time to market, image, risk, profits, …)?
  - How to perform and optimise engineering design processes – in new as well as in well known fields? How to assign methods and tools? How to optimise work distribution?

Seen from today's perspective, the authors think that some elements of the requirements listed above should be re-visited in order to improve, but also modernise present approaches to Engineering Design Science. The following (certainly not complete) list of remarks may serve as a more detailed version of some of the requirements stated above:

- Until today, terms in Engineering Design Science are not coherent, there still is a confusing variety of individual "schools" of Design Science, or Design Theory and Methodology respectively. Therefore, the "establishing" and "systematising" of a common terminology has to be regarded as a requirement of utmost importance. See more details and proposals in [7].
- We still do not have clear concepts about the criteria we might use to check statements from Engineering Design Science: Is it "truth", "quality", "completeness", "level of detail" or rather "generality" as the opposite, "timeliness", …? Clearly empirical studies of the design process have enhanced Design Science a lot during the last 10 to 15 years (see [12]) – so much so that we are inclined to ask why they were not done much earlier. And clearly, this type of descriptive studies (first in "laboratory", now progressing to "practice" environments) will be of additional importance as an instrument to verify – or falsify – design methods, tools, and methodologies [13]. But is it the only instrument? And: How do we check product-related statements?
- Interestingly, not all approaches to Design Science, or Design Theory and Methodology respectively, do in fact clearly distinguish between the two "objects" that Engineering Design Science deals with – the products/systems on one hand and the processes on the other – and be-

[4] The authors imply here that engineering is part of "exact sciences". It has to be admitted, however, that this is ***not*** entirely clear.

tween the two dimensions – the descriptive and the prescriptive one. The notable exception can be found in [2], [3] where a “map” of Design Sciences with quadrants is introduced (**Figure 1**).

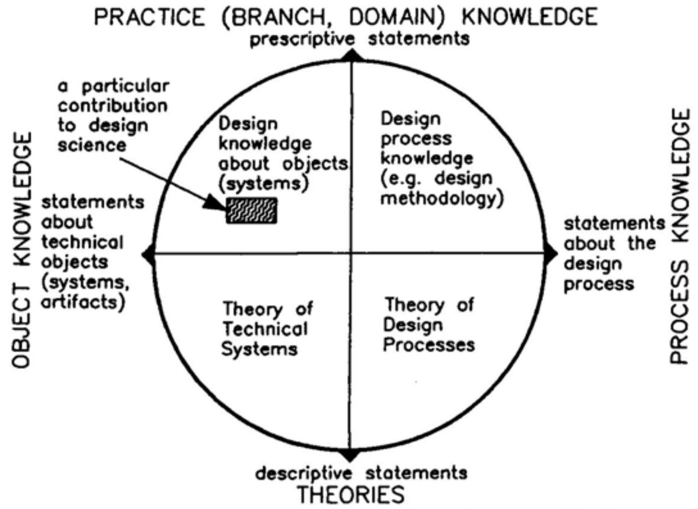

Figure 1. The four categories of Engineering Design Science according to [2], [3]

- Today, a lot more product properties than in the past have to be considered, and as early in the process as possible (see section 2). On the other hand, we have a lot more methods and tools (in particular: CAX tools). All this is not fully reflected in the present approaches to Engineering Design Science.
- Products become increasingly a multi-discipline/multi-domain affair (e.g. “mechatronics”, “Product-Service Systems”, see section 2). In existing approaches of Engineering Design Science we still have answers primarily related to purely mechanical products, but besides this we find approaches in other disciplines that are rather pragmatic, concentrate on methods (sometimes methodological fashions) and usually do not claim to be “scientific” [14]. These aspects have to be integrated into Engineering Design Science – into the product/system- as well as the process-related part of it.
- What is “general” and what is “specific” knowledge in engineering design and how to come from one to the other is not very thoroughly discussed, despite the fact that the gap between design science and design practice (see [15], [16], [17]) could be closed if we manage to find good concepts in this respect.
- As a consequence, the existing knowledge about specific products and specific design processes, methods and tools (e.g. DfX methods, practically all quality engineering methods which have great importance in industrial practice, most CAX-tools) is still only weakly integrated into Engineering Design Science.
- In this context, considerations about specific design situations have been introduced into Design Science by Gero [18], [19].
- Formalisations of product and process descriptions become more important because of an increasing amount of computer-support. One contribution which tries to integrate several existing approaches is offered by [20].
- The relation between product properties and their establishing via an engineering design process on one hand and reaching business goals on the other hand has not been considered very deeply. The best we have in this respect is the concept of so-called Integrated Product Development ([21], further developed in [22]) plus some more recent propositions to expand the focus of engineering to the product planning phase [23]. These activities, at present, run rather peripheral to Design Science: We have to ask whether we want them outside or inside our focus.
- Cultural influences on engineering design are a quite recent focus of research at several places (see e.g. [24]), will probably become of increased importance along with increasingly cross-cultural engineering processes in practice.

4.2 Designers (and design managers) in practice:

Designers in practice usually have their set of procedures, methods and tools to cope with day-to-day work. In most cases they will have an overview about basic design methodologies – maybe not so much scientific and broad-scale, but influenced by their practical experience in a particular field of products, in a particular branch of industry, maybe even in a particular company.

As outlined in section 2, however, innovation cycles become shorter and at the same time product complexity increases. Therefore, the main requirement of practitioners towards Engineering Design Science will be to adapt, update or even newly develop procedures, methods and tools. In this respect, they will be interested in product- as well as process-related knowledge:

- With regard to describing objects – i.e. products as well as processes – designers in practice would probably require information about what is new in the field:
  - What are new properties of technical products/systems that have to be considered? When do they have to be considered? How do they relate to known ones? How to formalise and express ("model") these, how to integrate additional model elements into existing product models?
  - What are new procedures ("processes") and their elements in engineering design? Which ones to apply where?
- Requirements of the prescriptive part of Engineering Design Science from the perspective of designers in practice would be:
  - Which new methods and tools are relevant to systematically predict and optimise properties of technical products/systems (for "old" properties as well as newly introduced ones). How to integrate them into an existing landscape of procedures, people, methods, tools, etc.? How to relate product properties to business goals (e.g. time to market, image, risk, profits, …)? Are there examples from areas similar to the own field?
  - How to perform and optimise engineering design processes – in new as well as in well known fields? What is an "optimal" design process? How to assign methods and tools? How to optimise work distribution? Are there examples from areas similar to the own situation?
- For all aforementioned issues: What does a change of existing practice cost in terms of time and money? How to quantify benefits? Means and effort necessary to further qualify people in the company? How to enhance acceptance of changes in the own company?
- Finally, designers in practice are dearly looking for answers on how to deal with the huge amount of existing and still increasing knowledge. Beyond approaches for accumulation and systematisation of knowledge, this requirement also addresses the education and life-long training of designers with regard to better conceptualisation as well as the need for research (and science) to create generalised solutions instead of solution islands.

In summary, the requirements of designers in practice will be more biased towards ***modularisation*** of knowledge gained in Engineering Design Science (see also [25]). Therefore:

- Engineering Design Science should present its findings in an appropriately modularised way and
- Engineering Design Science should also make greater effort in collecting, systematising, structuring/formalising knowledge about individual methods and tools,
- should even not refrain from statements about their usability and quality.

Again, some remarks to the list of requirements posed from the perspective of designers in practice in order to stress the issues that should be re-visited from today's perspective (some of which were already mentioned in section 4.1, will be therefore be only covered again very briefly):

- As already stated, a lot more product properties than in the past have to be considered, but we also have a lot more (even still increasing number of) methods and tools offered "on the market".
- Products as well as processes to design them become increasingly a multi-discipline/multi-domain affair.
- Designers in practice will in most cases tend to look for "specific" rather than for "general" knowledge on products and processes. Therefore, in order to increase benefits and acceptance of Engineering Design Science, it has to invest work in into application- as well as situation-specific "bundles" of methods and tools.

- Formalisations of product and process descriptions become more important, not least because of an increasing amount of computer-support.
- The perspective of designers in practice drawn up here is very closely related to what in Engineering Design Science in the 1990ies became known as building and using "designer's workbenches" or "designer's toolkits" (comprehensive overviews are given in [26], [27]). These approaches so far have been very experimental, sometimes entirely theoretical, and were not really accepted in engineering practice. As the commercially available CAX-technology has changed a lot in the last decade (e.g. parametric 3D-CAD as base, market concentration, decreasing problems with interfaces, first steps into "knowledge-based engineering") the topic could and should be taken up again and realised in close relation to commercial tools, if not in cooperation with commercial vendors.
- Only in the last couple of years studies investigating the acceptance of methods and tools in engineering practice have been conducted [28], [29]. Engineering Design Science has to watch and integrate these findings when defining, systematising and commenting upon methods and tools.

4.3 Students:

The term "students" covers a wide range of "stakeholders", from undergraduate, to graduate, finally PhD students who have slightly different requirements of Engineering Design Science:

- Particularly in undergraduate courses, Engineering Design Science, besides providing knowledge about the nature of products and about design processes, methods and tools, has an important role as a framework to fit in practically all other engineering disciplines students are confronted with (as was already described in [30]):
  - Systematisation aspects are particularly important (e.g. distinguishing between products/systems and processes on one hand and between descriptive and prescriptive dimensions on the other hand)
  - Besides this, building up knowledge about (internal and external) product properties and their determination via methods and tools is necessary (see remarks to section 4.1).
- The view of graduate students will probably be more similar to the view of designers in practice (see section 4.2), i.e. they will require:
  - Focus on modularisation of the (product- as well as process-related) knowledge.
  - Help in the selection and proper use of methods and tools.
  - In some projects additionally: Guidelines for the development and test of new methods and tools.
- Finally, for PhD-students the view of scientists (see section 4.1) will become more and more important as they work on their projects. From experiences with the yearly Summer School on Engineering Design Research (SSEDR) the authors know (see also [31], [32], [33]):
  - PhD students mainly criticise the lack of coherence in Engineering Design Science in general and in the terminology in particular.[5]
  - Additionally, the question of a proper research methodology implying scientific rigour as well as "craftsmanship" is to be discussed (e.g.: how to verify/falsify results?).

Comments upon these requirements would be very similar to what was already stated in sections 4.1 and 4.2, respectively, and shall not be repeated here.

4.4 Tool/software developers and users:

The promotion of Engineering Design Science, or Design Theory and Methodology respectively, took place in roughly the same period of time as the evolution of computer models and tools supporting product development (CAX-tools). The results of the latter activities, however, have always been more readily accepted in engineering practice for reasons which shall not be discussed here. Today, we almost have an abundance of CAX-tools, some of them being introduced into companies in a rather haphazard way in terms of methods and methodology, requiring an adaptation of procedures instead of supporting existing and proven methods/methodologies.

[5] To avoid misunderstanding: Of course, a PhD-student should be and is able to cope with that. But better coherence and an established terminology would save a lot of time in the project.

One reason for this situation is that the development of CAX-tools and decisions on their application follows business rather than technical considerations. While this is outside scientists' influence, the second reason could well be tackled: Engineering Design Science has not really involved itself deeply into the definition and development of (CAX-) tools, but should do so in the future. Therefore:

- Engineering Design Science should provide a sound formalisation base for the development and application of computer methods and tools. This requirement has, again, two sides – supporting the design***s*** and the design***ing***:
  - Which tool to use in order to model particular properties of products and their relations with computers? Which kind of tool to use in which situation (e.g. early/late phases)? Where are "white spots" on the map of CAX-tools (properties that can not yet be modelled properly)? How to systematise, store and provide product-related information and knowledge?
  - How to link CAX-tools and the information they process along with the progress of engineering design? What can be automated, what requires user interaction and human decisions? How to build customised chains (or networks?) of CAX-tools out of a toolbox? How to systematise, store and provide process-related information and knowledge?

Again, some remarks to these requirements posed from the perspective of tool/software developers and users/designers, most of which were already mentioned in the previous sections and will be therefore be only covered very briefly:

- As stated before, the computer support of engineering design processes is the main driver to formalise product and process descriptions much more rigorously than in the past.
- A lot more product properties have to be considered. For some, there is no computer-supported modelling strategy yet. On the other hand, some quite remarkable new tools have been proposed by researchers (e.g. [34]). This area should be investigated more sincerely, guided by findings of Engineering Design Science about product properties.
- Products as well as the processes to design them become increasingly a multi-discipline/multi-domain affair.
- As was already stated in the context of practitioners' requirements (see section 4.2), and even more strongly so, tool/software developers have to think in terms of modularisation, building (digital) "designer's workbenches" or "designer's toolkits" to support product as well as process models.
- Finally, issues of acceptance of tools in engineering practice are not at all addressed appropriately yet.

4.5 Summary of findings

Table 1 summarises the results of the authors' considerations by confronting requirements (in a compressed form) with "stakeholders". The individual lines of the table show which issue is important for whom and, in aggregation, which issue is of bigger or lesser importance. The columns of the table give a profile of requirements according to the respective "stakeholder". Finally, the table presents a sort of classification "map" to find potential addressees of contributions to particular fields of Engineering Design Science.

5 CONCLUSIONS

This contribution discusses what different "stakeholders" (scientists, designers in practice, students, tool/software developers) require of a comprehensive Design Science from today's perspective. In summary, this paper proposes a new systematic framework of activities within Engineering Design Science which is at the same time in accordance with Engineering Design Science's own claims (i.e. "clarify requirements first").

However, the authors do not claim to present final solutions, but rather first ideas to spark off discussions amongst experts which might, eventually, lead to an agreed and joint approach to consolidate and further develop Engineering Design Science.

Table 1. Requirements of Engineering Design Science confronted with "stakeholders"

Requirement			Students			
	Scientists	Practitioners	Undergrad.	Grad.uate	PhD	Tool-/SW-developers
Establishing and systematising terminology	●		○	○	●	○
Scientific reasoning:						
– Formulation of hypoth., findings, conclus.	●				●	
– Research methodology	●				●	
– Verification/falsification methods & tools	●	○			○	?
Coherent descript. and prescript. of products:						
– Properties and their relations	●	●	●	●	●	●
– Multitude of properties and relations	●	●	○	○	○	●
– Multi-discipline/-domain approach	●	●	○	○	○	●
– Formalisation	●	○	○	○	●	●
– Modularisation		●	○	○	○	●
– Devel./applic. of tools for product modell.	○	●		○	○	●
– Acceptance of methods and tools	●	●			●	●
– Relation to business goals		●	○	○	●	●
– Integration into existing environments		●			○	●
Coherent descr. and presc. of design processes:						
– General framework	●	○	●	●	●	●
– Specific/"situated" processes	●	●	○	○	●	●
– Assigning methods and tools to processes	●	●		○	●	●
– Assessing methods and tools	○	●		○	●	?
– Formalisation	●	○	○	○	●	●
– Modularisation, designer's workbench		●		○	●	●
– Devel./applic. of tools for process support	○	●		○	○	●
– Acceptance of methods and tools	●	●			●	●
– Work distribution	○	●		○	○	●
– Integration into existing environments		●			○	●
"Map" of product- and process-related as well as descriptive/prescriptive knowledge	●	○	○	○	●	○

● Core issue ○ Depending on particular project

REFERENCES

[1] Hansen, F.: *Konstruktionswissenschaft – Grundlagen und Methoden*. 1974 (Hanser, München-Wien)

[2] Hubka, V.; Eder, W.E.: *Einführung in die Konstruktionswissenschaft*. 1992 (Springer, Berlin-Heidelberg)

[3] Hubka, V.; Eder, W.E.: *Design Science*. 1996 (Springer, London)

[4] Hubka, V.: *Theorie der Maschinensysteme*. 1973 (Springer, Berlin-Heidelberg)

[5] Hubka, V.: *Theorie technischer Systeme* (2nd ed. of [4]). 1984 (Springer, Berlin-Heidelberg)

[6] Hubka, V.: *Theorie der Konstruktionsprozesse*. 1976 (Springer, Berlin-Heidelberg)

[7] Birkhofer, H.: The Consolidation of Design Science – A Critical Review of the Status and some Proposals to Improve it. In: *Proceedings of Workshop AEDS 2006 (Applied Engineering Design Science)*, Pilsen, Czech Republic, October 2006, pp. 13-22. University of West Bohemia, Faculty of Mechanical Engineering, Department of Machine Design

[8] Wallace, K.M.; Blessing, L.T.M.: Visions for Design Research. In: *Critical Enthusiasm – A Contribution to the Development of Design Science, Festschrift for Mogens Andreasen*, pp. 193-199. 1999 (Tapir, Trondheim)
[9] Lenk, H.: Epistemological Remarks Concerning the Concepts “Theory” and “Theoretical Concepts”. In: *Proceedings of the Universal Design Theory Workshop, Karlsruhe 1998*, Karlsruhe 1998, pp. 341-353. 1998 (Shaker, Aachen)
[10] Weber, C.; Birkhofer, H.: Engineering Design Science — What are the Requirements today. In: *Proceedings of Workshop AEDS 2006 (Applied Engineering Design Science)*, Pilsen, Czech Republic, October 2006, pp. 119-130. University of West Bohemia, Department of Machine Design, 2006
[11] Popper, K.: *Logik der Forschung*. 1935 (Springer, Wien)
[12] Lindemann, U., Birkhofer, H.: Empirical Design Research – Its Contribution to a Universal Design Theory. In: *Proceedings of the Universal Design Theory Workshop,* Karlsruhe 1998, pp. 291-304. 1998 (Shaker, Aachen)
[13] Blessing, L.T.M.; Chakrabarti, A.: *How to Do Design Research – a Design Research Methodology*. 2007 (Springer, London, in preparation)
[14] Weber, C.: Modern Products – New Requirements on Engineering Design Elements, Development Processes, Supporting Tools and Designers. In: *Holistic Product Development, Proceedings of the 5th Int. Workshop on Current CAx Problems*, Kaiserslautern 2004, pp. 165-178. 2005 (Shaker, Aachen)
[15] Birkhofer, H.: Methodik in der Konstruktionspraxis – Erfolge, Grenzen und Perspektiven. In: *Proceedings of ICED 91*, Zürich, August 1991, pp. 224-233. 1991 (Heurista, Zürich)
[16] Franke, H.-J.: Ungelöste Probleme der Konstruktionsmethodik. In: *Konstruktionsmethodik – Quo vadis? Proceedings of a Symposium on the occasion of the 80th birthday of Prof. Dr.-Ing. Karlheinz Roth*, pp. 13-30. TU Braunschweig, Institut für Konstruktionslehre, Report No. 56, 1999
[17] Birkhofer, H.: Some Comments on the Use of Systematic Design Methods in Industry. In: *Engineering Design – Theory and Practice: A symposium in honour of Ken Wallace*, pp. 22-31. 2005 (University of Cambridge)
[18] Gero, J.S.: Towards a Model of Designing which Includes its Situatedness. In: *Proceedings of the Universal Design Theory Workshop, Karlsruhe 1998*, Karlsruhe 1998, pp. 47-55. 1998 (Shaker, Aachen)
[19] Gero, J.S.; Kannengiesser, U.: The Situated Function-Behaviour-Structure Framework. *Design Studies* 25 (2003) 4, pp. 373-391
[20] Weber, C.: CPM/PDD – An Extended Theoretical Approach to Modelling Products and Product Development Processes. In: *Proceedings of the 2nd German-Israeli Symposium on Advances in Methods and Systems for Development of Products and Processes*, Berlin, June 2005, pp. 159-179. 2005 (Fraunhofer-IRB, Stuttgart)
[21] Andreasen, M.M.; Hein, L.: *Integrated Product Development*. 1987 (Springer, London)
[22] Schäppi, B.; Andreasen, M.M.; Kirchgeorg, M: *Handbuch Produktentwicklung*. 2005 (Hanser-München)
[23] Gausemeier, J.; Ebbesmeyer, P.; Kallmeyer, F.: *Produktinnovation – strategische Planung und Entwicklung der Produkte von morgen*. 2001 (Hanser, München)
[24] Felgen, L.; Grieb, J.; Lindemann, U.; Pulm, U.; Chakrabarti, A.; Vijaykumar, G.: The Impact of Cultural Aspects on the Design Process. In: *Proceedings of DESIGN 2004*, Dubrovnik, May 2004, pp. 1475-1480. Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb
[25] Birkhofer, H.; Lindemann, U.; Albers, A.; Meier, M.: Product Development as a Structured and Interactive Network of Knowledge – A Revolutionary Approach. In: *Proceedings of ICED 01*, Glasgow, August 2001, pp. 457-464. 2001 (Professional Engineering Publishing Limited, Bury St Edmunds, Suffolk, UK)
[26] Jensen, T.A.: *Functional Modelling in a Design Support System – Contributions to a Designer´s Workbench*. PhD thesis Danish Technical University, Institute of Engineering Design and Control Engineering (IKS), Lyngby, 1999

[27] Vroom, R.W.; van Haarlem, L.F., Ootes, F.P.A.: Overview of the Initiatives on the Development of Designer's Toolkits. In: *Proceedings of DESIGN 2002*, Dubrovnik, May 2002, pp. 443-448. Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb
[28] Birkhofer, H.; Jänsch, J.; Kloberdanz, H.: An extensive and detailed view of the application of design methods and methodology in industry. In: *Proceedings of ICED 05*, Melbourne, August 2005, pp. 276-277 (executive summary), full papers on CD-ROM. 2005 (Engineers Australia, Barton)
[29] Jänsch, J.; Birkhofer, H.: Providing Motivation to Use Design Methods and Systematic Design. In: *Proceedings of the 5th International Conference on Advanced Engineering Design (AED)*, Prague, 2006
[30] Albers, A.; Birkhofer, H. (eds.): Heiligenberger Manifest, Vorträge, Workshop-Ergebnisse. In: *Proceedings of the Workshop „Die Zukunft der Maschinenelemente-Lehre"*, Heiligenberg, April 1997. 1997 (Universität Karlsruhe/TH Darmstadt)
[31] Andreasen, M.M.: Experiences from a PhD-Course on Engineering Design Research. In: *Proceedings of the Research Seminar on Operations Management and Innovation*, CIP, Aalborg, 2002, pp. 1-10
[32] Flanagan, T.; Jänsch, J.: Models, Methodology and Finding Focus – Dealing with the Challenges of PhD-Research. In: *Proceedings of DESIGN 2004*, Dubrovnik, May 2004, pp. 297-302. Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb
[33] Blessing, L.T.M.; Andreasen, M.M.: Teaching Engineering Design Research. In: *Engineering Design – Theory and Practice: A symposium in honour of Ken Wallace*, pp. 32-41. 2005 (University of Cambridge)
[34] Dankwort, C.W., Podehl, G., A New Aesthetic Design Workflow – Results from the European Project FIORES. In: *CAD Tools and Algorithms for Product Design*, pp. 16-30. 2000 (Springer, Berlin)

Contact: Prof. Dr.-Ing. Christian Weber
Technical University Ilmenau, Department of Engineering Design
Max-Planck-Ring 12 (Building F)
D – 98693 Ilmenau, Germany
Tel.: +49 / (0)3677 / 69 – 2472
Fax: +49 / (0)3677 / 69 – 1259
email: christian.weber@tu-ilmenau.de
URL: http://www.tu-ilmenau.de/konstruktionstechnik/