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THEORY OF TECHNICAL SYSTEMS AND ENGINEERING DESIGN SCIENCE – LEGACY OF VLADIMIR HUBKA

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1. Personal Development

Vladimir Hubka was born in Prague, Czechoslovakia, on 29th March 1924. He attained his first degree of Dipl.-Ing. at the Czech Technical University, and was then employed in design offices in Czechoslovakia. From 1968 to 1970, Vladimir Hubka was active as chief designer at the Technical University of Denmark (Danmarks Tekniske Højskole). Since 1970, Vladimir resided in Switzerland, and was head of design education at the Swiss Federal Technical University (ETH) in Zürich. His PhD (Dr.-Ing.) was earned in 1978 at the University for Educational Science in Klagenfurt, Austria. He retired from ETH in 1990. Meanwhile he was appointed Visiting Professor at the University of Rome and at other major European universities. In 1994, Dr. Hubka was admitted to the degree of Doctor *honoris causa* of the University of West Bohemia in Pilsen. Our colleague and mentor, Dr. Vladimir Hubka, after a long battle with illness, died in his native, beloved Prague on October 29th, aged 82.
I first met Vladimir in 1968, at the 12th Scientific Colloquium of the Technical University of Ilmenau, then in the German Democratic Republic. I again met Vladimir at an IGIP Symposium in Klagenfurt, Austria, 1976, where we held some interesting discussions. My close collaboration started in 1980, in preparation for the first ICED in Rome. At this point, Vladimir contacted me to translate the book 'WDK 2 – Allgemeines Vorgehensmodell des Konstruierens' into English, published by Butterworths in 1982 as 'Principles of Engineering Design' [Hubka 1992].
My involvement with Vladimir continued, resulting in several books in German and English, the latest of which with Vladimir's involvement was 'Design Science' [Hubka 1996], published by Springer-Verlag, London, in 1996. We then started another book to explain the complex context of design engineering and its theory for use in engineering practice. Dr. Stanislav Hosnedl, from the University of West Bohemia in Pilsen, was coopted onto our editorial panel. Dr. Hubka remained active and enthusiastic in his efforts until his first major encounter with illness in 2001. Since then, I have led the work on this book to extend and clarify design science [Eder 2008a].

2. Professional Development

From 1957 to 1968, during his employment in Czechoslovak industry, Vladimir Hubka with four engineering colleagues initiated the development of a comprehensive design science. He was the first to recognize the need for an explicit theory of technical systems (TTS), because a sound theory allows developing an appropriate method – this was later confirmed via Klaus [1965], *'both theory and method emerge from the phenomenon of the subject'*. Major parts of TTS consider abstract forms of modelling of transformation systems, a generalized life cycle and classes of properties of systems. These themes constitute the main argument and basis for the theory of engineering design processes,

the second major pillar of engineering design science. Coordinated with these theories was his vision of developing and using a systematic design process in engineering practice, especially for non-routine situations such as conceptualizing novel systems. He was also concerned with suitably adapting the knowledge about technical systems to provide directly applicable information for designers. This includes defining the form of contents of areas of information (including knowledge and data) related to machine elements and to design for quality. His motivation was to generate a plausible, comprehensive and general theoretical description of the context of design engineering, with good explanatory powers, for application in the form of methods for engineering practice and for education.
Vladimir Hubka founded WDK – Workshop Design-Konstruktion, together with colleagues Prof. Umberto Pighini and M. Myrup Andreasen, at a meeting in 1978 at Halden, Switzerland. WDK was an informal and international network of people interested in advancing knowledge about engineering design, especially by relatively informal discussions. Dr. Hubka was its President for life.
Vladimir Hubka also initiated the first international conference on engineering design (ICED). Vladimir held an annual WDK-workshop meeting on Rigi mountain, Switzerland, from 1980 to 2000, when The Design Society was founded as replacement. The workshops functioned to plan the ICED conferences, and to discuss in a small circle matters related to Engineering Design Science. Participants included prominent professors, including Ropohl, Pahl, Beitz, Roth, Koller, and Ehrlenspiel. WDK publications resulted, including the Proceedings of ICED, which were published by HEURISTA, an organization established by Dr. Hubka for the purpose.
The first International Conference on Engineering Design (ICED 81 Rome) has resulted in the continued series of meetings of scientists and engineers interested in engineering design and its theory and methodology. On my arrival in Rome, and due to illness of Myrup Andreasen, I was coopted onto the technical organizing committee, and remained active in that capacity until the end of ICED 95 Praha. These bi-annual conferences have benefitted from the intensive enthusiasm, personal guidance, and management of Vladimir Hubka until ICED 97. They mirrored the central concerns of Dr. Hubka: design science, theory of technical systems and theory of design processes. They also covered those related topics that provide a bridge between the theory and engineering design practice, industrial applications, design management and education. The two intermediate conferences, ICED 88 Budapest and ICED 90 Dubrovnik, helped to overcome the east-west barriers, and promoted the current conference series – Design. Attending these meetings, I enjoyed the ambience of Vladimir's hospitality, including extensive walks in the woodlands around his home at Greifensee, swimming with him in the lake, and exploring Rigi mountain and its surroundings.
This valuable continuing series of ICED conferences and workshops has helped to cause some convergence of views and opinions, correlating research and theorizing, and transferring technology and knowledge of methods and tools. This international exchange showed that the various viewpoints have more in common than may be apparent, and permitted differences which do not raise barriers. Since 2000, the ICED conferences and workshops have been continued by The Design Society, of which Vladimir Hubka was declared the first honorary fellow.

3. Introduction

Each *Science* investigates an existing phenomenon, especially to obtain knowledge *per se*, sometimes even *only* for the sake of obtaining knowledge. *Research* and formulation of theories is closely related to scientific activities. According to [– Oxford 1984], the word 'science' is used in its wider interpretation of *accumulated systematized knowledge, esp. when it relates to the physical world*, and 'theory' denotes *the general principles drawn from any body of facts (as in science)*.
Research for human activities, generating knowledge and scientific theories, follows five parallel paths:

1. the classical experimental, *empirical* way of independent observing, e.g. by protocol studies, experiments, etc.: describing, abstracting, modeling, and formulating hypotheses and theories – observations can only capture a small proportion of thinking, usually over short time-spans;
2. *participative observation*, the observer is a member of the design team and takes part in the observed process, e.g. [Hales 1987] – observations may be biased by the observer's participation in the process;

3. the reconstructive, *detective* way of tracing past events and results by looking for clues in various places [Nevala 2005] – reconstructions can never fully capture the original events, human memory is limited, information about events is stored in many separate 'chunks' at different locations in the brain, and needs to be re-constituted for recall;
4. the speculative, reflective, *philosophical* way of hypotheses, theories, modeling, and testing, and transfer between practical experience and the insights of knowledge.

In 'designing' as a subject for research, the empirical ways include elements of self-observation, and impartial observation of experimental subjects. The self- and impartial observations should include not only the human activity, but also the resulting product of designing, irrespective of whether this product is an artistic work, or a technical process or system, or a suitable combination of these. None of these paths can be self-sufficient, and must be co-ordinated to attain internal consistency and plausibility.

Designing, Dr. Hubka's main interest, is involved in planning and executing (or having executed) any envisaged task, including writing, graphical work, representations, products, and other artifacts. It is now acknowledged that there are distinct differences in scope and approach between sciences and engineering, and that art also plays a role in engineering [– Oxford 1984]. Designing in engineering has the purpose of creating future operating artifacts, and the operational processes that they can be used for, to satisfy the needs of potential customers, stakeholders and users. These artifacts may be able to operate, i.e. actively work, or be (relatively passively) operated, e.g. as a tool by a human being. This is accomplished by designing suitable technical means, and producing the information needed to realize a manufacturable tangible product, usually of some utilitarian value. We therefore refer to *design engineering* as our activity of interest.

The information basis for designing lies mainly within the whole collection of existing areas of knowledge and knowing – many engineering developments were accomplished before the relevant sciences had been formulated. Even new inventions and science spin-off developments must be accomplished with the existing information basis – which for design engineering includes the engineering sciences, but also the information about culture, societal organization, economics, market development, and other areas, at both macro and micro levels [Eder 2007a] (refer also to figure 11).

Engineering Design Science [Hubka 1996] has been in development since the early 1960's [Hubka 1967]. Many papers have been published on these topics, a series of conferences and workshops have been organized lead by Workshop Design-Konstruktion (WDK) – continued by The Design Society – and several books were published in German and English [Hubka 1976, 1978, 1980, 1982, 1984, 1985, 1988a (1974, 1984), 1988b (1980), 1992 (1980, 1982), and 1996 (1992a), Eder 2008a].

This paper traces the development of some of the models and definitions from these works, the main legacy of Dr. Vladimir Hubka, and indicates recent developments that were needed to clarify some concepts, achieved by discussions and testing the concepts on industrial and educational applications.

4. Concept Developments

Concepts to be traced here concern mainly: differentiating designing in engineering and other fields; transformation systems and their operators; information and knowledge; location of object information regarding design advice and heuristics for products to be designed; and a hierarchy of design sciences.

4.1 Designing

In earlier publications, designing has been considered as a general process, especially in the artistic world of architecture, graphics, performing arts, etc. We must nevertheless distinguish various scopes of this activity for generic products, including processes and tangible products [ISO 9000:2005], see figure 1. 'Industrial design' covers mainly the appearance and usability, aesthetics and ergonomics, of tangible products in general. For tangible products aimed at consumers and made in large quantities, the management process has been formalized into 'integrated product development'. 'Design engineering' demands a wide range of technical information, and is concerned with manufacturability, functioning to produce certain desired effects, safety and reliability, and many other technical considerations. There is substantial overlap among these three forms of designing, but they do not coincide.

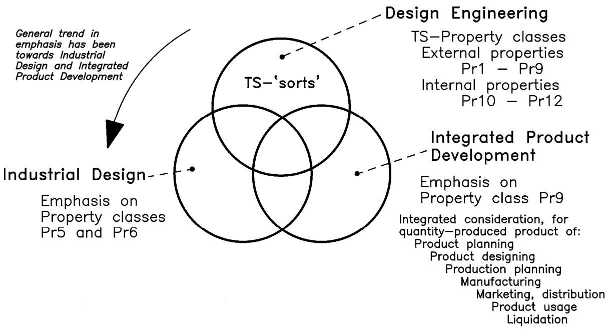

Figure 1. Scope of Sorts of Designing [Eder 2008a]

Within engineering, some practitioners do not recognize the word 'designing', they subsume the process under the name and activity of 'engineering'. In other places, the words 'engineering design' are used, but beg the question of whether the emphasis is on the process of designing, or on the product of designing, 'the design'. Yet others use 'design engineering', and this is now our preferred term to avoid ambiguities.

4.2 Transformation system

The model of a transformation system (TrfS) has developed from its original presentation in [Hubka 1967], to a first completion in [Hubka 1984/1974] see figure 2. The number of classes of operators (factors) was not well defined, and the kinds of operation were not specified. A more precise formulation appeared in [Hubka 1988a], see figure 3, especially with respect to the operators. The role of secondary inputs and outputs with respect to the transformation process (TrfP) was again recognized in [Hubka 1996], see figure 4. The most recent discussions between the authors and Dr. Hubka have led to a further refinement, see figure 5. Inputs and outputs have been redefined to assist design engineering. The figure now recognizes that assisting inputs and secondary inputs can influence both the transformation process and its operators. Secondary outputs can be generated by the transformation process and by the operators. The active or immediate environment can be a significant influence on the transformation process, and therefore at least a part of it should be considered as acting in the execution system. A peculiarity of a manufacturing process is that part of the information system (IS) acts as a direct executing operator of the transformation process – it delivers information about what is to be made, in what quantities and elemental design properties [Eder 2007c], and with what planned manufacturing methods and tools. The structure of the transformation process has been better defined, specifying the various kinds of operations that can occur, see figure 6. With the transformation system shown in figure 5, designers can develop a theory-based method for a novel system to be designed [Hubka 1988, 1992 and 1996, Eder 2008a]. This can then be applied to successively wider or narrower 'windows' [Nevala 2005] to resolve the relationships of the TrfP for that 'window' and the necessary output and internal functions and actions of the TS operator to be designed

For the purposes of designing (see [Eder 2005 and 2008a]), especially design engineering of technical systems, the concept has now been clarified that a transformation (or technical) process is best considered as external to its operators (technical system, human, and active environment). The technical system (TS), when it is operating, can act and react (internally and across the TS-boundary) to the presence of an operand, only then does it perform its purpose to cause the transformation of the operand. This allows separate considerations of the behaviours of process and operator, and indicates better how various simulations can help to investigate an anticipated system. It also allows during designing a progressive narrowing of the boundaries of the considered technical system into sub-systems, with (TS-internal) functions of the broader system now acting as technical process (TP) external to the considered sub-system – Nevala's [2005] 'windows'. Several case studies have demonstrated the expediency of this procedural step [Eder 2005, 2007b and 2008a].

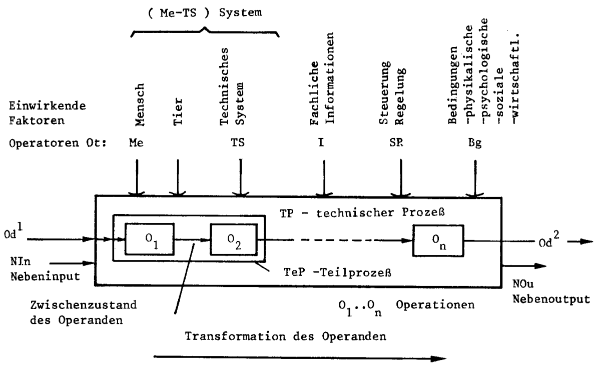

Abb.3.6. Allgemeines Modell des technischen Prozesses

Figure 2. Transformation System from [Hubka 1974]

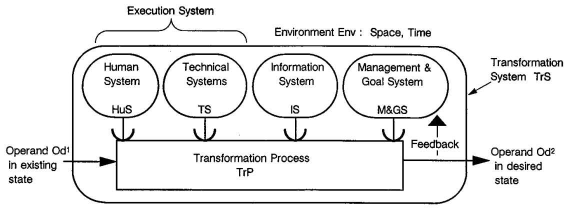

Fig. 3.1 Model of the Transformation System

Figure 3. Transformation System from [Hubka 1988]

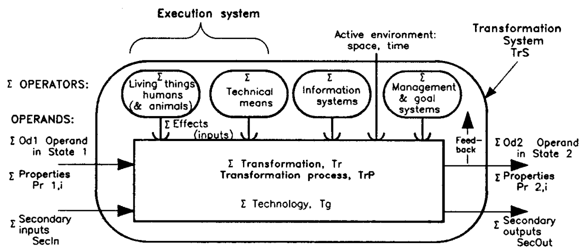

Figure 4. Transformation System from [Hubka 1996]

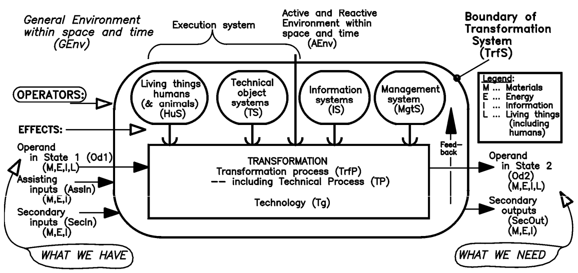

Figure 5. Transformation System from [Eder 2008a]

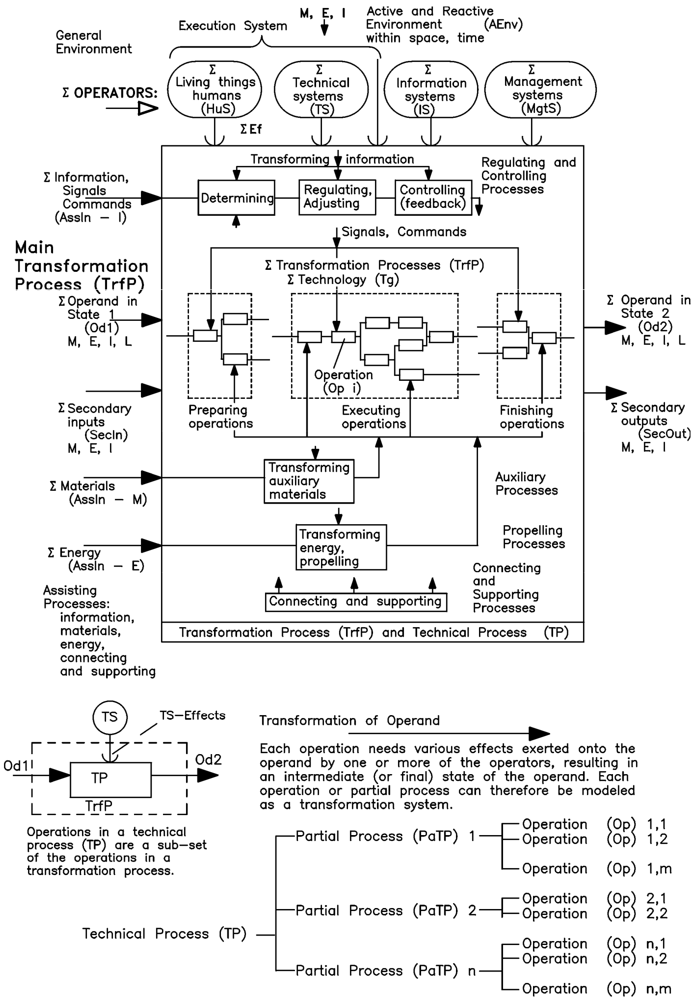

Figure 6. Structure of the Transformation Process from [Eder 2008a]

4.3 Information

In earlier publications such as [Hubka 1996], the map of Engineering Design Science used the word 'knowledge' for all four axes, see figure 7. This has now been recognized as limiting. 'Knowledge' implies that information has been processed, usually by abstracting, generalizing and codifying. Eder [2004a, 2007d] therefore proposed that 'information' should be regarded as general, and 'data' (as syntactic elements of information) and 'knowledge' (as codified information with semantic definition) are special cases of information. In its *recorded* form, on a suitable information carrier (e.g. paper) information, including knowledge and data, can be made available to others. Each human absorbs information, e.g. by learning, and builds in into his/her own idiosyncratic mentally internalized information structure, as *personal 'knowing' or tacit knowledge*. Each such personal structure is different, but all have much in common. The resulting changes are shown in the revised map of Engineering Design Science, as discussed in section 4.4 of this paper. In this way, a better coordination with the operator 'information system' in the transformation system has been achieved, see figure 5.

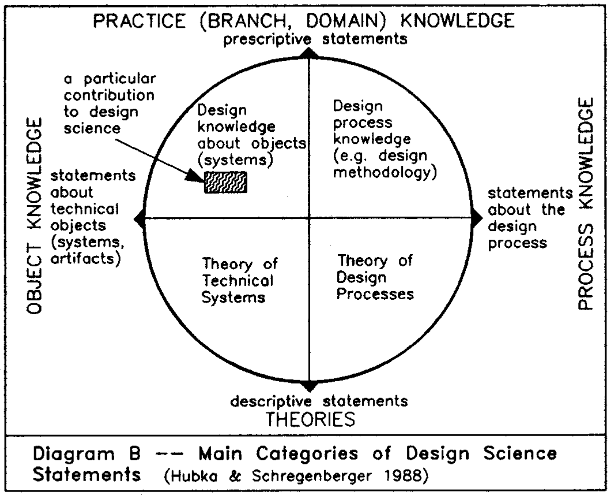

Figure 7. Map of Design Science from [Hubka 1996]

4.4 Object Information

Originally, in the papers leading to [Hubka 1996/1992a and 1996], 'knowledge' (see section 2.3) was separated into 'object knowledge' and 'design process knowledge' on the horizontal ('east'-'west') axis of the 'map' of Design Science [Hubka 1996], see figure 7. In the most recent developments and discussions (see section 4.3 of this paper), the word 'knowledge' has been replaced by 'information' in three axes, but has been retained with respect to 'theory', the 'south' axis. We also recognized that 'object information' has two components: (a) factual information about specific technical processes and (tangible) systems as they exist, in their 'as is' state, and (b) information about what manifestations and values are (heuristically) recommended or available in order to be able to design a technical process and/or system, their 'as should be' state, with reasonable confidence that it will operate as expected. Part (a) remains in the 'north-west' quadrant. Concerning part (b), any available theories are now allocated to the 'south-east' quadrant, see figure 8, and the heuristic advice is now allocated to the 'north-east' quadrant, because both are related more to design processes than to existing (designed) systems. A clear (but fuzzy) boundary exists to 'separate' the scope of Engineering Design Science from other contributing knowledge and information, see figure 8. The related contributing information has been brought into a relationship with the concepts of Engineering Design Science.

4.5 Design Science Hierarchy

Hubka [1996] indicated that knowledge with respect to engineering forms a hierarchy, see figure 9. An extension if this concept was outlined in [Eder 2004b], that sciences form a hierarchical network, from a 'science of sciences' to a set of more specific sciences that can be further sub-divided, see figure 10. Each such sub-division eventually claims to be a science in its own rights, that inherits the properties of the higher level, but adds further detail that is no longer generally valid, see also section 3 of this paper. In this way, 'design sciences' can be also sub-divided. One of these sub-divisions is 'Engineering Design Science' [Hubka 1996, Eder 2008a]. It is the only design science for which a clear (but fuzzy) boundary has been established between the science-based information (and knowledge) and the contributing information, based on Hubka's pioneering work. Even this Engineering Design Science could be sub-divided into 'Specialized Engineering Design Sciences' at various more detailed levels of abstraction and applicability, a task for research in academia and for industries for their 'own' TS products.

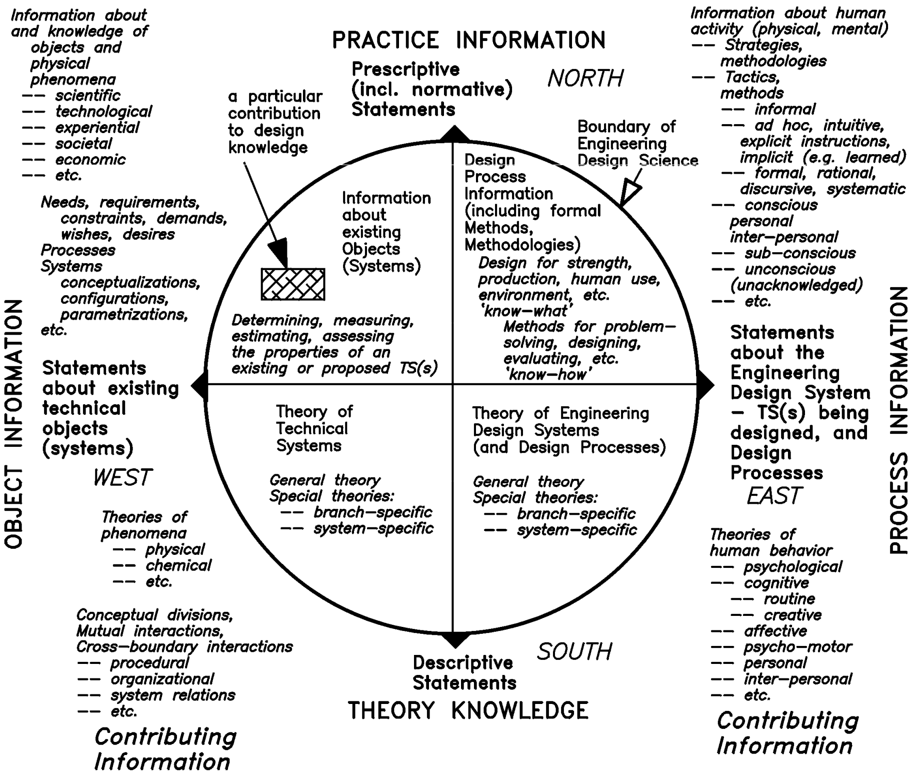

Figure 8. Map of Design Science from [Hubka 1996]

A hierarchical representation of these dependencies is not fully adequate. The arrangement of concepts and the interpretation of intentions depends on the order in which the criteria are considered. Any cross-connections among branches of the hierarchy are often neglected. Yet all information is multiply cross-connected, and some information should appear at several levels of such a hierarchy. In some respects, a better representation of relationships can be shown in a concept map, for instance figure 11, adapted from [Hubka 1996, Eder 2008a]. The central concepts for this paper, 'Designing of Products' and 'Detail Design', are surrounded by contributing concepts that are also interconnected. A hierarchy is perceivable, concepts that are more distant from the central concepts appear to be placed lower in the hierarchy. The contributing concepts are grouped into related formations, and boundaries could be drawn around these groupings. These can form the centres of interest for other specialities. Figure 11 allows a demonstration of this grouping by separating 'object information' from 'design process information'.

5. Closure

It is at times interesting to look back at how concepts develop over time. Refinement of concepts and diagrams mainly takes place by using them in case examples, practical applications, and further publications. This paper demonstrates some of the developments that have been achieved within Engineering Design Science during the last thirty years, and shows the most current interpretation of our ideas [Eder 2008a]. Various other aspects could have been used to illustrate Dr. Hubka's pioneering thoughts, and their current developments, e.g. the properties of technical systems [Eder 2007c]. They also outline the legacy of Dr Vladimir Hubka, who has been instrumental in developing this comprehensive body of theory and its relationships to practice.

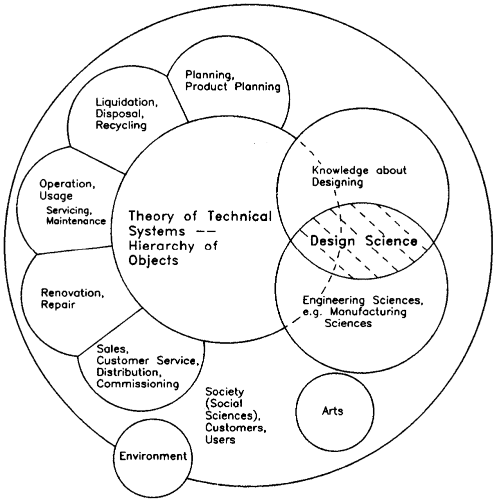

Figure 9. Hierarchy of Knowledge from [Hubka 1996]

Researchers in design engineering, and in integrated product development, would be well advised to become familiar with this body of knowledge and its contributing information. One path towards a better and more comprehensive Engineering Design Science is by attempting to find valid relationships among various design theories (e.g. [Eder 2004b and 2008b]) and contributing bodies of information, preferably confirmed by application on design projects in academia and industry.

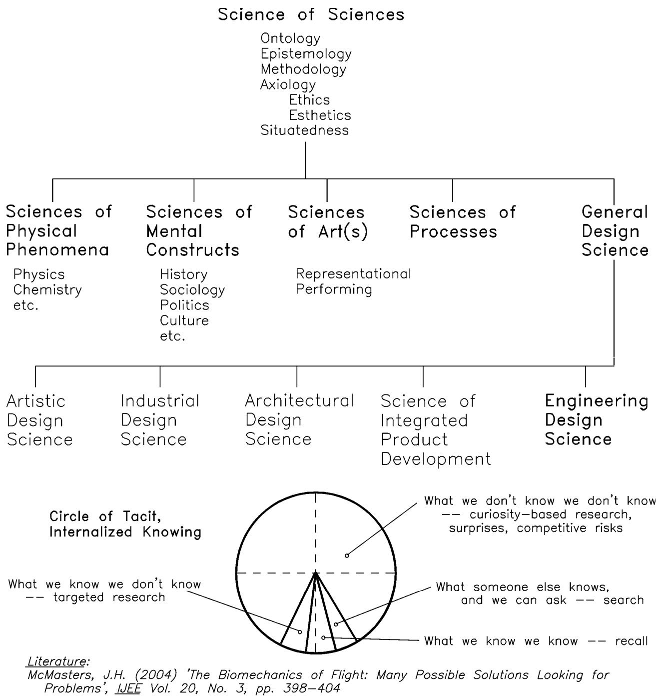

Figure 10. Hierarchy of Sciences [Eder 2008a]

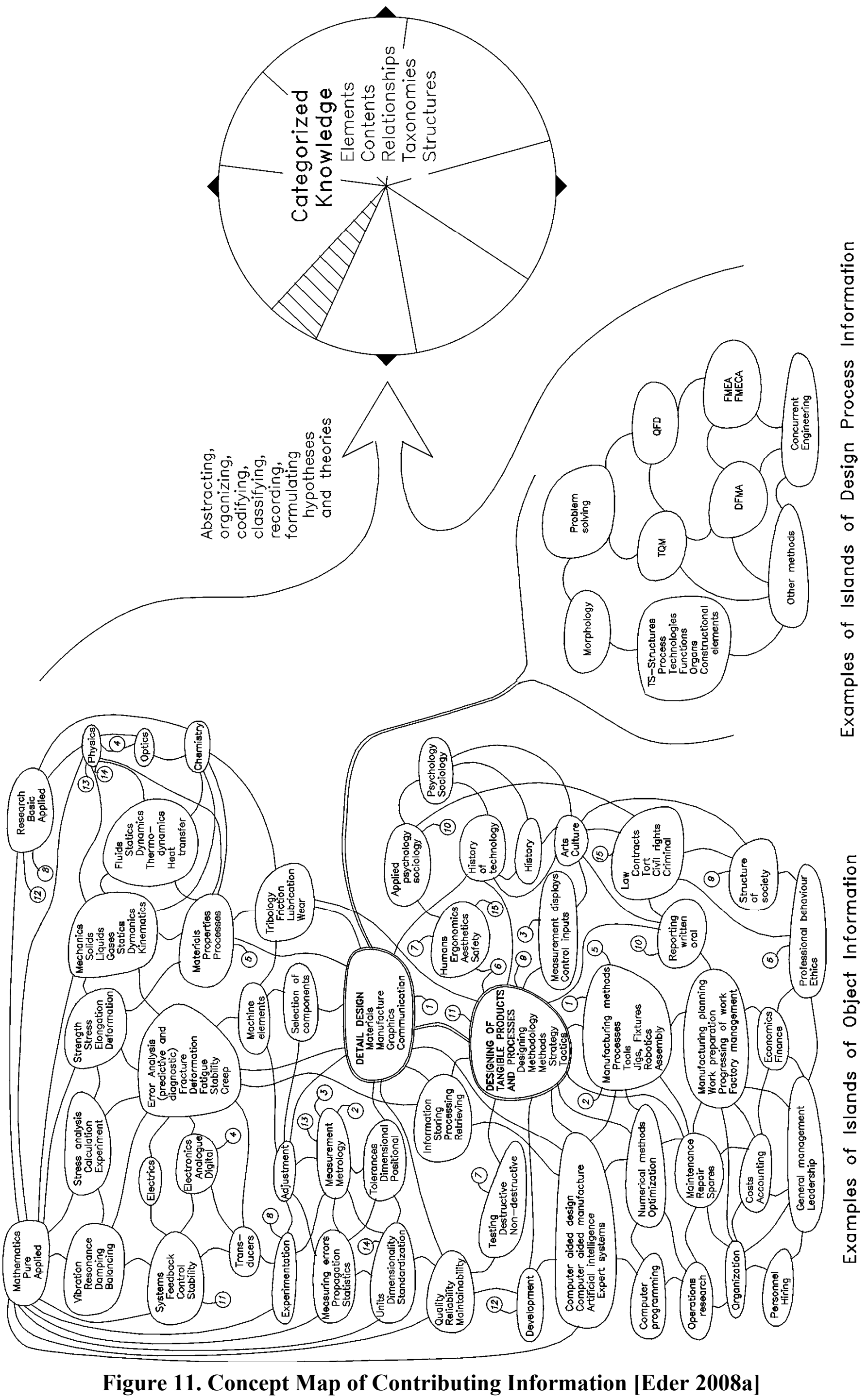

Figure 11. Concept Map of Contributing Information [Eder 2008a]

References

ISO 9000:2005 ***Quality Management Systems – Fundamentals and Vocabulary****, Geneva: ISO, 2005 http://www.iso.ch/*

Oxford (1984) ***The Concise Oxford Dictionary****, (7 ed.), Oxford: Univ. Press, see also http://www.askoxford.com*

Eder, W.E. and Hosnedl, S. (2004a) 'Information – a Taxonomy and Interpretation', in ***Proc. International Design Conference - Design 2004****, Dubrovnik, May 18 - 21, 2004, p. 169-176.*

Eder, W.E. (2004b) 'Design Sciences – An Overview', ***Proc. AEDS 2004 Workshop****, The Design Society – AEDS-SIG, 11-12 Nov 2004, Pilsen, Czech Republic; and* ***Proc. PhD 2004****, 2nd International PhD Conference on Mechanical Engineering, 8-10 Nov 2004, Srni, Czech Republic, both on CD-ROM*

Eder, W.E. (2005) 'Konstruktionsmethodik – Ein Werk in Entwicklung', in ***Proc. IWK 2005 – Internationales Wissenschaftliches Kolloquium****, Technische Universität Ilmenau, 19.-23. Sept. 2005, on CD-ROM*

Eder, W.E. (2007a) 'Design Engineering – Not Just Applied Science' in ***Proc. CDEN/CCEE Conference****, 22-24 July 2007, U. of Manitoba, Winnipeg, Manitoba, Canada, on CD-ROM*

Eder, W.E. and Hosnedl, S. (2007b) 'Transformation Systems – Revisited' in ***Proc. ICED 07 Paris****, 28-31 August 2007, Paris, France, on CD-ROM*

Eder, W.E. and Hosnedl, S. (2007c) 'Properties of Technical Systems – Augmenting a Legacy of Vladimir Hubka', Jnl. Eng. Design (in review)

Eder, W.E. and Hosnedl, S. (2007d) 'Information – Taxonomy and Interpretations', Jnl. Eng. Design (in review)

Eder, W.E. (2007e) 'Self-Starting Graduates – Industry's Needs', I.J.E.E. (in review)

Eder, W.E. and Hosnedl, S. (2008a) ***Design Engineering: A Manual for Enhanced Creativity****, Boca Raton: CRC Press*

Eder, W.E. (2008b) 'Comparisons of Design Theories – Relationship to the Legacy of Vladimir Hubka', Jnl. Eng. Design (in review)

Hales, C. (1991) ***Analysis of the Engineering Design Process in an Industrial Context*** *(2 ed., 1 ed. 1987), Winetka, IL: Gants Hill Publ.*

Hubka, V. (1967) 'Der grundlegende Algorithmus für die Lösung von Konstruktionsaufgaben' (Fundamental Algorithm for the Solution of Design Problems) in ***XII. Internationales Wissenschaftliches Kolloquium der Technischen Hochschule Ilmenau, Heft 12*** *Sektion L - Konstruktion, Ilmenau: T.H.I., p. 69-74*

Hubka, V. (1976) ***Theorie der Konstruktionsprozesse*** *(Theory of Design Processes), Berlin: Springer-Verlag*

Hubka, V. (1978) ***Konstruktionsunterricht an Technischen Hochschulen*** *(Design Education in Universities), Konstanz: Leuchtturm Verlag*

Hubka, V. et al. (1980) ***WDK 3 : Fachbegriffe der wissenschaftlichen Konstruktionslehre in 6 Sprachen*** *(Terminology of the science of design engineering in 6 languages), Zürich: Heurista*

Hubka, V. (1982) ***WDK 9: Dietrych zum Konstruieren*** *(Dietrych about Designing), Zürich: Heurista*

Hubka, V. (1984) ***Theorie Technischer Systeme****, Berlin: Springer-Verlag (2 ed, revised from Hubka, V. (1974) Theorie der Maschinensysteme)*

Hubka, V. (ed) (1985) ***WDK 11: Führung im Konstruktionsprozess – Reading*** *(Leadership in the Design Process), Zürich: Heurista*

Hubka, V., & Eder, W.E. (1988a) ***Theory of Technical Systems: A Total Concept Theory for Engineering Design****, New York: Springer-Verlag (completely revised translation of Hubka, V. (1984) Theorie Technischer Systeme 2 ed, Berlin: Springer-Verlag, 2nd edition of Hubka, V. (1974) Theorie der Maschinensysteme, Berlin: Springer-Verlag)*

Hubka, V., Andreasen, M.M. & Eder, W.E. (1988b) ***Practical Studies in Systematic Design****, London: Butterworths – English edition of Hubka, V. (1980)* ***WDK 4 – Fallbeispiele***

Hubka, V. & W.E. Eder (1992) ***Engineering Design****, Zürich: Heurista (2nd edition of Hubka, V. (1982)* ***Principles of Engineering Design****, London: Butterworth Scientific, translated and edited by W.E. Eder from Hubka, V.(1980)* ***WDK 1: Allgemeines Vorgehensmodell des Konstruierens****, Goldach: Fachpresse)*

Hubka, V., & Eder, W.E. (1996) ***Design Science: Introduction to the Needs, Scope and Organization of Engineering Design Knowledge****, London: Springer-Verlag, http://deed.ryerson.ca/DesignScience/ (completely revised edition of Hubka, V. and Eder, W.E. (1992a)* ***Einführung in die Konstruktionswissenschaft*** *(Introduction to Design Science), Berlin, Springer-Verlag)*

Klaus, G. (1965) ***Kybernetik in philosophischer Sicht*** *(Cybernetics in Philosophical View) 4th ed., Berlin: Dietz Verlag*

Nevala, K. (2005) ***Content-based Design Engineering Thinking****, Academic Dissertation, University of Jyväskalä, Finland, Jyväskalä: University Printing House, http://cc.oulu.fi/~nevala*

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