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ENGINEERING DESIGN SCIENCE - ADVANCES IN DEFINITIONS

W. Ernst Eder and Stanislav Hosnedl

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1. Introduction

In a normal development a science is never completed. According to Kuhn [1970 and 1977] each science is described by a currently agreed paradigm or disciplinary matrix. Additional insights always lead to revisions and re-definitions. Eventually, when sufficient further evidence has been accumulated (some of which will not fit the accepted interpretations), Kuhn [1970 and 1977] has indicated that what is accepted as currently valid knowledge (warranted true belief) will need to be revised, and new proposals are made to overcome the deficiencies. This results in a smaller or larger change of the disciplinary matrix, a paradigm shift, a scientific revolution, replacement by a new theory. This change may take place over a substantial time period. Even then, the established proponents will usually resist change. Examples of such changes are Newton's laws of motion, relativity, quantum theory, chaos theory, etc.

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 (generating knowledge, and formulating plausible scientific theories) generally follows two parallel paths:

(a) the classical experimental, *empirical* way of observing (e.g. by experiments, protocol studies, etc.), describing, abstracting, modeling, generalizing, and formulating hypotheses and theories; and

(b) the speculative, reflective, *philosophical* way of postulating hypotheses, formulating theories, modeling, and subsequent testing.

In any human-influenced activity, such as for instance 'designing' as a subject for research, the empirical way usually includes elements of self-observation, as well as impartial observation of experimental subjects. In the case of 'designing' in particular, 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.

It should be obvious that neither of these paths of empirical and philosophical investigation can be self-sufficient, and that they must be co-ordinated if an internal consistency and plausibility is to be attained.

Scientists, in their research interests, are involved both in producing and in expanding the forefront of the boundaries of a limited area of knowledge. They are not normally interested in the existing information of these areas *per se*, nor in their mutual relationships, except for the purposes of teaching future researchers. Nevertheless, these individual areas incidentally require information about the foundations and histories of those areas of knowledge, and a general awareness of history and the humanities.

The science is necessarily an abstraction, and should provide a logical framework into which the relevant information can be categorized. Sciences can form a hierarchy [Eder 2004b], and over time each branch of science sub-divides into more detailed sections, inheriting the broader views, but adding detail in the narrower definitions. At times, a newer sub-division combines views from different branches of sciences, completing the view into an interconnected network of knowledge.

Designing 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 for which they can be used, 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. Designing something useful with a substantial technical content, usually within market constraints, is what distinguishes engineering from scientific or artistic activity. We therefore refer to *design engineering* as our activity of interest.

In designing, many choices are open, and any one choice has a range of validity and appropriateness depending on the circumstances of the choices to be made, and the person doing the choosing.

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.

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 under the leadership of Workshop Design-Konstruktion (WDK) – now transferred to The Design Society, and several books have been published in German and English [Hubka 1976, 1978, 1980, 1982a (1980), 1982b, 1984, 1985, 1988a (1974, 1984), 1988b (1980), 1992, and 1996 (1992a)].

This paper traces the development of some of the models and definitions from these works, and indicates recent developments that were needed to clarify some concepts.

2. 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 heuristic values for products to be designed; and a hierarchy of design sciences.

2.1 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 9000:2000], see figure 1. The relevant property classes of technical systems are listed by title in figure 2. '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.

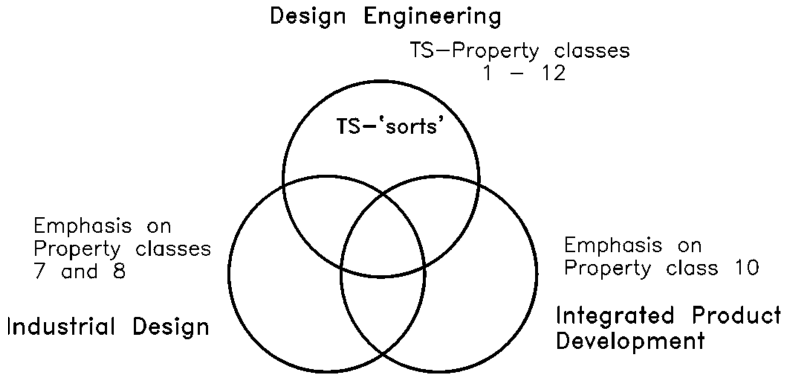

Figure 1 Scope of Sorts of Designing

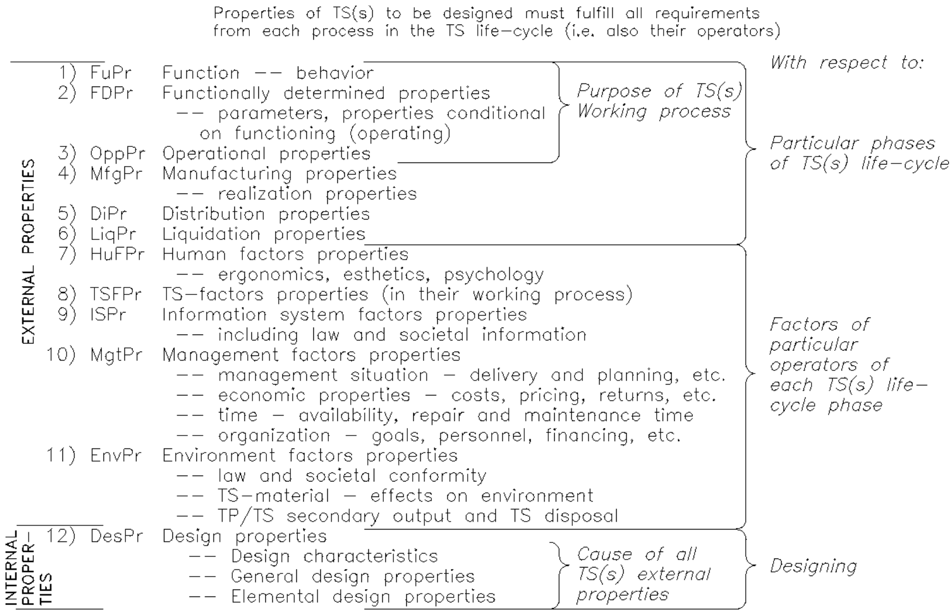

Figure 2 Classes of Properties of Technical Systems

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.

2.2 Transformation system

The model of a transformation has developed from its original presentation in [Hubka 1967], to a first completion in [Hubka 1974] see figure 3. 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 4, especially with respect to the operators. The role of secondary inputs and outputs with respect to the transformation process was again recognized in [Hubka 1996], see figure 5. The most recent discussions between the authors and Dr. Hubka have led to a further refinement, see figure 6. 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.

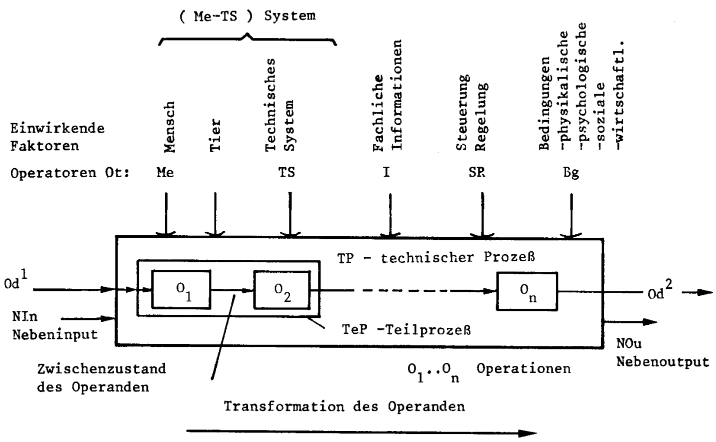

Figure 3 Transformation System from [Hubka 1974]

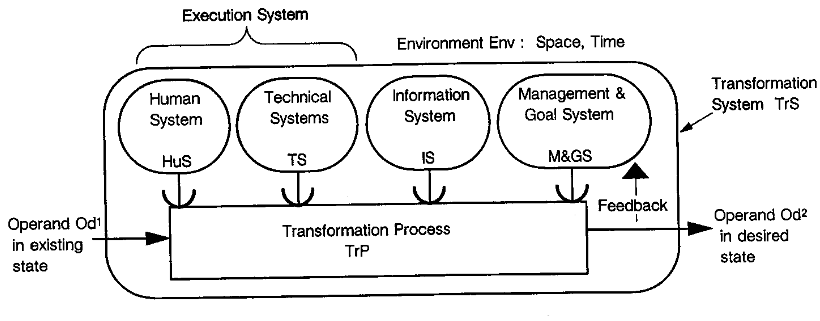

Figure 4 Transformation System from [Hubka 1988a]

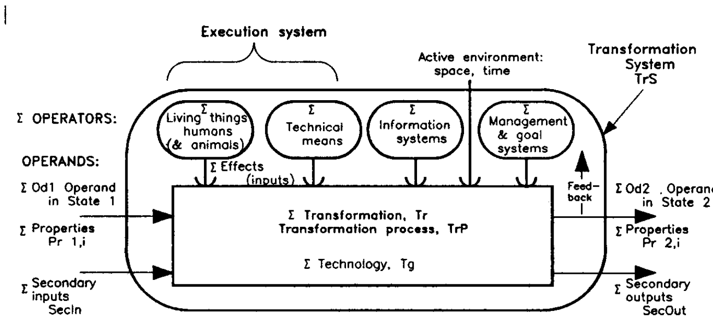

Figure 5 Transformation System from [Hubka 1996]

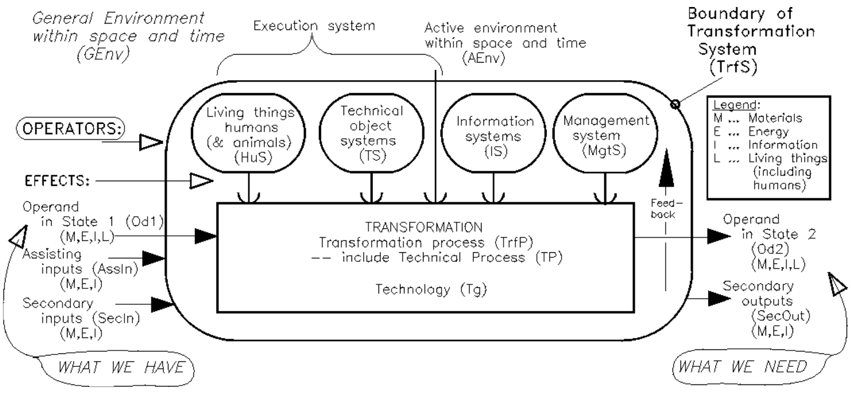

Figure 6 Transformation System

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. The structure of the transformation process has been better defined, specifying the various kinds of operations that can occur, see figure 7.

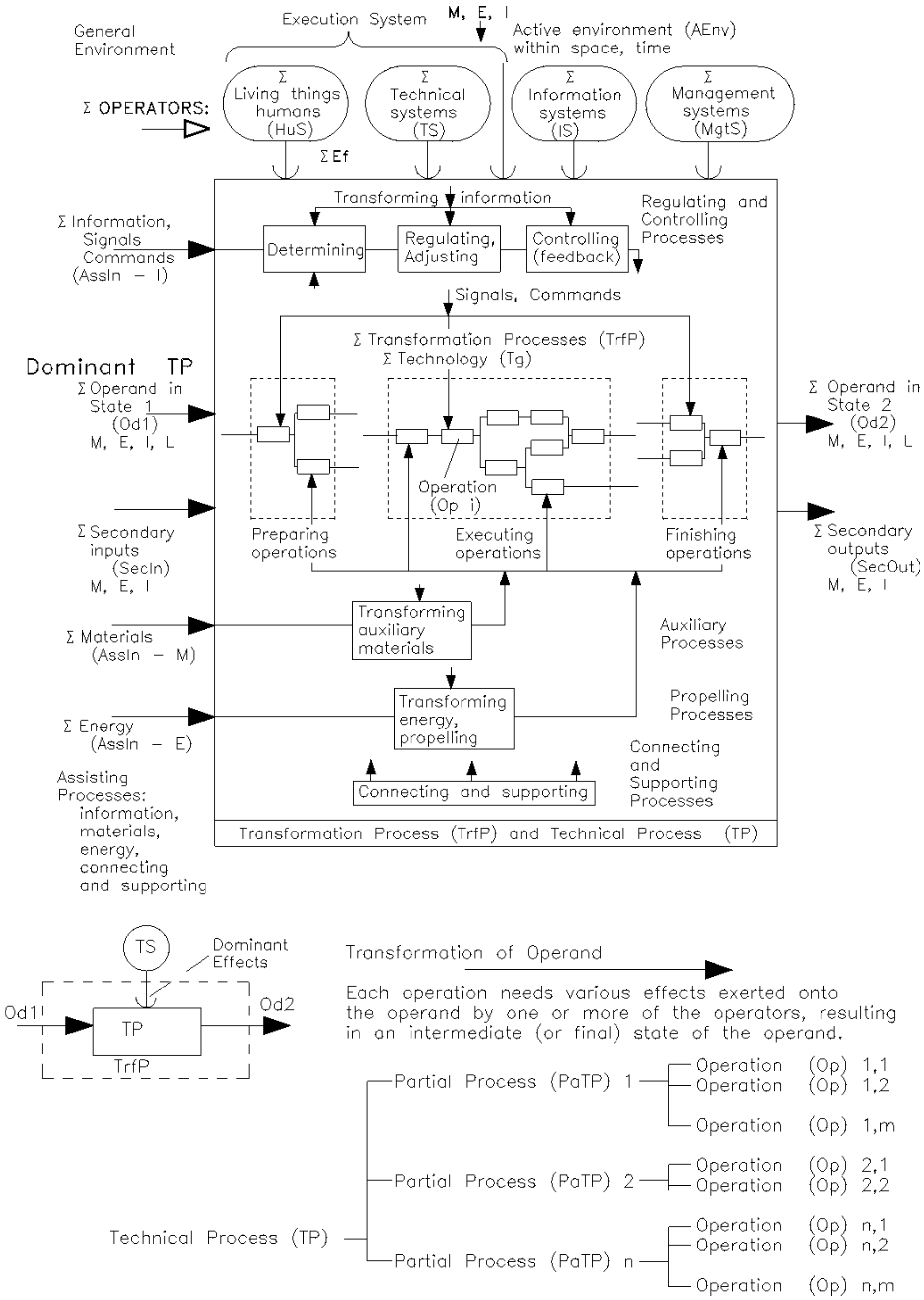

Figure 7   Structure of the Transformation Process

For the purposes of designing (see [Eder 2005a and 2005b]), 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) 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. Several case studies have demonstrated the expediency of this procedural step [Eder 2005a].

2.3 Information

In earlier publications such as [Hubka 1996], the map of Design Science used the word 'knowledge' for all four axes, see figure 8. This has now been recognized as limiting. 'Knowledge' implies that information has been processed, usually by abstracting, generalizing and codifying. In its recorded form, information, including knowledge and data, can be made available to others. Each human absorbs information, e.g. by learning, and builds it into his/her own idiosyncratic internalized information structure, as personal 'knowing'. Each such personal structure is different, but all have much in common. Eder [2004a] therefore proposed that 'information' should be regarded as general, and 'data' and 'knowledge' are special cases. The resulting changes are shown in the revised map of Engineering Design Science, as discussed in section 2.4 of this paper. In this way, a better coordination with the operator 'information system' in the transformation system has been achieved, see figure 6.

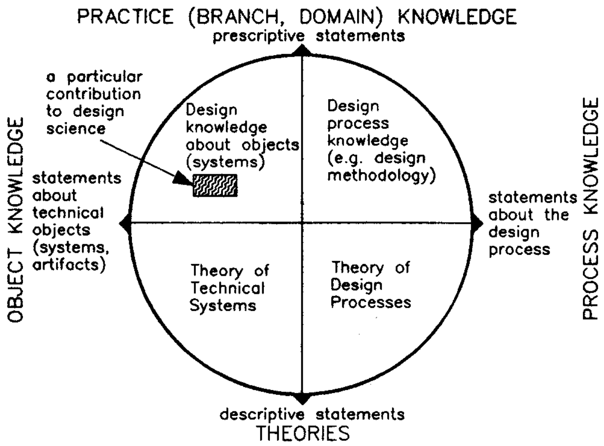

Figure 8 Map of Design Science from [Hubka 1996]

2.4 Object information

Before, and in the publications by Hubka [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 8. In the most recent developments and discussions (see section 2.3 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, 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 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 9, 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 has now been drawn to 'separate' the scope of Engineering Design Science from other knowledge and information. The related contributing information has been brought into a relationship with the concepts of Engineering Design Science.

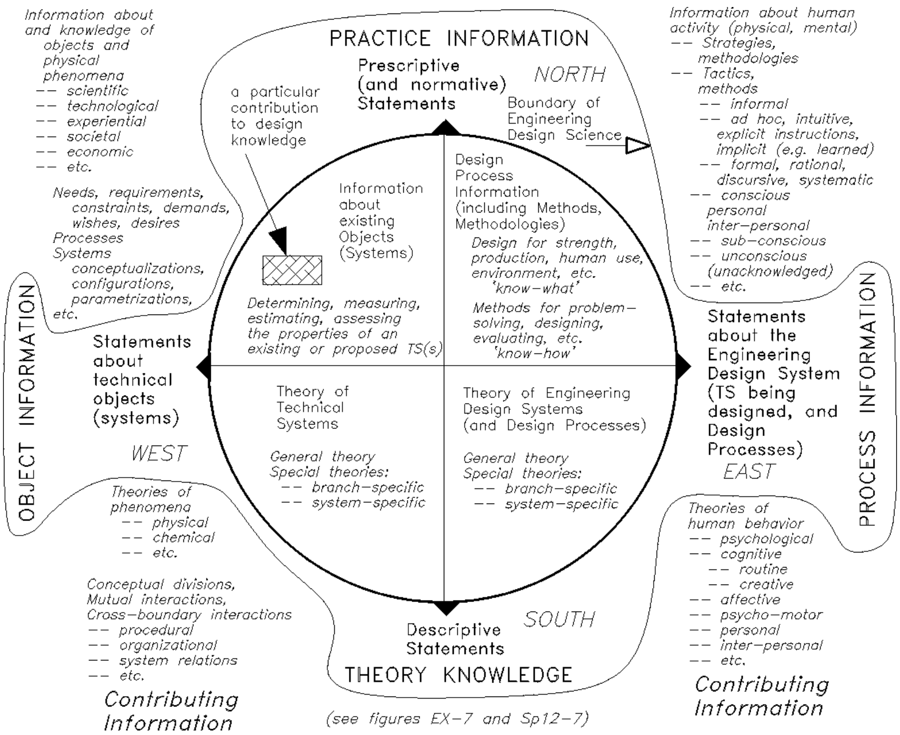

Figure 9   Map of Design Science

2.5 Design science hierarchy

[Hubka 1996] indicated that knowledge with respect to engineering forms a hierarchy, see figure 10.

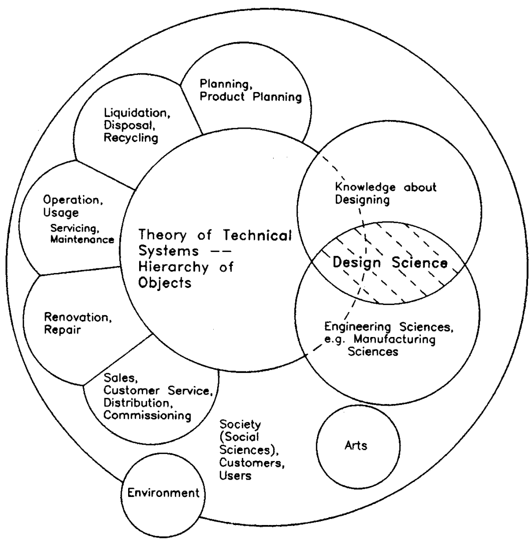

Figure 10   Hierarchy of Knowledge from [Hubka 1996]

An extension of 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. 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 1 of this paper. In a similar way, ‘design sciences’ can be also sub-divided, see figure 11.

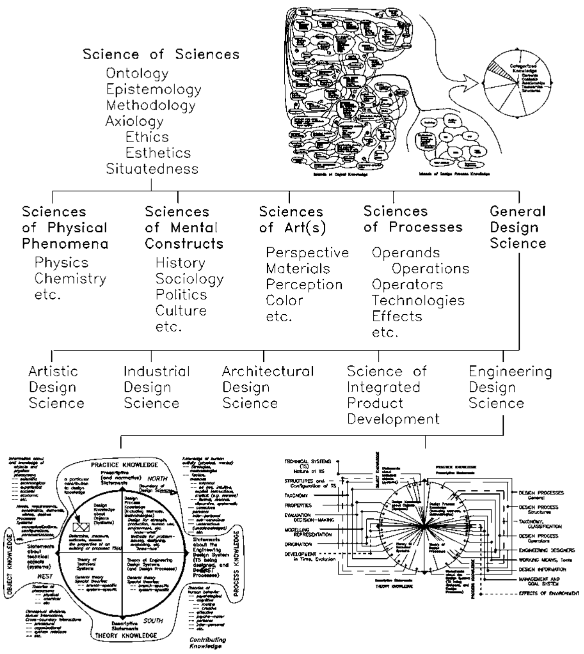

Figure 11 Hierarchy of Sciences

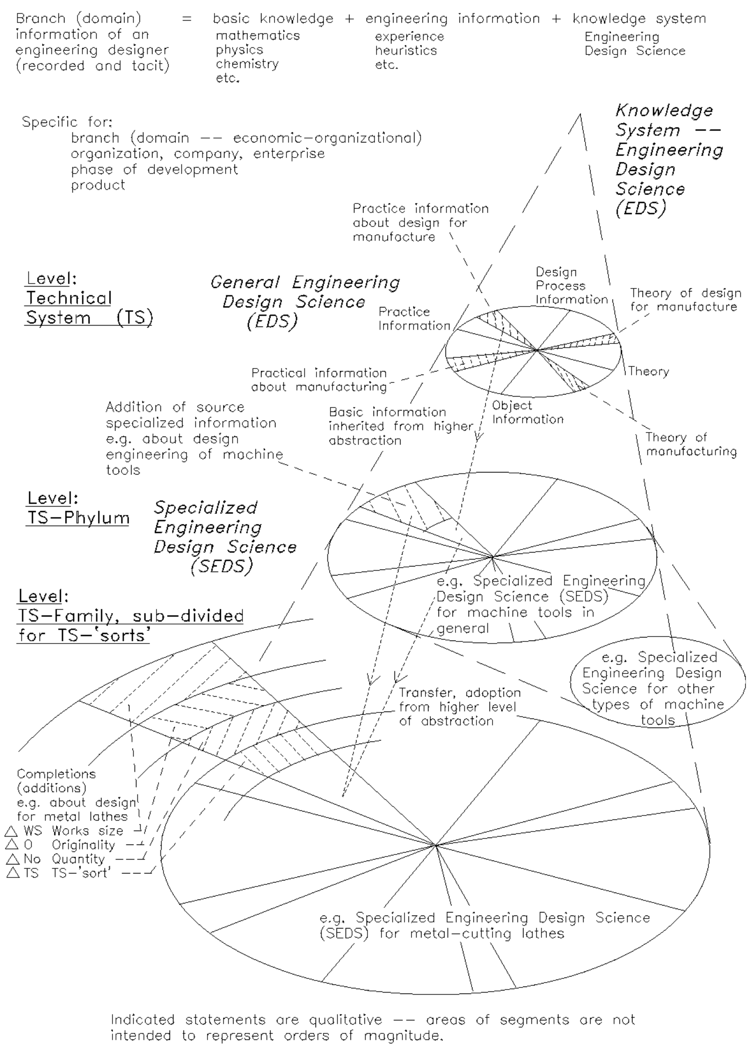

Figure 12 Constitution of Branch Information for Design Engineering

One of these sub-divisions is ‘Engineering Design Science’ [Hubka 1996]. Even this Engineering Design Science could be sub-divided into ‘Specialized Engineering Design Sciences’ at various more detailed levels of abstraction and applicability, see figure 12.
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 13, adapted from [Hubka 1996]. 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 13 allows a demonstration of this grouping by separating ‘object information’ from ‘design process information’.

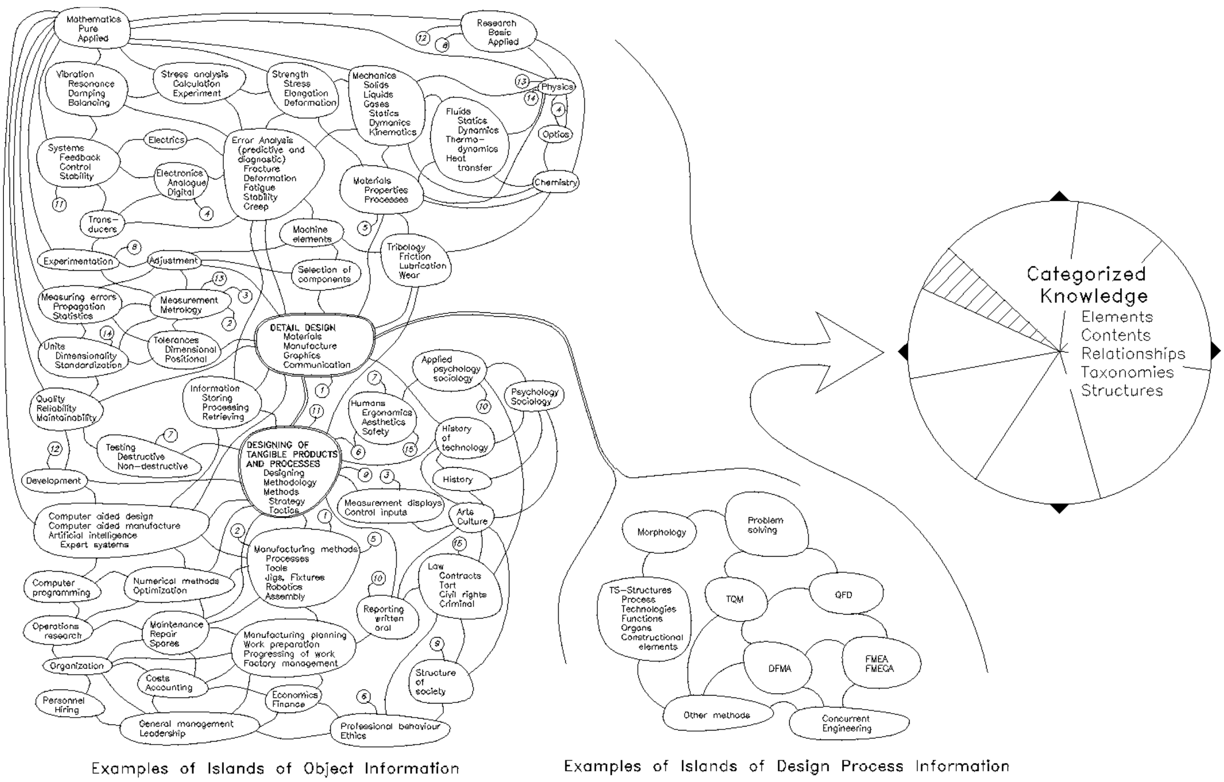

Figure 13 Concept Map of Contributing Information

3 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 several of our ideas.

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W. Ernst Eder
Royal Military College of Canada, Department of Mechanical Engineering (retired)
Home Address: 107 Rideau Street, Kingston, ON, K7K 7B2, Canada
x-1-613-547-5872, eder-e@rmc.ca