Chapter 10
Engineering Design: Role of Theory, Models, and Methods

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10.1 Introduction

Some strict distinctions need to be made. "Design" in the English language has two usages. The noun, "the design" refers to that actual manifestation of a product, a tangible man-made object, an idea, a concept, a pattern, an artificial process, etc.—the way it looks, feels, and behaves, the result of a human intention. As a verb, "designing" refers to the mental and other processes that occur during this activity in order to establish "the design." In Design Research, the main interest lies in "designing," the verb, and in any underlying theory that can provide guidance for methods to enhance or enable designing. Design Practice at times looks for such guidance to overcome problems—when the design situation is nonroutine, when expertise and competence is lacking [8], for instance in enabling experienced engineering designers to explore the design space beyond their level of competence. Research for activities such as design engineering follows at least six parallel paths [18, 19]:

- The classical experimental, *empirical* way of independent observing, e.g., by protocol studies, including self-observation, and impartial observation of experimental subjects, etc., describing, abstracting, recognizing, perceiving, understanding, modeling, formulating hypotheses—observations capture a proportion of thinking, usually over short time spans;
- *Participative* observation, the observer also acts as a member of the design team and thus acts in the observed process [23]—which in consequence may be biased by the observer's participation;

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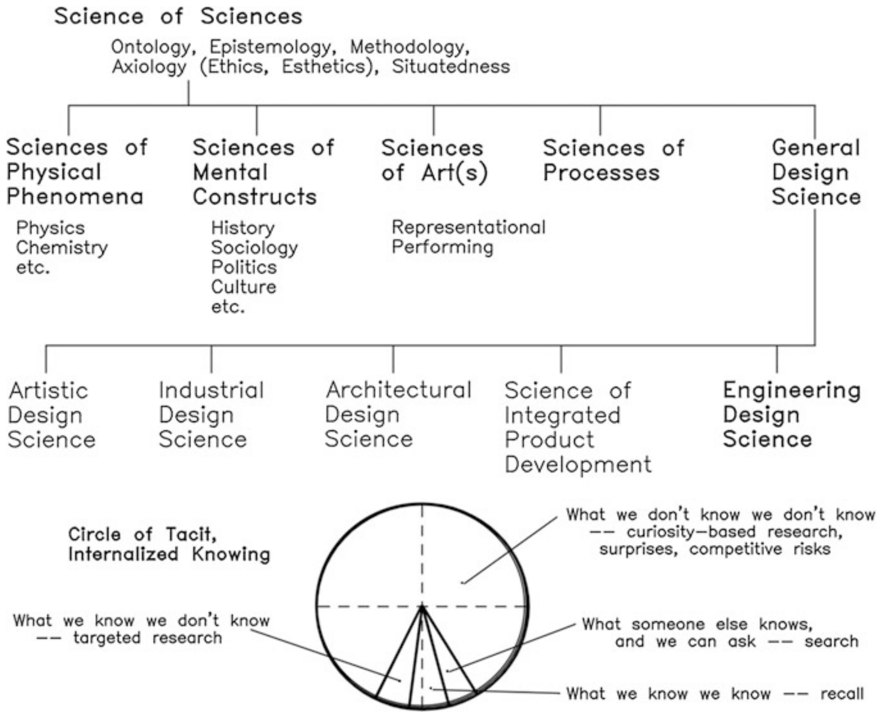

Fig. 10.1 Hierarchy of sciences ([18]; McMaster [38])

- A *reconstructive*, detective way of tracing past events and results by looking for clues in various places [40]—reconstructions never fully capture the original events, human memory is limited, and needs to be reconstituted for recall;
- Speculative, reflective, *philosophical* generating of hypotheses, and testing;
- Transfer between practical *experience* and the insights of knowledge; and
- *Development* of not-for-profit products [25].

These paths must be coordinated to attain internal consistency and plausibility. The theory and methods outlined here were developed from the fourth and fifth of these paths.

The purpose of design research is to clarify design processes, see Fig. 10.1, including designing in general, and particular forms of designing, e.g., design engineering, the focus of this chapter. In addition, design research should explore where assisting methods may be needed and useful—routine versus nonroutine design situations, and the needs of management versus practitioners [8].

A further necessary distinction is between a theory and a method. As formulated in cybernetics [34, 35], "*both theory and method emerge from the phenomenon of the subject*', see Fig. 10.2. A close relationship should exist among a *subject* (its nature as a concept or object), a basic *theory* (formal or informal, recorded or in a human mind), and a recommended *method*—the triad "subject—

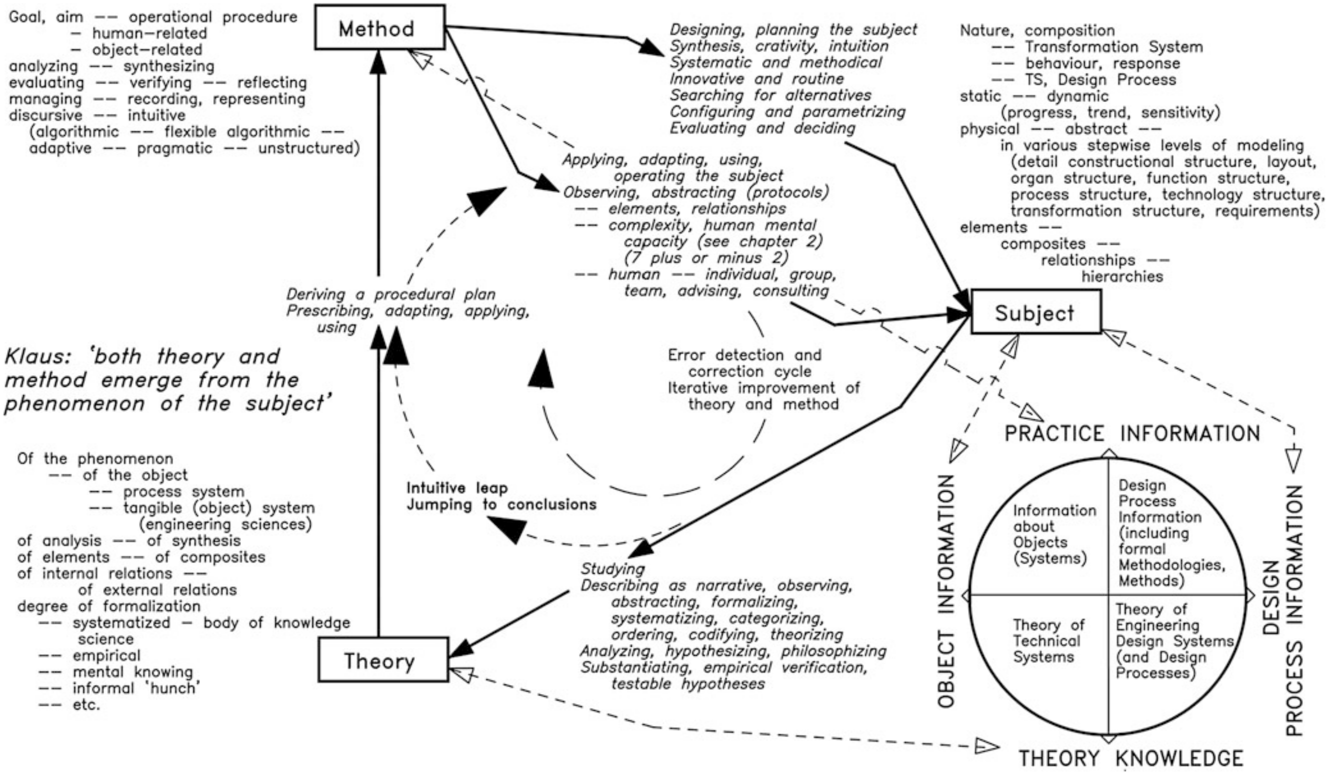

Fig. 10.2 Relationship among theory, subject, and method ([18, 19, 34, 35])

theory—method." The theory should describe and provide a foundation for explaining and predicting "the behavior of the concept or (natural or artificial, process or tangible) object," as subject. The theory should be as complete and logically consistent as possible, and refer to actual and existing phenomena. The (design) method, intended as a guide for more or less experienced engineering designers to assist them when their task reaches beyond their level of expertise, can then be derived, and consider available experience [19]. One aim is to separate declarative theory of the object being designed from both the theoretically logical method, and the suggested and voluntary method to be idiosyncratically applied.

In design engineering, the transformation process, TrfP(s), and/or the technical system involved in the TrfP, the TS(s)—see Sect. 10.4 of this chapter—are the subjects of the theory and the method. The *theory* should answer the questions of "why," "when," "where," "how" (with what means), "who" (for whom and by whom), with sufficient precision. The theory should support the utilized methods, i.e., "how" (procedure), "to what" (object), for the operating subject (the process or tangible object) or the subject being operated, and for planning, designing, manufacturing, marketing, distributing, operating, liquidating (etc.) the subject.

The *method* should be sufficiently adapted to the subject, its "what" (existence), and "for what" (anticipated and actual purpose). Graphic models that are part of the theory can be used as guides to design activity. Methods in application must remain voluntary, adaptable, and without guarantee of success. They must be learned, preferably on simplified examples, before they can be used (often from subconscious memory) on a problem of any substantial importance [8]. The phenomena of subject, theory, and method are of equal status.

10.2 Basic Considerations

Design engineering and the more artistic forms of designing (e.g., industrial design, architecture, graphic, and sculptural art) have much in common, with partly overlapping duties, but substantial differences, see Table 10.1—the descriptions show a contrast of extremes, rather than all aspects of designing.

If a product is intended to be visually attractive and user-friendly, its form (especially its observable shape) is important—a task for, e.g., *industrial designers*, and architects. Industrial design [20, 33, 44, 45], in the English interpretation, tends to be primary for consumer products and durables, emphasizes the *artistic elements*, appearance (size, shape, etc.), ergonomics, marketing, customer appeal, satisfaction, etc.—observable properties of a product. This includes color, line, shape, form, pattern, texture, proportion, juxtaposition, emotional reactions [21], etc.—these are mainly *observable properties* of a tangible product. The task given to or chosen by industrial designers is usually specified in rough terms. The mainly *intuitive* industrial design process emphasizes "creativity" and judgment, and is used in a studio setting in architecture, typographic design, fine art, etc., Industrial designers can introduce new fashion trends in their products.

Table 10.1 Scope of sorts of designing [18, 19]

Objectives, design conditions	Design engineering	Artistic-architectural-industrial design
The object to be designed, or the existing (designed) object	Transformation process and/or technical system; primary: functioning, performing a task	Tangible product; primary: appearance, functionality
Representation and analysis of the object as designed and its "captured design intent"	Preparing for TS(s) manufacture, assembly, distribution, etc., AI, CAD/CAM/CIM	Rendering for presentation and display, product range decisions
Design process (for the object), methodology, generating the "design intent"	Theories of designing, Engineering design science, formal design methodologies	Intuitive, collaborative, Interactive designing
Properties of the object as output of design	Mediating and elemental design properties, to establish observable properties	Observable properties to achieve customer satisfaction
Design phenomenology	Empirical, experimental, and implementation studies	Protocol studies
Responsibilities	Professional, ethics, reliability, safety, public, legal liability, enterprise, stakeholders	Organization, stakeholders (Architecture adds organizational and contract responsibility)
Location	Design/drawing office	Studio

For industrial designers, "conceptualizing" for a future tangible product consists of preliminary sketches of observable possibilities (even if somewhat abstract)—a direct entry into observable hardware (the constructional structure) and its representation. The sketches are progressively refined, and eventually "*rendered*" (drawn and colored, or modeled by computer or in tangible materials—*maquettes* or full-size clay models) into visually assessable presentation material, full artistic views of the proposed artifact, to provide a "final" presentation, for management approval. Considerations of engineering may need to take place, depending on circumstances, e.g., stability and self-strength of a sculpture. Industrial designers usually work "outside inwards", defining the observable envelope, thus constraining any envisaged internal constituents and actions.

In contrast, if a tangible product should work and fulfill a purpose by helping to perform a transformation process, TrfP, e.g., by mechanical, electrical, chemical, electronic, etc., means, its *functioning and operating* (verb form) are important—a task for engineering designers. Anticipating and analyzing this *capability for operation* is a role of the engineering sciences. *Engineering* intends to create what does not yet exist, that is likely to work, even if the way it works (its mode of action) is only partially understood by scientific means. Engineering needs designers to be aware of a wide range of existing information (e.g., scientific and experience-based heuristic) and its complex interactions, and to consider and accommodate all relevant influences (e.g., scientific, technical, economic, societal, political) to achieve a technically and economically successful and optimal product. The outcome of design engineering is a set of *manufacturing instructions* (detail and assembly drawings to scale, including tolerances and raw material specifications [1]—these, more recently, are likely to be computer-resident) for each constructional part, including instructions for assembly, adjustment, testing, use, spare parts, etc., see Fig. 10.3. These were traditionally produced manually in a design/drawing office, using drafting machines. Computer “seats” have more recently taken over some duties. In addition, documented analytical verification of anticipated performance in all life-cycle phases must be delivered by a qualified professional engineer. The resulting tangible product is a *technical system* (TS).

Design engineering is more constrained than industrial design, because:

- a design specification is usually prescribed by a customer or a marketing department, and is often the basis of a legally binding contract for delivery of a desired *performance* (a transformation process, TrfP),
- the relevant engineering sciences must be applied,
- societal norms and regulations (including laws) must be satisfied,
- risks and hazards must be controlled, the existing information must be respected, and
- economic considerations apply, e.g., survival and profitability.

Design engineering has available a theory of technical systems [28], see Sect. 10.3, and its associated engineering design science [31], which suggests several abstract models and representations of structures for existing transformation processes, TrfP-Str, and technical systems, TS-Str. These structures can be used stepwise during designing as tools for establishing requirements, and for verbal, graphical, cognitive, and conceptual modeling of novel or redesigned products (tangible and process), see Sects. 10.4 and 10.5—mathematical modeling is well established in the engineering sciences.

In fact, design engineering must consider a wide spectrum of information, and fit into the various cultural schemes applicable to different regions and countries, see Fig. 10.4. This is one of the many challenges facing engineering. Conversely, design engineering influences many of the cultural, social, political, and other environments. The process of implementing any technology (process or tangible object, old or new) almost invariably begins with design engineering.

Is a car an engineering product? The steering mechanism, suspension, motor and drive train, instruments, and a range of other items internal to the car (often hidden from view) are certainly engineering products, to which industrial-artistic designers can have little input. Mostly, these items cannot normally be observable for the driver, passenger, or casual observer, they are described by the *mediating* and *elemental design properties* of a technical system. Some of these intermediate products are OEM or COTS parts (original equipment manufacturers supplies, commercial off-the-shelf engineering products) manufactured by other organizations, e.g., springs, starter motors, alternators, computers, etc. Even the interior of

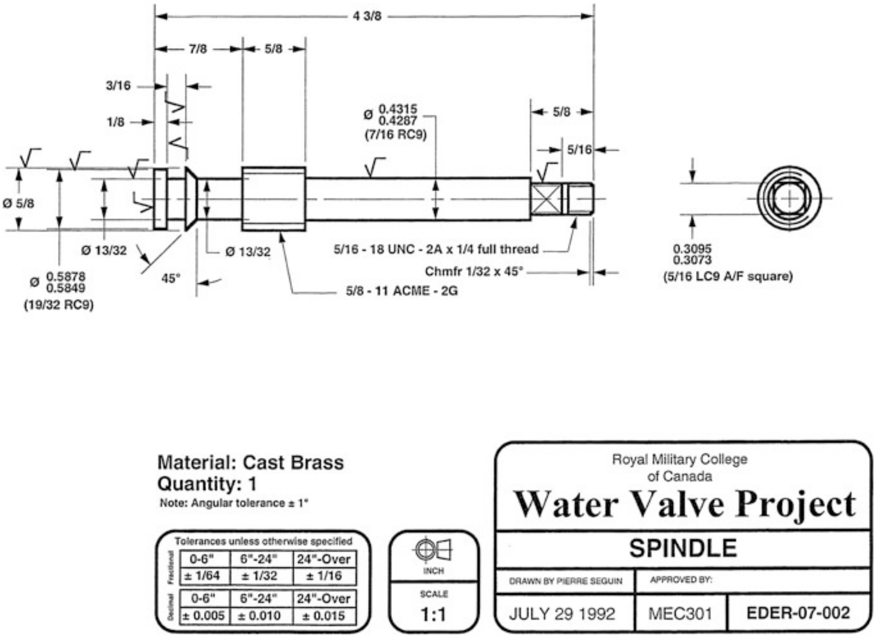

Fig. 10.3 Engineering detail drawing with typical geometric features [15]

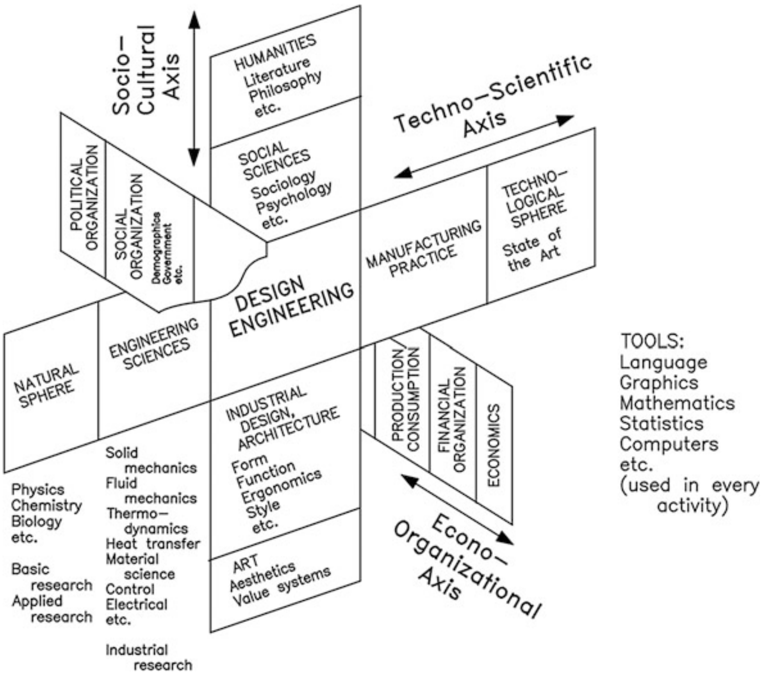

Fig. 10.4 Dimensions of design engineering in technology and society [16]

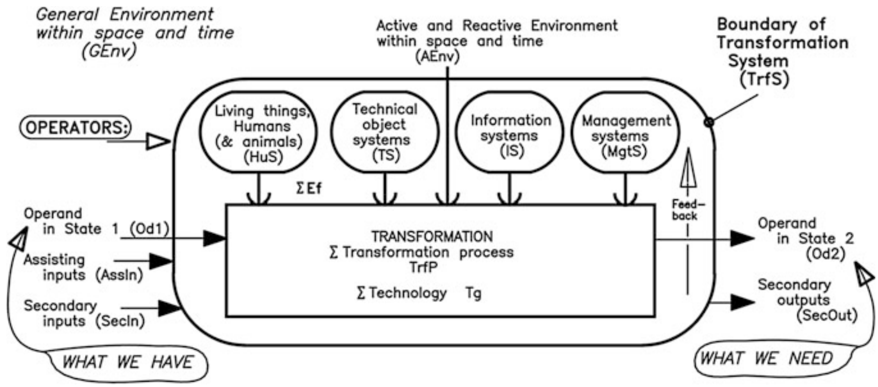

Fig. 10.5 General model of a transformation system [18, 19]

doors and other body parts (structural members, stiffeners, window mechanisms, etc.) are much more engineering than artistic. The exterior of the body parts (including the enclosed volume of the passenger compartment) is certainly more industrial-artistic. But the arrangement and division of individual body panels and their strength and structural integrity are engineered for durability, manufactura-bility, etc.—an engineering responsibility. In fact, a car is definitely an engineering product—without the engineering you only have an essentially decorative mon-ument. Without the industrial design, the appearance and appeal of the car may be unsatisfactory, reference the "U.S. Army General Purpose Vehicle (GP)" of the 1940s, the original Jeep. Is this is a reason why the industrial designer often gets named, but the engineering designers are not ever mentioned, and credit for the engineering items is often given to "(applied) science?" In contrast, an electrical power transformer (500 MVA, 110 kV) hardly needs industrial design.

This comparison of artistic versus engineering designers is, of course, extreme and exaggerated, the truth is somewhere in between, many technical systems also need industrial design, and cooperation is often essential. The comparison is based on the author's personal experience in industry and life—10 years in industry (1951–1961) "on the drawing board" for electrical power transformers and switchgear, vehicles for alpine forestry, and other nonconsumer engineering products [11].

10.3 Outline of Technical Systems

This section presents a brief outline of the Theory of Technical Systems and its supporting graphical models, under development since about 1965—its latest version is Eder and Hosnedl [19]. Figure 10.5 shows the basic model on which the theory and method are based, the transformation system, TrfS, which declares:

- *An operand (materials, energy, information, and/or living things—M, E, I, L) in state Od1 is transformed into state Od2, using the active and reactive effects (in the form of materials, energy and/or information—M, E, I) exerted continuously, intermittently, or instantaneously by the operators (human systems, technical systems, active and reactive environment, information systems, and management systems, as outputs from their internal processes), by applying a suitable technologyTg (which mediates the exchange of M, E, I between effects and operand), whereby assisting inputs are needed, and secondary inputs and outputs can occur for the operand and for the operators.*

This model, initially proposed in 1974, is now recognized as the prototype for a Product-Service-System, PSS, recently the focus of research in product development [37]. Hubka's theory (and consequently the recommended design methodology, see Sects. 10.4 and 10.5 of this chapter) also includes many other considerations. The operators can be active or reactive in their interaction with each other and in their technology interaction with the operand. A hand power tool is reactive to its human operator, but active toward the operand. An automotive automatic transmission is mainly active.

The operators of a TrfS can in most cases be regarded as full transformation systems in their own right. For instance, the management system (MgtS) performs its management process, driven by human managers, management technical systems, a management environment, a management information system, and an upper-level management system.

Both the general environment (regional, national, and global) and the active and reactive environment cover physical, chemical, societal, economic, cultural, political, ideological, geographic, ecological, and all other influences directly or indirectly acting on or reacting to the transformation system, its process, and its operators.

The transformation process, TrfP, that is the main purpose of the transformation system, TrfS (and therefore is the task of the technical system as its operator), has a structure of operations and their arrangement or sequencing. The transformation process, TrfP, can take place if (and only if): (a) all operators of the transformation system, TrfS, are in a state of being *operational*, they (especially the TS) should be able to operate or be operated, if appropriate inputs are delivered to the operator; (b) an operand in state Od1 is available; and (c) both are brought together in a suitable way, with an appropriate technology. The TrfP must therefore be totally external to the operators.

A typical life cycle of a technical system, TS(s), is defined as a sequence of TrfS: *LC1*—Planning of TS(s) and TrfS(s), product planning, *LC2*—Designing of the TrfP(s) and the TS(s), *LC3*—Technological and organizational preparation for subsequent life cycle processes, *LC4*—Manufacture of the TS(s), *LC5*—Distribution of the TS(s), *LC6*—Operational usage to perform the TrfP(s), plus (*LC6A*) TS(s) maintenance, repair, refurbishing, etc., and *LC7*—Liquidation, re-engineering, recycling, etc. Life cycle stages *LC6* and *LC6A* are often referred to as the Product-Service-System, PSS [37].

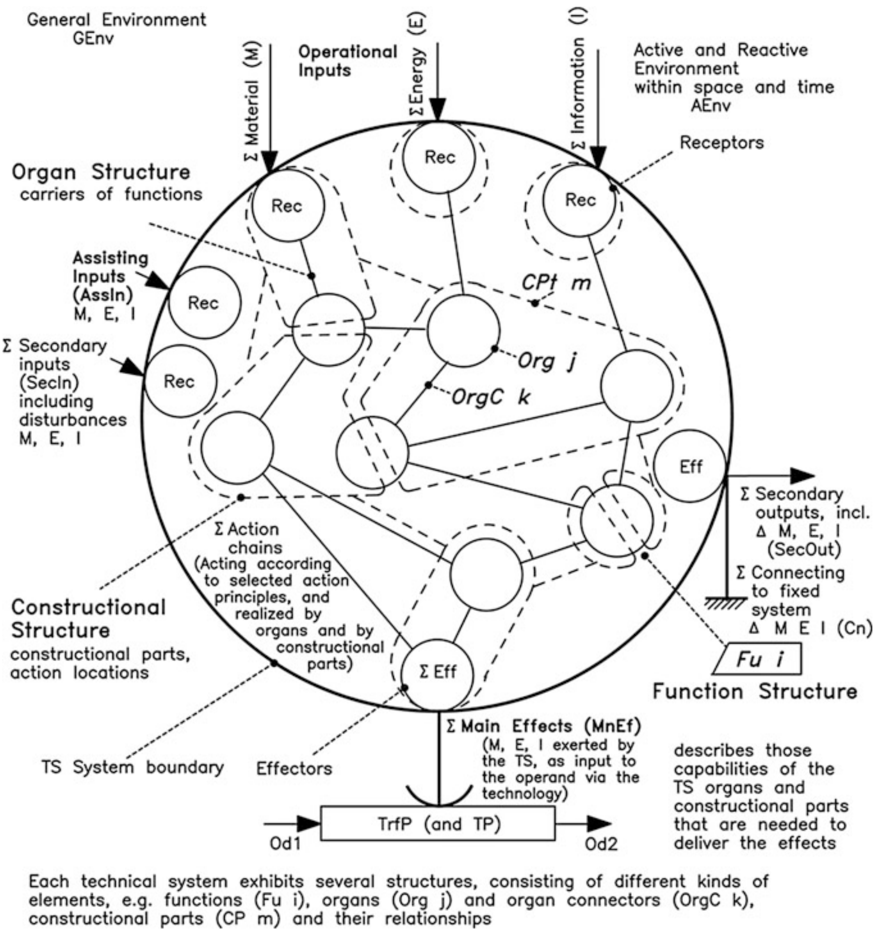

Fig. 10.6 Model of a technical system—structures [8, 18]

Various useful structures can be recognized, see Fig. 10.6: (a) transformation process, TrfP(s), and its structure of operations (see above), (b) technology, Tg, (c) TS-function structure, FuStr, a structure of TS-internal and cross-boundary capabilities of operation—also adopted in [41], (d) organ structure, OrgStr, action locations on constructional parts interacting—[41] replaces this with "physics", (e) constructional structure, CStr, the acting constructional parts—the main emphasis of [41]—for engineering design this structure is represented (usually graphically [1]) in (e1) preliminary layout, (e2) definitive/dimensional layout, and (e3) detail, assembly, parts-list, etc. These structures are, of course, closely interrelated, but almost never in a 1:1 relationship. Such structures are recognizable in technical system, but usually not in artistic-designed objects (products).

The TrfP and the TS exhibit properties. These are arranged in classes appropriate to each constituent of the TrfS derived from Fig. 10.6, and the classes are arranged in major groupings of *observable*, *mediating*, and *elemental design* properties. The mediating properties are separated into the *intrinsic* (heuristic and experience information) and *general* (engineering sciences) properties.

The *states* of TS-properties exist and change among the different states of existence, e.g., various life-cycle phases of a TS(s), and under various operating states, the "duty cycle" of an operational TS(s): (a) at rest, no operation; (b) during start-up; (c) during normal operation—idling, full-power and part-load, overload, etc., for self-acting operation (automatic), or running and ready to be operated by another operator, e.g., human or another TS; (d) during shut-down, ending an operational state and returning to "at rest" conditions; (e) in fault conditions—(e1) internal faults—overload, safe trip-out, breakage or equivalent, and (e2) external faults—damage, wrecking, etc.; (f) during maintenance, repair, testing, etc.; (g) at "life ended"; (h) any other states. The TS(s) can thus be operational, and even operating, in the absence of the operand of the TrfP.

Further considerations include mode of action, development in time, and other items of interest for engineering design processes.

The models of Hubka's theory are closely interconnected, and have been extended into considerations of engineering education [18], engineering management [18, 19], the design process itself [8, 18], and others. These models allow explanation of a usual operation of a manufacturing organization, the need for a distribution and servicing network for the product, the need for a supply chain to the manufacturing organization, and several other societal and economic factors.

10.4 Outline of Engineering Design Methodology

Using the models in Figs. 10.5 and 10.6 as bases, the stages and steps for a novel design process [18, 19] use the various structures in a sequence from abstract to more concrete, and considering all the aspects described by the theory of technical system, see Sect. 10.3. Constituting life cycle stage *LC2*, they are summarized as:

- *task defining*:

(P1) establish a design specification for the required system, a list of requirements; partly clarified also in [41];

(P2) establish a plan and timeline for design engineering;

- *conceptualizing*:

(P3a) from the desirable and required output (operand in state Od2), establish a suitable transformation process, TrfP(s), with alternatives;

(P3.1.1) if needed, establish the appropriate input (operand in state Od1);

(P3.1.2) decide which of the operations in the TrfP(s) will be performed by technical systems, TS, alone or in mutual cooperation with other operators; and which TS(s) (or parts of them) need to be designed;

(P3.1.3) establish a technology, Tg, (structure, with alternatives) for that transformation operation, and therefore the effects (as outputs) needed from the technical system, TS(s);

(P3b) establish what the technical system needs to be able to do (its internal and cross-boundary functions, with alternatives);

(P4) establish what organs (function carriers in principle and their structure, with alternatives) can perform these functions. These organs can be found mainly in prior art, especially the machine elements, in a revised arrangement as proposed in [4, 5, 51];

- *embodying/laying out and detailing*:

(P5a) establish what constructional parts and their arrangement are needed, in sketch outline, in rough layout, with alternatives;

(P5b) establish what constructional parts are needed, in dimensional-definitive layout, with alternatives;

(P6) establish what constructional parts are needed, in detail and assembly drawings, with alternatives.

The suffix "(s)" indicates that this TrfP(s) and/or TS(s) is the subject of design interest. Adaptation for redesign problems (probably about 95 % of all design engineering tasks) proceeds through stages (P1) and (P2) above, then analyzes from (P6) or (P5b) to (P4), and/or to (P3b) to reverse engineer these structures, modify them according to the new requirements, and use the stages in the usual order to complete the redesign.

The classes of properties of existing TrfP(s) and the TS(s), and the classes of properties related to the life cycle phases *LC1–LC3* (the manufacturing organization), lead directly to the list of primary and secondary classes of *requirements* that are the basis for step (P1), establishing a design specification [19].

Only those parts of this engineering design process, possibly coupled with other design methods, that are thought to be useful are employed. Such an "idealized" procedure cannot be accomplished in a linear fashion—iterations, and recursions are essential, using analysis and synthesis [6], see also Sect. 10.5.

The Hubka engineering design methodology allows and encourages the engineering designers to generate a wider range of solution proposals at various levels of abstraction from which to select—one of the hallmarks of creativity is a wide range of proposed solutions. Designers should also use serendipity, opportunism, spontaneity, pragmatic, and "industry best practice" methods, etc. The apparent linearity of this procedure is only a broad approximation [8, 39], parts of the TrfP(s) and/or TS(s) will inevitably be at different stages of concretization, and of different difficulty (routine to safety [39]), and will force iterative working—repeating a part of the design process with enhanced information to improve the solution proposals, within a stage or step of the engineering design process, and between stages—and recursive working—breaking the larger problem into smaller ones, subproblems and/or subsystems, to recursively solve (e.g., using the same systematic design methodology) and recombine. In this design process, the perceived or assumed TS-boundary is frequently redefined to restrict and focus, or expand, the designer's "window" of observation [40]—using the hierarchical nature of TrfS.

CAD—computer-aided design—can effectively be used in stages (P5a), (P5b), and (P6)—in earlier stages the representations are often too abstract for computer graphic processing (including semantics and implications), but mathematical analysis and simulation in earlier stages are often useful—CAE, computer-aided engineering.

Stage (P3b), development of a TS-function structure, reveals a special position. For instance, the TS-cross-boundary functions can include such nonobvious functions as "present a pleasing appearance to the TS(s)" or "allow easy and ergonomic operation by a human"—a direct connection to the need for involvement of industrial design. Also, the TS-internal functions can include "adjust" or "regulate and control" with respect to some TS-properties—this can be solved mechanically, electrically, fluidically, electronically (plus software), etc., and can provide a direct connection to mechatronics and other disciplines.

10.5 Problem Solving

Superimposed on the systematic approach to design engineering is a subprocess cycle of problem solving, frequently and repeatedly applied in every one of the design stage listed in Sect. 10.4, see Fig. 10.7.

Iterative working is related to TrfP/TS properties, requirements, and both heuristic and analytical use of the mediating properties, the engineering sciences, and the problem solving cycle [6, 7, 49, 50], see Figs. 10.7, 10.8 and10.9. Observable and mediating properties of future "existing" TrfP(s)/TS(s) can be analytically determined from the established elemental design properties, giving a reproducible result. The inversion of this procedure, synthesis, is indeterminate; each required observable property is influenced by many different elemental design properties that therefore need to be iteratively established to approach the desired state of the observable property. Analysis is in essence a one-to-one transformation, convergence to one solution. Synthesis goes far beyond a reversal of analysis; it is almost always a transformation that deals with alternative means and arrangements, involving divergence as well as convergence, a one-to-many (or few-to-many) transformation. Synthesizing, as part of Op-H3.2 "Search for Solutions," is the more difficult kind of action [6, 7]. Figure 10.8 constitutes proof that iterative procedure is a theoretical necessity in engineering design science, and a practical necessity in design engineering.

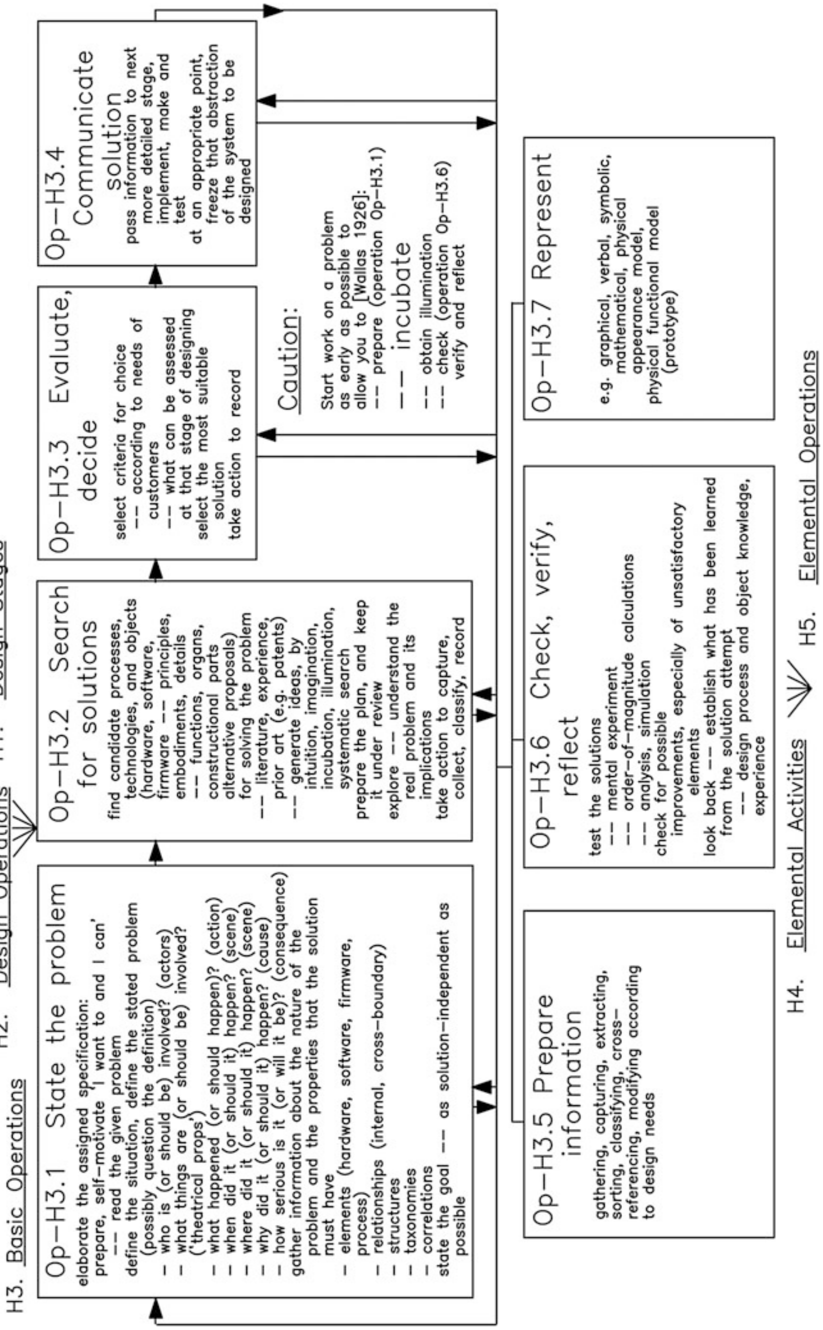

Fig. 10.7 Basic operations – problem solving in the engineering design process [18, 19, 22, 31, 36, 42, 43, 46–48]

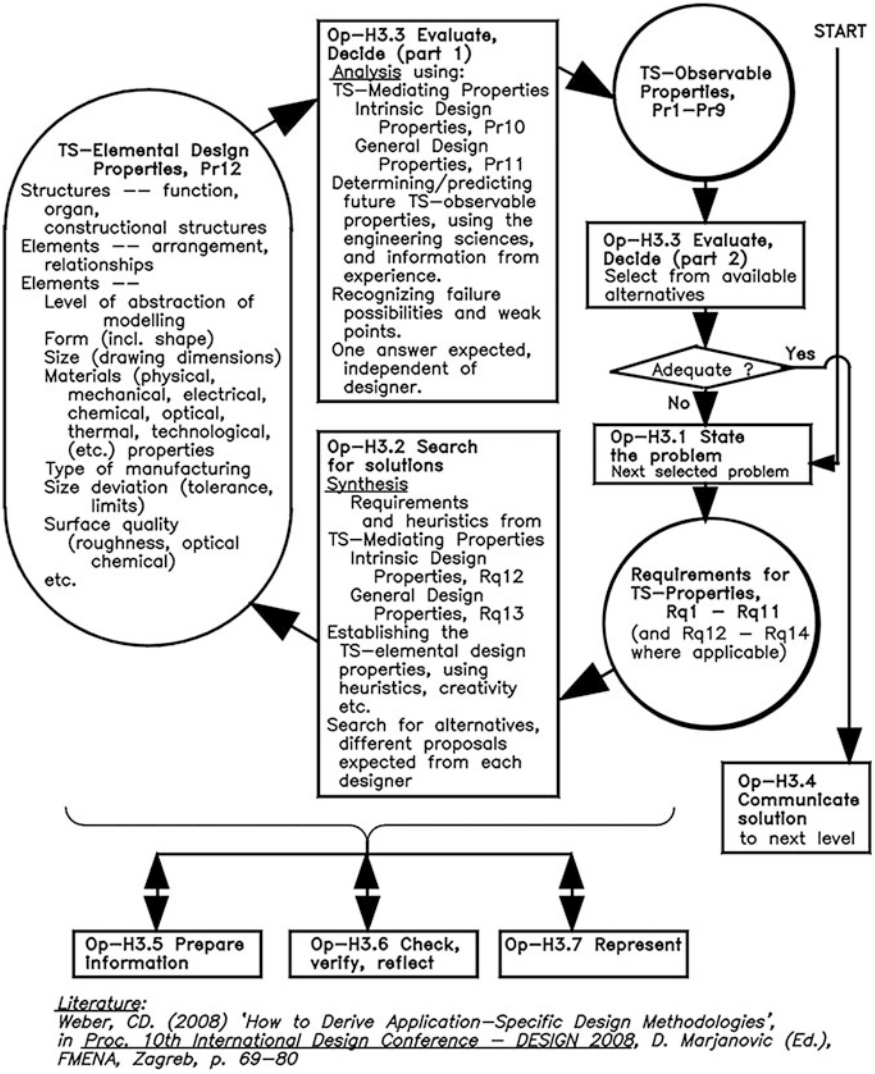

Fig. 10.8 Main relationships between problem solving, and mediating elemental design and observable properties (adapted from [19, 50])

10.6 Clarification and Verification

As shown in [8], such a fully systematic procedure is only necessary in limited situations, when an engineering designer is faced with an unfamiliar and non-routine situation [8, 39]. Systematic design engineering as a procedure is the heuristic-strategic use of a theory to guide the design process—Engineering Design Science [31] is recommended as guiding theory. Methodical design

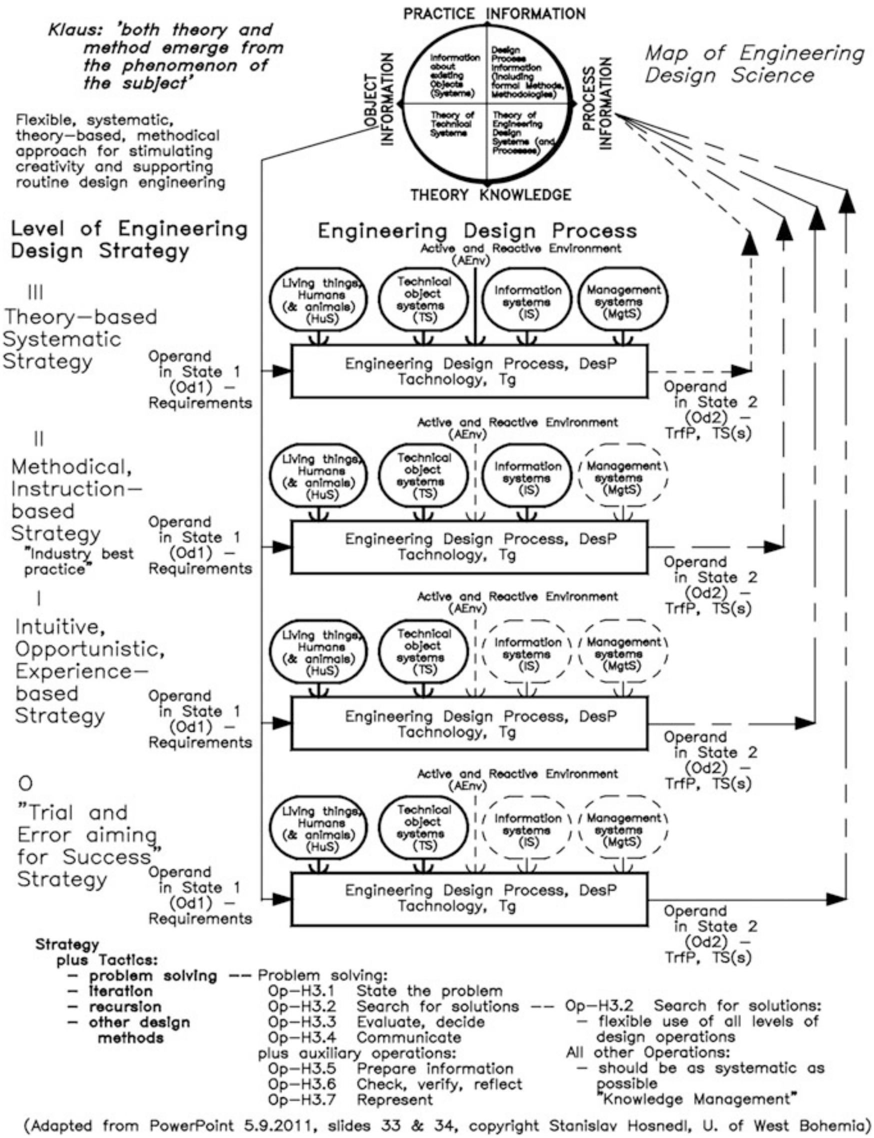

Fig. 10.9 Strategies for design engineering and problem solving

engineering as a procedure is the heuristic use of newly developed and established methods within the engineering design process, including theory-based, pragmatic, and "industry best practice," strategic and tactical, formalized and intuitive methods. Systematic and methodical procedures have a substantial overlap, but are not coincident. The engineering and other sciences can provide some assistance, especially for heuristic "what-if" investigations, and for analyzing expected behaviors. Engineering designers can then apply their intuition, trial-and-error procedures, and other methods, coordinated by systematic design methods, to the specific project, and still be aware of systematic project management, see Fig. 10.9.

Figure 10.9 indicated that whatever basic strategy is used during engineering design (level 0—trial and error, level 1—intuitive, level 2—methodical), it is probably advantageous to bring the results into the full theory-based systematic strategy of level 3, which provides the best documentation of the design process. Such documentation may be needed in case of litigation.

Creativity [3] is usually characterized by a wide search for solutions, especially those that are innovative. This search can be supported by the recommended systematic and methodical approach. All generated alternatives should be kept on record, to allow re-tracing and recovery from subsequent detection of a better alternative. Each step in the overall procedure should be concluded by selecting the most appropriate (one or two) solutions for further processing, in order to control a tendency toward "combinatorial complexity."

Various comparisons have been made between over 100 proposals for engineering design theories and methods [14, 31]. Some of these have caused clarifications, almost all have been found to enhance aspects of the Hubka theory and/or methodology.

The primary purpose of the case examples based on the Hubka design methodology is to present teaching examples for procedural application of the recommended engineering design method, especially for the conceptualizing phases of the engineering design process. Students and practitioners can follow and study them to help learn the scope of the method and its models, and show that the systematic method can be made to work. This purpose has been applied in courses at the EidgenössischeTechnischeHochschule (ETH) by Dr. Vladimir Hubka (1976–2000), at The Royal Military College of Canada (1981–2006), and at the University of West Bohemia (1990-present)—for all levels of education and for industry consultations. A secondary purpose was to verify and validate the theory, models, and methods, check for correctness, illustrate and document the theories, procedures, methods, and models that can be used within systematic design engineering, and to show up deficiencies—which were corrected in the theories, models, and methods. The emphasis in all case studies was on the engineering design procedure and use of the models. Care should be exercised when reading these case examples, they were not intended to show a plausible optimal proposed TS(s), and some of these cases are doubtful in that respect, the chosen technical systems were not necessarily optimal.

The systematic procedure must be adapted to the problem. The cases demonstrate that an engineering designer can idiosyncratically interpret the models to suit the problem, and develop information in consultation with a sponsor. Opinions will vary about whether, e.g., a requirement should be stated in a particular class of properties, or would be appropriate in a different class.

Hubka's engineering design methodology is demonstrated by the scope and variety of our case examples. As far as the author is aware, no other engineering design methodology is accompanied by such case examples. The initials after the case title show the originator—(VH) = Vladimir Hubka, (MMA) = Mogens Myrup Andreasen, (WEE) = W. Ernst Eder, and (SH) = StanislavHosnedl.

The first case study, systematic according to the state of the theory and method at that time, appeared in [26]—a machine vice (VH). Hubka and Eder [29] included the second case study—a welding positioner (VH). An English edition of case studies was published in [32], and included a riveting fixture (VH), a milling jig (VH), and a powder-coating machine (MMA), a P–V-T-experiment (WEE), a hand winding machine for tapes (VH), a tea brewing machine (MMA), a wave-powered bilge pump for small boats (MMA), and an oil drain valve (VH)—the (MMA) cases took a more industrial-artistic design approach, and only loosely followed the systematic method. Three further case studies were published in [18]—the tea machine revised to current systematic procedures showing enhanced engineering information (WEE); re-design of a water valve (WEE—first demonstration of systematic re-design); and an electro-static smoke gas dust precipitator, with rapper for dust removal (WEE—first demonstration of treatment for sub-problems, and the hierarchical nature of TS) [9]. The most recent book in this sequence [19] contains three new case studies, a portable frame for static trapeze display demonstrations (WEE) [10] which was built and used, re-design of an automotive oil pump (WEE—second demonstration of re-design) [17], and a hospital intensive care bed (SH—second demonstration of treatment for sub-problems)—the latter shows cooperation between industrial design and design engineering [24], and is one of many projects operated in cooperation with Czech industry. Hosnedl has also introduced the Hubka theories and methods into industrial use. Two new cases were presented at the International Conference DESIGN 2012 (WEE) [12, 13], both subsystems from the Caravan Stage Barge [2] which has been in operation in Canadian and U.S.A. coastal waters, and now in the Mediterranean, since 1995. The Canadian Engineering Education Association 3rd Annual Conference 2012 received two further case examples (WEE), a subsystem of the Caravan Stage Barge [15], and an auxiliary subsystem for a wind tunnel balance [16].

10.7 Closure

Depending on the nature of the (tangible or process) product, it is obvious that both engineering designers and artistic-industrial designers must in many cases work together. Their duties are partially overlapping. The Theory of Technical Systems [18, 19, 28, 31] is partially applicable to architecture and to industrial design (as demonstrated in [37]—of the five cases presented in this booklet from the Technical University of Denmark, only one refers to an engineering product, but exclusively with the external observable properties).

Nevertheless, engineering design is distinct from other forms of designing, and this needs to be acknowledged.

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