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# A TYPOLOGY OF DESIGNS AND DESIGNING

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## Abstract

A typology and taxonomy based on Design Science is proposed to help to explain and characterize the differences among designed artifacts and among the processes of designing. Designed artifacts (including technical systems) include many kinds of products from industrial and other enterprises. Each designed artifact, whether a single part or composed of several to many parts (including sub-assemblies) carries a range of properties, is subject to a life cycle, has various structures, etc. which form one set of aspects of the typology.

Designing is a process that is intended to deliver the manufacturing specifications for a designed artifact. The processes can range from 'purely' intuitive to very systematic. They can emphasize the external appearance, ergonomics and customer satisfaction (industrial design) and/or the internal functioning and life cycle (design engineering) of a future artifact. The processes should anticipate the intended (and unintended) usage of the artifact to be designed.

The proposed taxonomy covers not only the system to be designed, but also the ways in which it is being designed (intuitive to systematic and methodical), the designing team (composition, competencies, etc.), the facilities and equipment available, the information available in recorded form and in internalized knowing, the management and goals of designing, and the environment in which designing takes place. These affect the procedures and the outcome of designing, and form another set of aspects of the proposed typology.

This typology and taxonomy should be useful in characterizing the circumstances of any observations and publications about designs and designing. It should also be able to provide guidance in research about design.

*Keywords: design typology, design process, design research*

## 1. Introduction

Design research is at a state where a comprehensive classification system is needed. Much research is published in books, journals and conferences (e.g. [1] lists 465 references). Comparisons of results is becoming increasingly difficult, because authors use varying terminology, and omit to define their region of research in meaningful ways to allow such comparisons. Designing (as a process) and the resulting artifacts need to be characterized, so that generalization and cross-fertilization among the design disciplines can be made possible.

A *typology* and *taxonomy* based on insights from Design Science [2,1] is proposed here to help to explain and characterize the differences among designed artifacts and among the processes of designing. According to a dictionary [3], a *typology* (noun) is a study and interpretation of (esp. biblical) types, and a *taxonomy* (noun) specifies the (principles of) classification, esp. in biology. Ideally, each future publication should then refer its subject content to that typology so that comparisons can be meaningful. Note that Design Science has been under continual development since about 1965 by Dr. V. Hubka and his co-workers, using all available information from many other sources.

Earlier examples of attempts to create a typology have been published [4,5]. They list the ‘basic elements of designing’ as: (1) the design strategy we formulate; (2) the design task we choose to solve; (3) the way we choose to design; (4) the organisation (what we are and know) we create for the task and how we use it; (5) the actual context and how we react upon it.

From this they propose: (a) a design task typology; (b) a design results typology; (c) ‘the’ design chain typology; (d) a design operation typology – which was the main subject of [5].

These proposals are fully compatible with Design Science [1,2], but need to be re-interpreted. Figure 1 shows the model of a transformation system and its process as refined from [1]. Ultimately, each part of this model has been (exists) or has to be (future) designed.

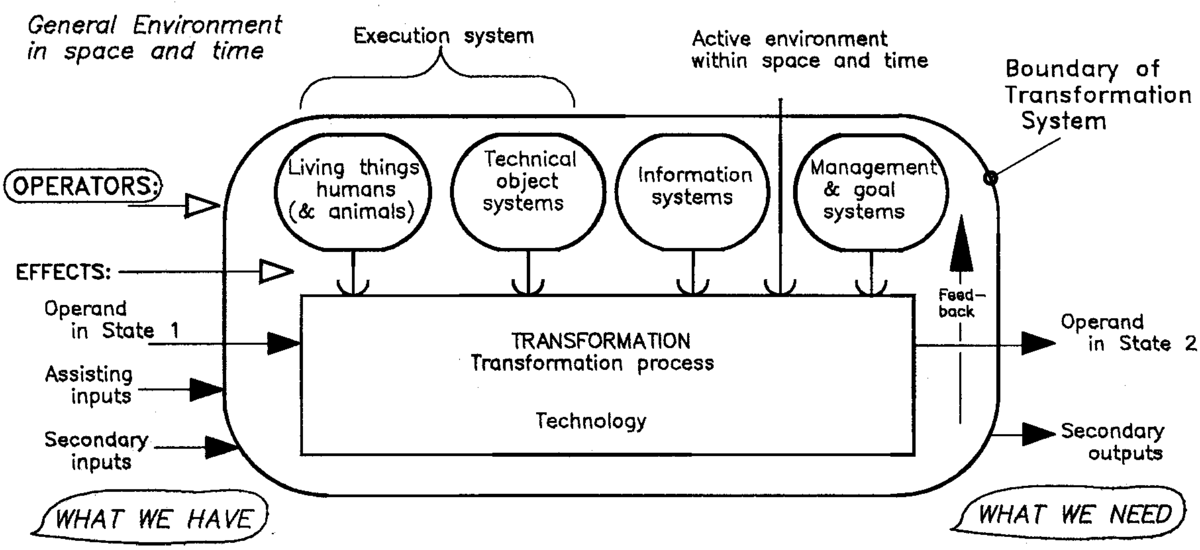


Figure 1 Model of a General Transformation System

The design system derived from this model is shown in figure 2 (see below). The elements from [5] can be assigned as follows:

- the design strategy we formulate – the *technology* of designing within the design process, and its strategy;
- the design task we choose to solve – the *operand* of designing in state 1, information about the requirements for the future technical system;
- the way we choose to design – the *design process*, and its steps and stages, tactics, and methods used;
- the organisation (what we are and know) we create for the task and how we use it – the *operators* of the process: humans as designers and consultants and their tacit-internalized ‘knowing’; technical systems (drafting machines, computers, etc.); information systems, recorded information, data and knowledge; management and goals system, controlling and coordinating for product management, design management, and general enterprise management;

- the actual context and how we react upon it – the *design situation* at any time in the designing process.

# 2. Types of designing

Designing is a process [1,2,6,7,8,9,10] that is intended to deliver either proposals for the appearance and presence of a designed artifact, or a manufacturing specifications for a designed (engineering) artifact. Whilst both kinds have much in common, the differences are significant.

Design processes can emphasize the *artistic elements*, external appearance, ergonomics, marketing, customer satisfaction and other properties of the artifact to be designed. The task given to or adopted (chosen) by the designers is usually specified in rough terms, with few data, but the design team should agree about their task. The process consists initially of conceptualizing possible future artifacts (including products), especially regarding their appearance. Then, rendering and or physical modeling of the artifact provides a 'final' presentation for approval. The artifact can then be made as a single display item, or as a quantity-produced product. Economic assessments and calculations are common, but technical/scientific analysis is largely absent. Designing is mainly intuitive, with few methods – and these emphasize 'creativity' and artistic judgment, e.g. brainstorming. Such designing is usually subsumed under industrial design, architecture, typographic design, and many other expressions, even fine art. Relevant parts of the proposed typology for engineering design are also applicable to this artistic design.

Alternatively, designing can emphasize the *internal functioning*, workings, functionality and life cycle (design engineering) of a future artifact (i.e. a *technical system*). The processes should anticipate as much as possible the intended (and unintended) usage of the artifact (system) to be designed, its manufacturing processes, impacts on the environment (life-cycle engineering), etc. Designing should proceed by first (usually from a given design brief) developing a comprehensive design specification (list of requirements, contract brief) to obtain a full understanding of the problems, and to obtain concrete criteria by which to choose among possible alternative proposals – *clarifying the problem* [11]. Several abstract structural elements are available to search for candidate solutions and to investigate their behavior – transformation process operations, technologies, functions, organs (abstract function-carriers in principle), hardware components, and others – these also represent different levels of abstraction of the technical system (most abstract to most concrete) [1,2,6,7,8,9,10]. The elements from transformation process operations to organs can be used for *conceptualizing*, the hardware components in configuration and parametrization are used for *embodiment* (in sketch layouts and dimensional layouts) and *detailing* (in detail and assembly drawings, parts lists, etc. or their computer-resident equivalent models). Even though all these elements and structures are always present, they need not be used for a particular design engineering problem. The processes can thus range from 'purely' intuitive to very systematic, and can apply several methods (including computer applications) for steps of the design process.

In many design processes, a combination of these two forms of process is needed, either because the appearance and customer attraction is the primary aim, or because the results of design engineering may not be acceptable from the marketing and/or ergonomic viewpoint. Integrated product development [12,13] places emphasis on the artistic forms of designing for an artifact to be quantity-produced, and then, if needed, involves design engineering.

An important element of a design typology and taxonomy must therefore be the proportion of artistic *vs*. design engineering content in the problem and design process.

A sub-classification for industrial designing is ‘conceptualizing’ *vs*. ‘rendering’. For design engineering, the sub-classification can be the highest level of abstraction needed or used in the conceptualizing phases of designing (see also section 5, 6, 7 and 8 of this paper).

This leads to a further classification according to a *degree of novelty*:

- *novel designing*, – most likely in complexity class II for design engineering, or complexity class III for industrial design (see section 4, where definitions are placed in context), accounting for about 5% of design tasks, ‘radical technology’ [14] and ‘radical design’ [15],
- *redesigning* for changes of functions; for performance variants – size and performance range; for constructional and manufacturing alterations; for modular adaptations; for configuration tasks; or direct adoption of an existing system,

It is obvious that the majority of design problems (about 95%) are tasks of redesigning, ‘normal technology’ [14] and ‘normal design’ [15] – previous experience (tacit-internalized knowing, and recorded knowledge) of existing artifacts, and of previously performed design processes is the starting point for any innovation, we use ‘dirty blackboards’ [5] extensively for both. The systematic models of design processes that have been published (e.g. [1,2,6,7,8,9,10,16,17]) attempt to lay out a complete design process for novel design engineering, from which designers can choose the portions they wish to employ. These procedural models can also be applied to redesigning as demonstrated in [1], figure 7–24, see also section 7 of this paper.

## 3. Types of designed artifacts

Designed artifacts (including technical systems [7,8]) include many kinds of products from industrial and other enterprises, compare [1,2]. Any one product may appear in more than one category, further structuring of this list is at present not possible.

At one extremity of the (non-linear, branched) ‘scale’ of artifacts are *artistic works*. The artist is usually both the designer and manufacturer. Appearance is the primary property, esteem value (beauty in the eyes of the beholder, and therefore the asking price) tends to be very high compared to costs. Usage of these artifacts tends to be relatively trivial.

*Consumer products* are frequently consumable items and materials. Designing (and product development) involves to some extent the product, but of probably more importance is designing the packaging and advertising (somewhat artistic works).

*Consumer durables* must have appropriate appearance and operability. They must project the ‘right’ image, of the product, but also of the manufacturing (or selling) company. These products must also be designed (and product-developed) to perform useful tasks, they must function with suitable performance parameters (i.e. they are *technical systems*), and be made available at a (usually pre-defined) suitable cost.

*Bulk or continuous engineering products* generally act as raw materials for other manufacture (e.g. in other enterprises).

*Industry products* are generally items or assemblies that are bought by a manufacturing company for assembling into their own products. They include machine elements, purchased OEM goods (products intended for 'original equipment manufacturers' to build into their own devices), COTS (commercial off-the-shelf products), and other hardware supplies (i.e. *technical systems*, usually of lower levels of complexity), but also software.

*Industrial equipment products* are self-contained devices (e.g. *technical systems*) which can perform a more or less complex function, and are intended for use within industry.

*Special purpose equipment*, including jigs, tooling, fixtures, and specialized manufacturing and assembly machinery, special-purpose robotics, handling and packaging machinery, but also ocean-going ships. These *technical systems* are usually produced to special order ('made to order'), as single items ('one-of-a-kind', 'one-off') or a small series.

*Industrial plant* usually consists of collections of industrial equipment products, and devices to provide control and/or connections among them – i.e. *technical systems*. The plant (and some of the connecting devices) is designed to special order, most of the items are bought from other suppliers.

*Configuration products* are items of special purpose equipment and/or industrial plant for which the components are quantity-produced and standardized industrial equipment products (OEM, COTS) designed deliberately as modular interchangeable *technical systems*. The configuration products are assembled to the customers' requirements, with little further designing or modifications.

*Software products* are computer programs of various kinds and for various purposes.

*Intangible products* are typically documents such as contracts, insurance policies, etc.

This list of types (classes) of products is neither complete nor unique. Many overlaps exist, and the boundaries of the individual classes are fluid. Nevertheless, such a list represents another important element of the proposed design typology.

# 4. Nature of designed artifacts

Each designed artifact is composed of one to several to many parts. Regarding this *complexity* for technical systems [1], we typically define four levels: (level IV) *plant*, which consists of (level III) *machines* (in the widest sense, including electronics), which in turn consist of (level II) *assembly groups* (sub-assemblies, modules), which are composed of (level I) *constructional parts* (components, elements – but these can be quite complex in themselves, e.g. a motherboard as 'component' of a computer). These levels obviously form a hierarchy, members of a lower level are combined to form a member of the next higher level. E.g. the internal support structure and facilities for the 'Statue of Liberty' (New York Harbor) is a technical system. The level of complexity forms another aspect to the proposed typology.

Each designed artifact carries a range of *properties*, [1] and for design engineering these may be classified (completely, but not uniquely, into 12 classes, each property affects one or more classes, and each property is intentionally or unintentionally designed into the producct):

- properties related to the **artifact life cycle**: (1) *function* (e.g. behavior, purpose, functionality); (2) *functionally determined properties* (e.g. parameters, performance, properties conditional on functioning (operating), environmental impacts of using the artifact; (3) *operational properties* (e.g. reliability); (4) *manufacturing properties* (realization properties); (5) *distribution properties* (e.g. transportability, deadlines); and (6) *liquidation properties* (disposal, recycling);

- properties related to the **operators** of the transformation process (each individual life-cycle process, including usage of the designed artifact): (7) *human factors properties* (e.g. ergonomics, esthetics, psychology); (8) *technical system factors properties* (technical systems in their own working processes, as used for the life cycle processes of the artifact); (9) *information system factors properties* (including law and societal information); (10) *management and goal factors properties* (management situation - delivery and planning, etc.; economic properties - costs, pricing, returns, etc.; time - availability, repair and maintenance time; organization - personnel, financing, etc.); and (11) *environment factors properties* (law and societal conformity; materials and energy usage - effects on environment; TP/TS secondary output and TS disposal;
- **engineering design properties** – class (12), the ones being established by the designers during their designing activity: (12a) *design characteristics* (technological principle, transformation operations internal to the artifact, applicability of technical system, mode of internal action, effects supplied to operands, technologies, action sites, action conditions, principles of form-giving, tolerance control, mode of adjustment, etc.); (12b) *general design properties* (strength, stiffness, wear, corrosion resistance, polluting emissions, etc.); and (12c) *elementary design properties*: i.e. *Structure* – elements, components; arrangement, relationships; level of abstraction of modeling; *Elements* – form (including shape); dimensions (sizes); materials; manufacturing methods (and their constraints on elementary design properties), surface quality, tolerances, etc. all of which are the subjects of detail and assembly drawings, parts lists, etc

Each product is subject to a life cycle, has various structures (see the elements above), etc. Where necessary, these should also be characterized for any publication, and are therefore included in the proposed design typology, see also [1].

# 5. The designing system

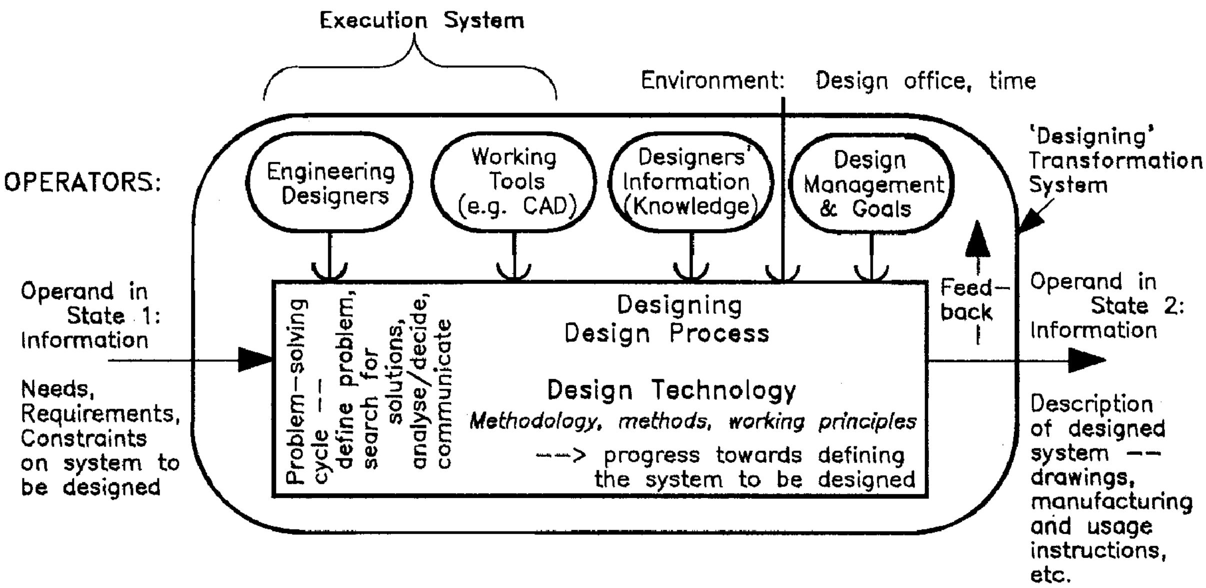


Figure 2 Model of a Design Process for Design Engineering

The *model of the engineering design system* shown in figure 2 [7,10] is derived from the model of a general transformation process [1], and has the following components:

1. the processed operand of designing – *information in state 2*: a full description of a technical system to be designed, that completely and optimally fulfills the given requirements, as the goal (closely approximated by the output) of the design process;
2. the initial operand – *information in state 1*, ready to be processed: the given requirements (including wishes, desires, dreams, but also restrictions and constraints) for the technical system to be designed as the input to the design process, the nature of the task at the start of designing – these may be in the form of a customers' or marketing design or requirements specification, a design brief, a request for proposals, etc.;
3. an *engineering design process*, during which a transformation of information from state 1 (list of given requirements) to state 2 (description of a designed technical system with appropriate properties) takes place; this includes the procedures (formalized and informal, and methods and techniques) employed by the engineering designers, the *technology* of the design process.

This transformation is realized or influenced by five *operators* of the process, see in figure 2:

A. *engineering designers*, the most important operator (i.e. individual designers and teams of various composition – other specialists, e.g. from manufacturing, cost estimating, purchasing, sales, customer service, etc. – working partly in sequence and partly in parallel – simultaneous, concurrent – individually or in a team). A model of the ideal designer indicates the necessary knowledge and awareness (acquired by suitable education, training, and experience, especially that related to a specific sort of technical system [14,15], see sections 3 and 4 of this paper – the designers' tacit-internalized knowing), responsibilities, capabilities for teamwork, skills and abilities, attitudes and values, other personal characteristics, etc. This also involves characterizing the engineering design process in terms of *criteria for evaluation* of design engineering (the processes) and of the designer, and from this deriving the educational requirements for engineering designers;

B. *working means and tools*, the technical assisting means available to designers – tools, equipment, etc., including computers and programs, their sorts (e.g. CAD, engineering science analysis, finite element methods), and their coordination;

C. *information systems* (information, knowledge, data, etc.) – knowledge about and for designing, knowledge about objects and phenomena, the existing technical knowledge, and information, knowledge and data recorded in the available literature, collectively the available information system – preferably externalized (from the designers' tacit knowing), recorded, collected and codified into a specialist information system;

D. *design management* (including goals and objectives) – management of the design process and its tasks, organization, leadership system (i.e. as distinct from the management of the organization and product range for an enterprise, which has a different task and purpose);

E. *working conditions* (organization factors that directly affect designing), the active environment in which the engineering design process takes place, including the working climate of the enterprise; the situation within the task at the current stage of designing (including state of the engineering design project); sorts of artifacts being designed; measure of effects on designing.

## 6. Design process considerations

A strategic process for design engineering, using the levels of abstraction of product modeling, can be derived from the model of a transformation system [1], figure 1. With this transformation system, designers can (for a novel system to be designed): (1) establish the desirable output (operand in state 2) of the transformation; (2) establish a suitable (working) process and its operations, and (if needed) suitable inputs (operand in state 1); (3) decide which operations will be performed by humans, and which by technical systems, alone or in mutual cooperation, and which of the technical systems (or parts of them) needs to be designed at that point (i.e. does not yet exist); (4) establish a technology for that operation for which the technical system needs to be designed, and therefore the effects-outputs needed from the technical system; (5) establish what the technical system needs to do (its internal and cross-boundary functions) to produce these effects-outputs, and what its inputs need to be; (6) establish what organs (function-carriers in principle) can perform these functions, and what added functions (and organs) are recognized as needed (a function-means chain); (7) establish with what constructional elements (in sketch-outline, in rough layout, in dimensional-definitive layout, then in detail and assembly drawings) are needed, and what additional functions (and organs, and constructional elements) are now revealed as being needed (a more extended function-means chaining), to produce a full description of a future TS in the shortest time at lowest cost. Only those parts of this designing process that are thought to be useful are employed.

Redesign can be accomplished by: (a) establishing a design specification for the revised system; (b) analyzing the existing system into its organs and (if needed) its functions; (c) then following the last one or two parts of the procedure listed above for a novel system.

This cannot possibly be done in a linear procedure, feedback, iteration and recursion (dividing a problem into smaller parts, solving, then re-combining) are always needed.

Design processes include *problem solving* [1], both as *tactical* short-term iterative cycles, and as a *strategic* paradigm, which consists of: (A) *clarifying the problem* and establishing a design specification, e.g. based on the required and desired properties of the proposed technical system; (B) *generating various alternative solutions* to the design problem, using various forms of abstract structuring, and incorporating creativity [18] in all its aspects; (C) *evaluating* the properties of a technical system (existing and projected future) by estimation and calculation, including the use of engineering sciences; considerations of manufacturing possibilities [19], cost and time [20]; *and decision-making* among alternative proposed solutions; (D) *representing*, inclusive of manual and computer-resident techniques. These need some *auxiliary processes*: (E) *preparing and using information*; (F) *verifying and checking*, including design audits and reviews, and reflection on the product in its current designed state, and on the design process; (G) *communicating*, in words, graphics, models, tool-path programs, etc.

Designers can use any suitable design methods within the strategic and tactical procedures, including creativity tools [18], analysis tools (engineering sciences, etc.), applications of CAD, CAE, IT and other computer-based tools.

# 7. Design situations

During design work, the state at a specific point in time of the artifact (product, technical system) being designed and the state of the operators of designing are collectively termed the *design situation* [1]. These are influenced by various factors. From the point of view of design engineering we can distinguish:

- the classes of *internal factors* which describe the design system (at a particular stage of designing), see section 6 of this paper, and the *design potential* available to the enterprise, especially the *operators* of design (see above), namely: *humans*, *technical systems*, *information systems*, *leadership / management*, and the *active environment*;
- the classes of *external factors of the situation*, the environment of the design system:

**FT** factors of the *design task*, the current state of establishing the artifact during designing, and any problems that arise (see section 8 below); but also planning and thinking ahead for a future enterprise product, assisted, for instance, by the distinction between artistic design and design engineering, and the classifications of artifacts, see section 4 of this paper. These factors will change as designing progresses, they relate in more detail to:

- the immediate contract for a design task;
- a list of requirements, design brief, design specification, as developed and agreed
- production quantity, manufacturing potential
- sorts of product
- originality, novelty of product
- degree of complexity of the product
- degree of difficulty of the design tasks
- particular requirements on the product
- deadlines, time to design
- particular requirements with respect to procedures
- stage of development of the technical system being designed
- differentiated submission of data, e.g. parts of ‘the design’ must be ‘frozen’ before others
- employment conditions of designers
- customer, user, maintainer, disposer
- particular stage and step of designing for that portion of the product under immediate consideration;

**FO** *organization* factors, enterprise factors, administration, policies

- -- manufacturing, selling, servicing, etc.;
- -- enterprise aims
- -- production program
- -- size of company

– -- sorts of manufacturing
– -- potential of the enterprise
– -- development and market strategy
– -- employment conditions;

**FE** *environment* factors:

(a) of human society: local and world economy, cultural, social and political factors;

(b) of nature: local and world climate range, environmental impacts, pollution sensitivity, etc.

- enterprise, local, region, country, world
- politics, laws, standards
- society, social system
- company policies
- science, knowledge, know-how [14,15]
- technology
- market for goods, personnel, acquisitions, services, financing, etc.

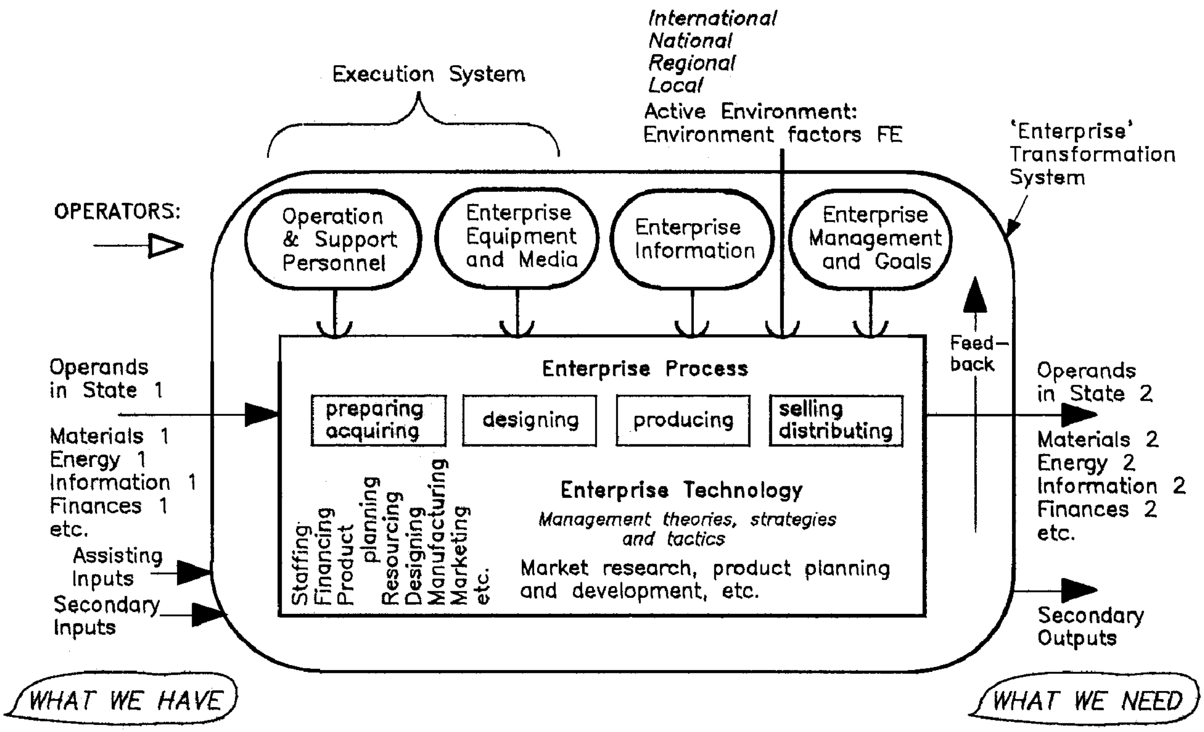


Figure 3 Model of an Enterprise System

This also indicates that a hierarchical ordering of the individual factors exists: the design system is at all times a factor of the enterprise system (the organization), see figure 3, which forms a factor of a national economic and cultural system, which belongs to the world economy system. All these systems are factors of the planet earth and are subject to the laws of nature – those that have been formulated into sciences, and those that are to be discovered.

Even if it is not necessary to examine all the factors in each situation, we must understand the connections and possess a complete mapping for orientation. The design situation is initially affected by the novelty of the design task, see section 2 of this paper.

This listing summarizes the proposed design typology. It is almost equivalent to that proposed by Andreasen [5] as its ‘design operations typology’. For purposes of integrated product development [12,13], further classes need to be added to accomodate the management and business development tasks, ‘a design task typology’, ‘a design results typology’, and ‘“the” design chain typology’ according to Andreasen [5].

# 9. Closure

The proposed taxonomy covers not only the artifact (product, technical system) to be designed, but also the ways in which it is being designed (artistic to design engineering, intuitive to systematic and methodical), the designing team (composition, competencies, etc.), the facilities and equipment available, the information available in recorded form and in internalized (tacit) knowing, the management and goals of designing, and the environment in which designing takes place. All these affect the procedures and the outcome of designing , and form a set of aspects of the proposed typology.

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