Eindhoven Centre for Innovation Studies

On the design of design processes in architecture and engineering: technological rules and the principle of minimal specification

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Working Paper 03.08

Department of Technology Management

Technische Universiteit Eindhoven, The Netherlands

June 2003

version 24 June 2003

On the design of design processes in architecture and engineering: technological rules and the principle of minimal specification

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As complexity and scale of design processes in architecture and in engineering increase, as well as the demands on these processes with respect to costs, throughput time and quality, traditional approaches to organise and plan these processes may no longer suffice. In this conceptual article it is argued that more innovative approaches may be needed. The content and nature of process designs is discussed, as well as the design knowledge to make them, and ideas are presented on research approaches to further develop design knowledge that can support more innovative process design. An important type of such design knowledge is the technological rule, to be based on the principle of minimal specification.

Key words: design processes, design knowledge, design research

Designing is the basic activity in architecture and in every engineering discipline (Simon,1969). The mission of an architect or engineer is to design buildings or bridges, new machines or electronic equipment,. Planning and organising the process to design artefacts – especially if large and complex - should, therefore, be a major issue for these professionals. Planning and organising a design process can also be regarded as making a *process design,* the design of the design process itself.

As will be discussed below in more detail, in making their process designs architects and engineers tend to use tradition-based *evolutionary design.* However, in view of increasing technical and organisational complexity of design processes, of increasing scale and increasing demands on the design process, one may want to use more innovative approaches to making process designs. In this conceptual article I intend to make two contributions. Firstly I will discuss the content and nature of process designs and the design knowledge to make them. Secondly, I will discuss research approaches for developing design knowledge for process design in the form of technological rules, using the principle of minimal specification, and I will identify a number of issues in process design, for practice to experiment on and for research to investigate and test.

Although sound process design can be important for small-scale design processes, traditional approaches to process design may well suffice in such cases. The discussions in this article are, therefore, more aimed at process design for large and complex in-house design processes in industry, like the design of automobiles and aeroplanes and to large and complex design processes for building projects, often not in-house but executed by combinations of independent organisations: multi-party design projects.

This article has been developed on the basis of the literature and in the context of the two-year postgraduate course programme ADMS (Architectural Design Management Systems), established in 1997 at Eindhoven University of Technology. This course programme trains engineers to design large-scale complex design processes in the field of building and urban development and to design supporting methods and tools for such design processes. The graduation projects of the students of this course programme have provided starting material for this article. However, my own background is more in innovation management in industry than in building, a background also providing starting material. Thus, this article does not have a specific orientation towards building projects; it will be as much as possible domain-independent.

1. Designing a design process

Design processes are as old as modern man, even hand-held rock tools were probably designed, i.e. the maker of such tools developed some ideas on their shape and the materials and instruments to be used to make them before he/she actually started the physical work. However, generally artefacts were designed by their makers themselves and followed over time an evolutionary design process: passed on from generation to generation, these artefacts underwent an evolutionary design process involving gradual improvement. In this way, Stone Age tools were developed, as well as instruments like the scythe and the violin

(Jones, 1980; French, 1994). Also the designs of houses and ships have undergone many centuries of such evolutionary development.

A radical improvement of the design process arose from the use of drawings, which allowed a separation of making the designs from realising them, and which facilitated innovations in the designs of artefacts. Generally, it is far easier and quicker to experiment with new designs on paper than in physical reality. However, for many centuries the design process itself continued with craftsman-like evolutionary design. In crafts, building and other engineering disciplines, the design of artefacts was learned through experience and under the guidance of teachers, masters and peers. Process knowledge (i.e. knowledge about the characteristics of the design process itself) was usually tacit and explicit process designs were seldom used.

As the complexity and scale of design processes increased more use was made of explicit process designs in order to enable the various participants in the design process to get to know their own roles in that process and those of others and to get to know the design problems they had to work on. Often such explicit process designs are made on the basis of a formalisation of the present design practices of the organisation or professional group in question, like the so-called BNA-model for architectural design in the Netherlands or the VDI-model for engineering design (VDI, 1987). This approach to process design can be regarded as *evolutionary design*, as discussed above: the experience of past generations of designers in that organisation or professional group was codified. Sometimes, however, one departs from this evolutionary design of design processes. A new approach to design processes is developed, tested and documented, like in New Product Development the stage-gate process (Cooper, 1990) and evolutionary design is exchanged for *variant design*: the new process is used as a design exemplar and one designs one's own specific design process as a variant of that design exemplar, adapted to one's own specific situation (see e.g. Fowler, 1996, on variant design).

In New Product Development one makes the distinction between *incremental* and *radical* innovation (see e.g. Green, Gavin and Aiman-Smith, 1995). Using this distinction one may regard evolutionary design of design processes as incremental design. However, incremental process design may become unsatisfactory as the demands on design processes increase. The scale of these processes may become very large, as in the design of automobiles or aircraft or in the design of large buildings in urban areas. The organisational complexity may increase as many departments as well as customers and suppliers are to become involved in large in-house design processes or in multi-party design processes as in building. The technical complexity may increase as many different engineering and non-engineering disciplines may have to get involved. And the demands on the costs, the through put-time and quality of the design process may increase. Using traditional approaches to process design and management may lead to "great planning disasters", in extreme cases like the Sydney Opera House or the supersonic Concorde (Hall, 1980) These factors may lead to a search for more radical design of design processes. Experimentation in practice and rigorous academic research could then lead to the development of innovative design exemplars, subsequently to be used in variant design of design processes.

2. Design knowledge

Next to experience and creativity a designer needs knowledge to make his/her designs. Specific knowledge on the design assignment in question and more general knowledge on designs and designing. In this article we are interested in this more general design knowledge of which there are several categories. These will be explored below.

2.1 Design knowledge for three types of designs

In order to realise an artefact one needs in principle three designs (Van Aken, 2001 and Van Aken, forthcoming). First of all the *object design,* a representation – e.g. in the form of drawings – of the artefact to be realised. Next the *realisation design,* the design of the physical process which is to produce the artefact, like the building plan in case of a building or the assembly instructions in case of a machine. And finally the *process design,* the design of the design process itself, e.g. the various steps from specification, outline design, detail design and, furthermore, the specification of the various people or bodies that will execute those steps. Fig 1 gives the position of these three types of designs in the overall design and realisation process and their interdependencies.

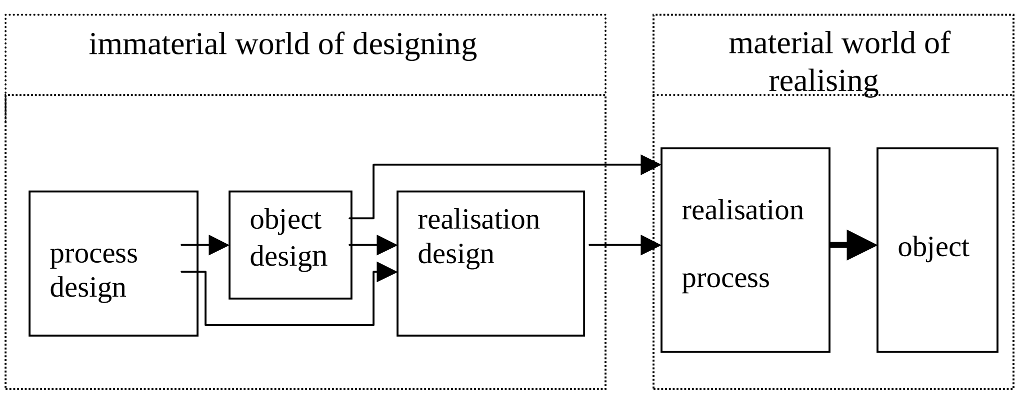

Fig.1 Process, object and realisation design

As said, these three types are needed in principle. In practice, however, one does not always make an (explicit) realisation design. If the designed object can be realised largely through an already existing realisation process – as is e.g. often the case in New Product Development – one does not redesign that process or one merely develops some additional instructions for the people in the factory that will produce the new products. In process design, this may also be the case: process designs often remain tacit. Large, experienced organisations may have explicit process designs, but such an organisation tends to use repeatedly the design process it has developed over the years, possibly combined with some variant design on the basis of its traditional process design, in case a certain design project clearly differs from previous design projects. In multi-party one-off design projects, however, one does not have such a "traditional" process design, so in these cases it is more customary to make explicit process designs (again usually still using evolutionary design on the basis of the experience with design processes of the various partners in the project).

Also in the literature the attention given to process design is limited. An example of an exception is Cross' brief discussion of the concept of "design strategy": "A design strategy describes the general plan of action for a design project and the sequence of particular activities, which a design team expects to take to carry through the plan" (Cross, 1994, p165). As we will see in section 3.3 this is the process structure, which together with a position structure gives the overall process design.

In designing an experienced engineer uses his/her *repertoire of design knowledge* (Schön, 1983). *Design knowledge* can simply be defined as general knowledge that can be used in making designs. In line with the three types of designs, discussed above, one has *object knowledge,* knowledge about the objects to be designed, *realisation knowledge,* knowledge about the production processes to be used to realise the designed artefacts and *process knowledge,* knowledge about the design process itself. The stunning technological development since the Industrial Revolution is primarily based on the development of object knowledge by the various design disciplines, like knowledge on materials, constructions, machines, automobiles, aeroplanes, rockets, computers, etc. etc. In these design disciplines most research tends to be done on objects, developing object knowledge.

For each type of object also the matching realisation knowledge has been developed. Process knowledge, however, tends to be more elusive. It is not knowledge on physical processes, but on more elusive, immaterial cognitive processes and their essentially immaterial products, i.e. designs. As said, engineers tend to learn the designing of the artefacts in their discipline in a craftsman-like way, they learn to design by doing and by following the examples of their teachers, masters and peers. In that way, much process knowledge remains tacit. Still, on the basis of the idea that often the quality of a product is largely determined by the quality of the process producing it, the quality of the design process should be an important issue for engineers.

2.2 further categories of design knowledge

Next to the distinction between these three categories of design knowledge, one can make a further distinction between tacit and codified design knowledge (Polanyi, 1966; Nonaka and Takeuchi, 1995). And with respect to codified knowledge, one can distinguish further experience-based knowledge and evidence-based knowledge, the latter category being knowledge based on the evidence resulting from formal research rather than (only) on practical experience. Fig 2 gives an overview of these categories of design knowledge. In this article we are primarily interested in codified process knowledge, indicated with an asterisk in the figure.

Much of this design knowledge is domain-bound, i.e. developed within a specific (engineering) discipline and in principle only valid within that discipline. Next to that, also domain-independent design theory has been developed, theory that aims to be valid across various disciplines.

design knowledge				
nature \ subject matter		object knowledge	realisation knowledge	process knowledge
tacit				
codified domain-bound	experience-based			
	evidence-based			*
codified domain-independent	experience-based			
	evidence-based			*

Fig. 2 the various categories of design knowledge (descriptive and prescriptive)

Even if process knowledge is somewhat more elusive than object and realisation knowledge, each engineering discipline develops quite some codified process knowledge, knowledge on the design process and on the nature of the designs produced by that process. One can distinguish the following four categories of codified process knowledge.

- *Design language*, the system of conventions with which to represent a design. According to Dym “the key element of design is representation” (Dym, 1994, p.1). For instance, mechanical engineers use a specific “design language” to make their drawings. Because the people of the workshop where the machine is to be made also have mastered that language, designers can pass on their drawings to the workshop without having the need to explain what they mean with the various symbols and other elements of these drawings.

- *Design process theory*, descriptions and analyses of, and prescriptions for design processes. Technological rules are an important example of prescriptive design process theory. In design process theory such technological rules are tested and documented models of design processes, which can be used to design a variant of such a model for one's own design process. Examples are the stage-gate process (Cooper, 1990), mentioned above, and the VDI 2221, a general model of a design process developed by the Verein Deutscher Ingenieure (VDI, 1987).
- *Design methods* and *design tools* (the latter often computer-enabled), to be used in the execution of certain design activities (see e.g. Jones, 1980, for a classic survey of domain-independent design methods).
- *Design methodology*, the theory of the use of methods, models and tools in design and of the general approaches to design.

2.3 A special kind of design knowledge: the technological rule

Design knowledge can be of a *descriptive* nature, describing and analysing design activities, design processes and designing agents, and of a more *prescriptive* nature, describing how design-activities and design processes can be organised and planned to achieve certain objectives and what competencies designers should have or should develop to be able to execute the various design activities. Descriptive design knowledge can be used by designers in a *conceptual* way, giving general enlightenment of the design process and its products, while prescriptive design knowledge can be used in a more direct, *instrumental* way for the planning and organising of design processes (see Pelz, 1978, for the distinction between conceptual and instrumental use of knowledge).

A special kind of prescriptive design knowledge is the so-called "technological rule". A technological rule can be seen as a solution type for a certain type of field problems. The term "technological rule" is derived from Bunge's philosophy of technology, who gives as definition: "an instruction to perform a finite number of acts in a given order and with a given aim" (Bunge, 1967). In this article I use this concept in a somewhat more general way. A technological rule, then, is "*a chunk of general knowledge linking an intervention or artefact with a desired outcome or performance in a certain field of application.* "General" in this definition means that it is not a specific prescription for a specific situation, but a general prescription for a class of problems. A powerful subset of technological rules is the "field-tested and grounded technological rule" (Van Aken, 2001, and Van Aken, forthcoming). "Field-tested" means that the rule is tested in its intended field of application, and "grounded" means that it is known why the intervention or artefact gives the desired performance.

There are two types of technological rules, field-tested and grounded or not. On the one hand the *algorithmic* rule, which is to be used as an instruction and which often has a quantitative format: "if you want to achieve Y in setting Z, then perform action X”. And on the other the *heuristic* rule, which is to be used as a design exemplar. In order to apply the rule, one has to design a specific variant of that well-tested and well-documented design exemplar, adapted to one’s specific situation. So a heuristic technological rule is not an instruction to be followed blindly (as in the Bunge-definition), but a starting point for variant design. Examples of object knowledge in the form of heuristic field-tested and grounded technological rules are in mechanical engineering a type of transmission system (drawings, description and an analysis of its advantages and disadvantages on the basis of field tests), and in electrical engineering a type of electrical circuit for a TV-receiver. Similarly one can have technological rules for the two other types of designs, i.e. technological rules for the realisation, the actual making of certain artefacts and technological rules for process design. In this article we are primarily interested in these latter technological rules for process design.

Finally one may remark that the application of a technological rule presumes competence on the part of the practitioner: in architectural and engineering design technological rules are generally not developed for laymen, but for competent professionals.

2.4 Domain-independent design theory

The codified, evidence-based part of the process design knowledge of an engineering discipline may be called design *theory*. So design theory is seen here as a special kind of design knowledge. A trajectory for developing such design theory may consist of a transformation of the tacit knowledge of experienced designers into codified, experience-based design knowledge, to be followed by testing such knowledge in various settings by research, providing evidence and evidence-based design knowledge.

As said, every engineering discipline has developed design theory for its discipline, domain-bound design theory. Next to that, there is also an important research stream developing domain-independent design theory, see Cross (1993) for a brief historical overview of its development and see e.g. Reymen (2001), Love (2002), and Eekels (2000, 2001) on the issue of domain-independent design theory.

This research stream was started in the nineteen-sixties of the previous century, mainly through British initiatives (Jones and Thornley, 1963; Gregory, 1966; Glegg, 1973; Jones, 1980). In this context one may also mention Simon’s seminal book ‘the Science of the Artificial’ (Simon, 1969,1981), an important contribution to the development of design science as a field. These pioneers had powerful ambitions and great expectations (Cross, 1993): the traditional and intuitive designs of the various engineering disciplines would be replaced by rational, theory-based and possibly even formalised approaches. These were to be used for the design process itself, but also to train young designers, and to serve as a point of departure to fit the design process with methods and tools. It was all for the benefit of mankind and would lead to revolutionary improvements in the quality of designs.

Good examples of domain-independent design theory are Cross (1994), Dym (1994), French (1994) and Roozenburg and Eekels (1995). However, some feel that up until now there has been only limited success. Theory has been developed, but the impact on the actual practice of designing has remained modest (see e.g. Andreasen, 2001). This view may be related with the ambition that design theory should be used in a direct, instrumental way by senior designers. Indeed, as yet that ambition has largely not been realised. However, design theory can and has been used in a more conceptual way, informing the general discourse on design. That is an important result, useful among other things for training junior designers and a prerequisite for further development of the field. I share the ambition for instrumental use of design theory (see section 4), but this may only come true for third generation methods (to use Rittel's multi-generation idea, see Rittel, 1973).

Another type of disappointment with design theory is mentioned by Cross (1993). He cites the pioneers Christopher Alexander and J. Christopher Jones, who were turned off by 'the continual attempt to fix the whole life into a logical framework' (Jones, 1977). This is an important issue and will be discussed further in section 3 and 4 as the principle of minimal specification. At this point I would like to say that this type of disappointment may be related with the (implicit) expectation that theory and method should be used as instructions, to be followed strictly. As we have seen in section 2.3, here the idea rather is that a chunck of prescriptive knowledge should be used as a design exemplar, a starting point for the design of one's own, specific approach to a design issue and not as an instruction.

With respect to the impact of design theory on practice one can draw interesting parallels with General System Theory and Cybernetics (Boulding, 1956; Ashby, 1956; Beer, 1972) and with decision-making theory (Simon, 1960). These too arose in the same period as design theory with great expectations for more rational, and possibly more formalised approaches with an aim to improve actual practice. Decision-making theory only started to mature after the rational and normative desk theories were complemented with results from thorough empirical studies about real-life decision-making processes (see e.g. Rajagopalan, Rasheed and Datta,1993). General, supra-disciplinary System Theory dissolved largely into the various mono-disciplines, but its concepts and analytic approaches are still being used in a conceptual way in these mono-disciplines.

For architectural and engineering design one may expect similar developments, i.e. further conceptual development and the conceptual use of that like in General System Theory and further development of design theory for instrumental use through combinations of descriptive empirical work like in decision-making (see e.g. Cantamessa, 2001, for an example of such empirical work in design theory) and more prescriptive work, see section 4.

3. Design knowledge for process design

This article discusses design knowledge for process design. In order to make these discussions not too abstract and in order to be able to identify in section 4 issues for experimenting and research, I will give in the present section some elements of design knowledge for process design. Some concepts are new, some are not. The presentation includes a number of definitions. These are no universal truths, but are working definitions, through which concepts are defined which can be used in the design of design processes. For many of these concepts there are quite some other useful definitions. The ones given here are largely chosen from existing ones, on the grounds that they are useful for the design of design processes. The presentation will start with a discussion of the principle of minimal specification, important for process design, followed by a discussion of the start-up of a design process and will then zoom in on process design itself.

3.1 Designing and the principle of minimal specification

The process of creating artefacts is driven by two essentially different human action systems: one producing designs and one producing the artefacts on the basis of those designs. The first operates in the essentially immaterial world of knowledge, texts, drawings and the like, and the second in the material world of physical processes, producing physical artefacts. This article deals with design processes in the immaterial world.

Now a *design* can be defined as a *model of an artefact to be realised, as an instruction for the next step in the creation process*. That artefact can be an object or a process. The model can take various forms, like a drawing, a text, a flowchart, a scale model, a computer 3D-representation, etc. A design is not an end in itself, but an input for the next step, which can consist of further detailing of the design in the world of designing or of the actual realisation of the artefact in the material world.

A model is an abstraction of reality. Usually it is an abstraction of an already existing reality, but in case of a design it is a model of a possible future reality.

Compared to the model, the physical object or process – the existing reality or the realised design - has innumerable *hidden properties,* properties that are present in reality but remain invisible in the model[1]. This brings us to the *principle of minimal specification:* a completed design should only specify what the makers of the artefact need to realise that artefact. Designing is producing information on a need-to-know basis. For instance, a design of a machine may not specify the colour of the housing of that machine. Either because the designer feels that that is unimportant (so the people of the workshop may choose a colour), or because the company in question has a standard policy on the colour of the housing. If the designer wants to deviate from that policy or feels that it *is* important, the colour of the housing of the machine will not be outside but inside the boundaries of minimal specification.

Designing can also be seen as a process of consecutive detailing, from a rough sketch, via an outline design to detailed designs. So the principle of minimal specification not only applies to the transition from designing to realising, but also to the various steps within the design process.

For the design of material artefacts this principle of minimal specification is not very important: in practice designers learn fast not to underspecify their designs and overspecification usually doesn't do much harm. However, as we will see, for process design it *is* important.

3.2 Starting the design process

As already discussed, designing involves the making of three designs. First the process design, be it an explicit design or a more tacitly developed variant of previous, maybe also tacit, process designs. Then the object design and finally the realisation design (see fig.3). Also the realisation design may be a tacit variant of previous realisation designs, if the new object can be realised through largely the same process as previous ones.

The realisation of a physical artefact takes place in the material world, but the realisation of a process design takes place in the immaterial world of texts and thoughts.

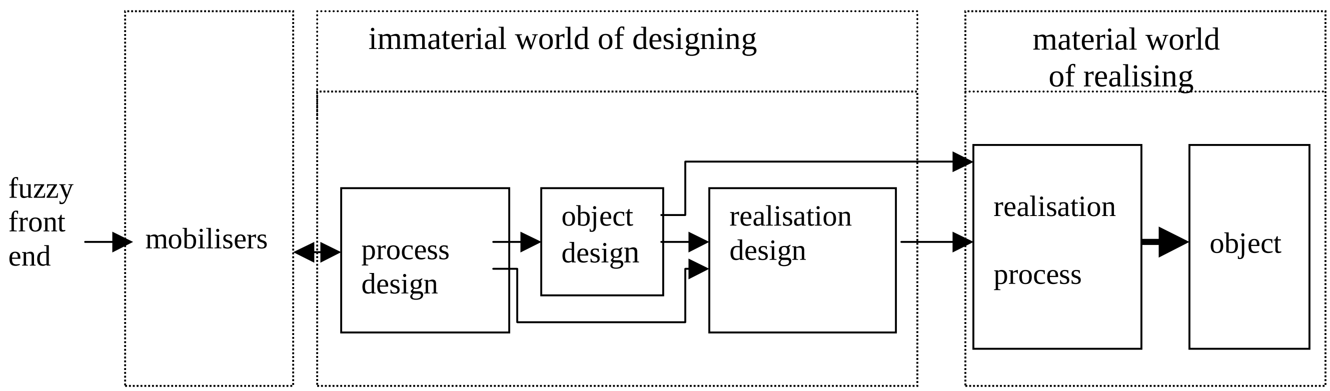

Fig.3 Process, object and realisation design in context

In the so-called *fuzzy front end* of the design process (see e.g. Rubenstein, 1994 and Khurana and Rosenthal, 1997) initiatives are developed to develop and realise a new object[2]. These initiatives lead to the start of a design process if a sufficiently powerful *coalition of mobilisers* comes into being. This coalition may consist of the following parties or agents

- *principal,* the agent deciding on the content of the design and having the authority over the resources needed to create the new object
- *problem owner,* the agent responsible for solving the problem, which the new object has to address
- *user,* the agent that will actually use the new object.

For instance, in new product design the marketing department may be regarded as the problem owner, their problem being the realisation of growth in sales. The principal in that case is senior management. Principal and problem-owner can also be the same agent, e.g. when senior management of a company wants to realise a new headquarters building.

In building projects the user may also be part of the mobilising coalition, whereas in new product design that may be the case in design-to-order situations.

The object to be designed has to fulfil a certain function for the user. Designing can be defined as making a design. A more specific definition is "*designing is the process of determining the required function of an object to be designed, combined with making a model of it".* One can also say that designing is developing a *functional specification* of the object to be designed, combined with making a *technical specification* of it, i.e. a specification of the object in such a way that the makers of the object will have sufficient technical information to produce it.

The definition is specific, among other things because the process of making the functional specification is regarded as being part of the design process and not as being input to it. The reason for this is, that in general the designers have more design knowledge and more insight in the technical aspects of designing and realising the new object than the mobilising coalition and that in organising and planning the design process one should give much attention to the interactions between designers and mobilisers (interactions, that are not only important in the first steps of the design process, but all along the whole design process).

Finally some words on the functional specifications for a design. There are various categories of such specifications. These are listed below, in each case followed by an example taken from the specification for the design of a new model of freezer:

- *functional requirements:* the core of the specification in the form of performance demands on the object to be designed (freezer: temperature in the cool space can be controlled for the interval 10^{o}C – minus 10^{o}C).
- *user requirements:* specific requirements from the viewpoint of the user (freezer: easy to defrost)
- *boundary conditions:* to be met unconditionally (freezer: the system will use a 220V power supply)

- *design restrictions:* preferred solution space (freezer: the new model should preferably use the same compressor as the existing one).

3.3 Concepts with respect to process design

Planning and organising a design process can be regarded as designing that process, as making a process design. Like in general organisation design a process design involves two inter-linked sub-designs, viz. the design of the *process structure* and the design of the *position structure*. The process structure gives the various process steps or sub-processes into which the overall process has been decomposed, plus the time relations between them. The position structure gives a specification of the agents (individuals, departments or companies) that will execute the various sub-processes, again with the relations between those agents. This dual objective can be compared with the script of a play, giving the various (speech) acts of the play and their time sequence as well as a general description of the character of each of the various roles.

Below I give some remarks on the specifications for the process design, using the categories given above. In actual process design one often does not use explicit specifications. These remarks are given to show that it might be worthwhile to make such specifications.
Functional requirements: the realised design process should be *effective*, i.e. producing high quality object and realisation designs in terms of fitness-for-use (rather than in terms of according-to-specifications, as I regard the development of functional specifications for the object design as being part of the design process; this point is especially important for large-scale complex design projects). And the realised design process should be *efficient* in terms of costs and throughput time (the actual norms or this being situation-dependent).
User requirements: the process design should be an easy-to-use support for the designers to organise and schedule their design work (therefore one may also want to supply some tools to support the use of the process design). And the process design should preferably fit the “natural” way of working of the designers or, alternatively, supply support for the learning of new ways of working if the process design is to realise such new ways.
Boundary conditions: general boundary conditions are e.g. legal conditions as given by labour laws and civil laws on contractual relations. On the whole, however, the boundary conditions tend to be rather situation-bound; they are mentioned here to stress that it may be important to list the boundary conditions explicitly.
Design restrictions: the same applies to the design restrictions; these often include the demand that the process design should use only the (design) resources that have been made available by the mobilising coalition.

In figure 4 a general descriptive model is given of a design process. This is but one of the many possible descriptive models of a design process (see e.g. Evbuomwan, Sivaloganathan and Jebb, 1996, for a survey of design process models). This one is developed to show some basic steps in the design process and to show the functions of (design) process management. It will also be used in section 4 to identify a number of issues in process design.

The process of fig 4 has as input a “perceived and validated need” of a certain target group. With that is meant that not the need itself is input for the design process, but a perception of that need, which is validated by the principal, i.e. seen as sufficiently worthwhile to invest the required resources to design and realise the object in question. The term “perceived” is also used because one may need further analysis (and interactions with the problem owner and the intended users) to get further insight in that need.

Further input to the design process is design knowledge, which usually predominantly consists of object knowledge. One has public design knowledge, acquired among other things through literature and by hiring well-trained and educated designers. And one has proprietary design knowledge, for example acquired through buying licences, through collaboration with organisations having valuable design knowledge and through own R & D.

In fig. 4 the overall design process is decomposed into a number of sub-processes or process steps, each of which can be further detailed. The arrows above the sub-processes refer to *iterations* and *explorations:* iterations by going to a previous step, e.g. because one discovers that one needs more information from that step, and explorations by briefly going to a step further on in the process to explore possible design solutions. *Process management* has the task of scheduling the work on the various process steps and the iterations and explorations. Fig. 4 is not a phase-model in which the phases follow a fixed sequence, but a *process-step model*: the overall process is decomposed into essential process steps, while work on each of the steps is scheduled and controlled by process management

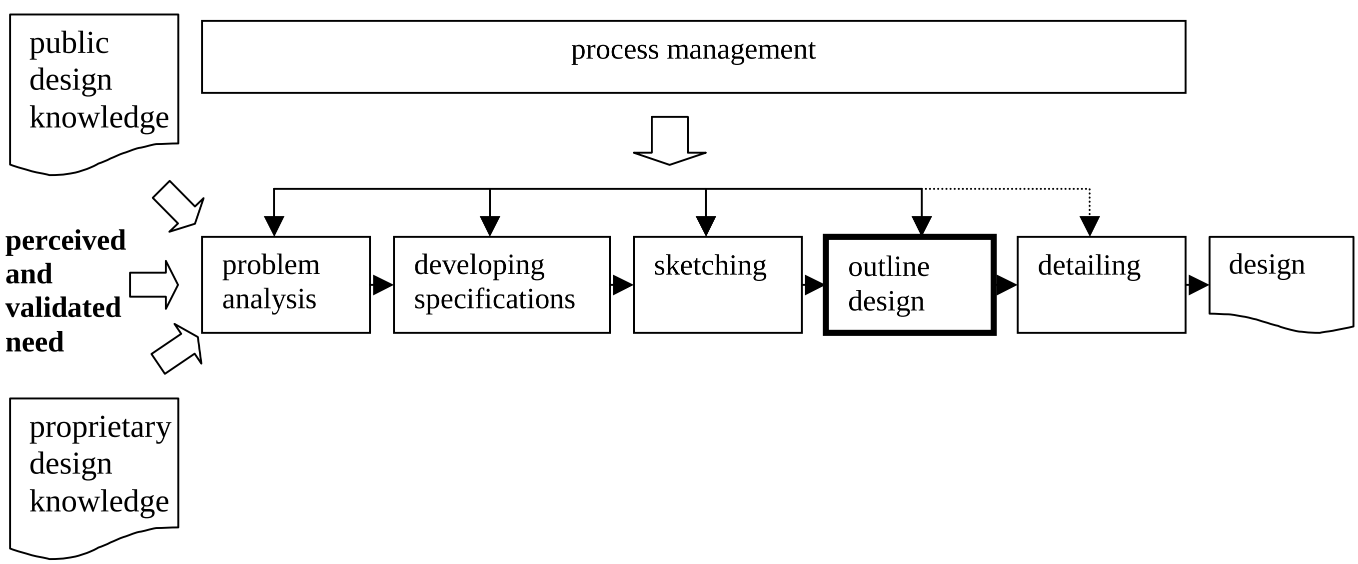

Fig. 4 A general descriptive model for a design process

The key iterations in designing are *synthesis-evaluation iterations* (see fig. 5). One creates a synthesis, a solution for a certain design problem (possibly by making a variant of some design exemplar) and evaluates to what extent this solution satisfies the functional requirements. If not satisfactory, a new or adapted synthesis is made and again evaluated, etc. If this iteration process fails to produce a satisfactory solution, a second type of iterations is started: *specification-design iterations.* In consultations with the principal (and possibly other members of the mobilising coalition) the functional specifications are adapted and a design process (synthesis-evaluation iterations) is started to see whether it is possible to meet the new specifications. If not, the specifications are again adapted, etc.

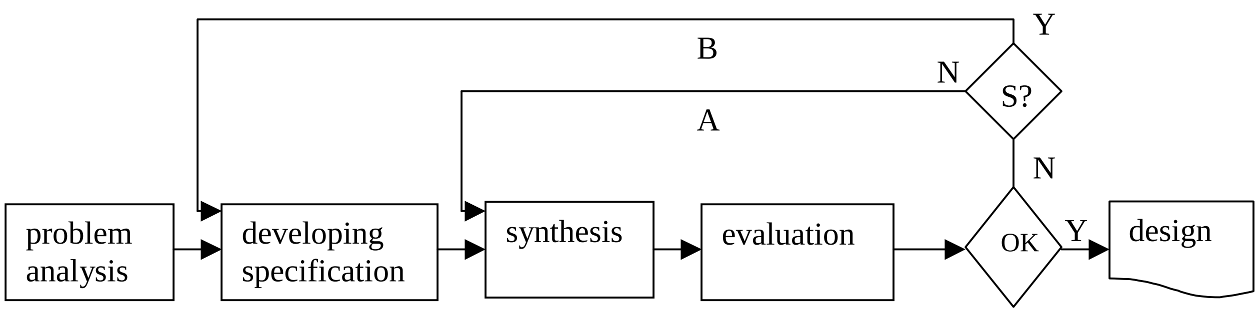

Fig. 5 Synthesis-evaluation iterations (loop A) and Specification-design iterations (loop B), which are started if the answer on question S ("change specifications?") is "Yes".

Sometimes one does not have sufficient object knowledge to be able to evaluate a design "on paper" (which may be the case in radical design). In that case one may want to make a prototype and to evaluate the performance of that realised artefact against specifications. This may also involve an iterative procedure.

One can have various types of process structures: a *step structure,* like in figure 4, a *fluid structure* without a clear separation between the various process steps, a *concurrent structure,* with various process steps executed in parallel and a *phase structure.* An example in new product design of a phase-structure is the already mentioned stage-gate system (see e.g. Cooper, 1990), in which the overall design process is divided in a number of stages and in which one is supposed only to proceed to a next stage if a review at the gate, giving access to that next stage, proves that all the work planned for the present stage has been properly concluded. In a phase-structure one has in theory no iterations and explorations, which leads to a well-ordered process (important, especially in large-scale processes), at the expense of flexibility. In so-called third generation stage-gate models (Cooper, 1994), a more flexible approach is used, allowing fluid gates and overlapping stages.

A process design specifies in principle the *undisturbed process.* It is a model of what will happen if all goes according to plan. Of course, in actual realisation of the process design there will be various disturbances, like delays in finding solutions to certain design problems, changes in the functional specification because the external world and its competitive conditions will not stand still during the design process or because increasing insight in the validated need or in the potential of technology triggers changes in specifications or plans. On the one hand it is the task of process management to deal with such disturbances in a kind of management-by-exception and on the other hand a process design should have some in-built flexibility (with e.g. buffers in time) to deal with disturbances.

An important element of the model of fig. 4 is the *outline design* (or conceptual design, see e.g. French, 1971, or Hubka, 1992). The outline design is a design in main lines, which contains all design decisions with respect to the key design dilemmas. The intention is that many iterations and explorations may take place during sketching and making the outline design, but that the outline design itself should be fairly robust in order that the time and money-consuming detailing can be done without iterations. Therefore, the iteration-exploration line between outline design and detail design is dotted.

As said, designing can also be seen as a process of consecutive detailing, going from rough sketches to detail design. From a content point of view one may regard the execution of actual design activities as *navigating* through the design, going from design issue to design issue and going from one level of detail to another. The process design gives a first route through the design, while process management adapts that route to the problems encountered on the way. Both process design and process management may focus on design dilemma's because their solution often has a big impact on the overall design, and one will tend to keep one's solutions fluid until a sound outline design can be made.

The other part of the process design is the design of the position structure, the specification of the actors that will execute the various sub-processes in the process structure. The quality of a design is not only dependent on the quality of the process producing that design, but probably even more dependent on the quality of the designers producing it.

In that position structure one has *designing positions* and *control positions*. Positions have ultimately to be filled by individuals, but a designed position structure can also specify departments or independent organisations to fill certain positions, leaving the choice of individuals for later on.

Control positions have the responsibility for process design and process management. Some are management positions, some are planning positions. A special type of control positions are the ones with the responsibility for making the process design. Here again one has a choice between various types of positions: process designers can be technical advisors to the design team, or project planner(s) – developing plans, but not having the authority to implement them – or project-managers (possibly supported by staff), who *do* have the authority to implement their process designs themselves.

Design positions are in the first instance to be filled on the basis of relevant talent and expertise. In the case of in-house development one also has to take into account the distribution of responsibilities over the various departments in the assignment of design positions. In the case of a multi-party project one has the additional problem that one does not have the unity of ownership, command and culture that one has in in-house design (see e.g. Van Aken and Weggeman, 2000, on the problems of distributed ownership, command and culture in multi-party situations).

A key issue in process design is its realisation. A realised object design is a material artefact, made by makers – like building contractors or workshops – through material processes. A realised process design, however, is not a material object but a human action system, driven by the thoughts and feelings of the actors. Hence the more elusive character of process designs. Like designing itself, also the realisation of a process design takes place in the immaterial world of texts and thoughts.

A new process design is realised through the *internalisation* of that design by the designers in question: they have to learn the contents of the process design and they have to be motivated to work according to it. That internalisation process is guided by verbal and written texts, flow charts, organisation schemes and the like, but not determined by those. Designers usually take and get quite some *realisation freedom* in realising the process design.

The realisation of a *new* process design implies a departure from established routines, is therefore a process of organisational change and should be managed as such. According to Tichy's well-known TPC-model (Tichy, 1983), organisational change should not only be managed in the Technical-economic subsystem (T), but also in the Political (P) and Cultural I subsystems. In the T-system the content of the work and the objectives to be realised through that work are managed and the technical interventions used in that system include reports and other content-oriented communications. In the P-system one has the interests (material and immaterial) of the various individuals, groups and organisations, and the formal and informal power those actors use to further their interests. Interventions in the P-system include formal orders and also dismissals and appointments. In multi-party projects one may even use legal steps as political interventions. The C-system reflects the fact that organisations are not only technical-economic systems, but also social systems. The key intervention in the C-system is participation through which the members of the organisation can develop a sense of ownership with the new process. Training people in new ways of working can be an intervention in both the T-system (just learning the content) and the C-system (getting motivated to use the new ways). Technical oriented people tend to focus on the T-system and to expect that a clear explanation of the new process is sufficient to introduce it. However, one also may need interventions in the P- and the C-system to effectively realise a radically new process design.

As said before, a design should only specify what the makers of that design need to realise that design: the principle of minimal specification. A process design is not made for robots but for individuals and groups with expertise and with selfcontrol and selforganisation. So process designers should try not to over-specify but should make conscious use of the principle of minimal specification.

Like any organisation design, a process design only specifies the formal system. Actual work, however, is also strongly influenced by the informal system and one may need interventions in the C-system, like training, to ensure that the informal system is sufficiently congruent with the (new) formal system.

Furthermore, the process design only specifies the formal *undisturbed* process, so process management supported by the informal system should be able to handle disturbances.

In small-scale design processes much can be left to self control and self organisation. To much detailed process designs lead to resistance with the designers and hence to a low degree of internalisation of those process designs. In large-scale design processes, however, one generally will have to design a more elaborate formal system. But also here, one has the danger of over-specification.

Finally, the ambition of this article is to say something useful for both architectural and engineering design. Much of the above discussed theory can be used for both fields, but one has to keep in mind that there are also significant differences between the two. According to Cross and Roozenburg (1992) common approaches to engineering design assume that problems can be defined and thus put much emphasis on problem analysis and the decomposition of the overall design problem into manageable sub-problems, where after the design process tends to follow a linear process from specifications via outline design to detailed designs. On the other hand, common approaches in architectural design assume that problems are ill-defined, start from solution-conjectures, using design exemplars for that, and tend to follow a “cyclical, opportunistic and argumentative design process”. So one has to take such differences into account when making process designs. For instance, the balance between process design (organising and planning the process before its start) and process management (adapting organisation and plan to the unfolding reality of the process) may be different: relatively more process design and less improvisation by process management for engineering design than for architectural design.

3.4 On more radical process design

Above I have discussed the need for large-scale and complex design projects to make explicit and possibly more radical process designs.

In the field of New Product Development a number of approaches have been suggested to stimulate radical product innovation, see e.g. Stringer (2000) and McDermott and O'Connor (2001). Some of these can also be used in making more radical process designs, like hiring more creative people in process planning, small-scale experimenting with more innovative process designs and setting up small teams with the task of developing new ideas in process design. However, in this article the main interest is in design knowledge for more radical process design. More specifically, the use of domain-independent design theory to identify design issues for more radical process design, like the theory given in sub-section 3.3

The potential of domain-independent design theory is connected with the fact that every design contains many *implicit design decisions,* elements of the design that are incorporated in the design by the designer without a conscious choice, without a consideration of possible alternatives. Such elements are incorporated on the basis of intuition or experience, or because the designer just used his or her first solution to a design problem or because he/she just copied it – consciously or unconsciously – from previous designs or from technological rules. Of course, without the consideration of alternatives there is a great danger of using sub-optimal design solutions. The danger of implicit design decisions is greatest in evolutionary design. In evolutionary design one more or less copies the design decisions incorporated in previous process designs. In using domain-independent design theory, the elements of the process design are described in more general, abstract terms, which implies that those elements are elements from a general class of elements and thus represent a choice rather than a necessity. In this way one is in a better position to avoid implicit design decisions and may look for better solutions than the first one at hand. The concept of mobilising coalition of 3.2 and the various types of process steps of 3.3 are examples of more abstract concepts that allow more innovative interpretations.

A more radical process design implies a departure from established routines. Introducing new routines is a process of organisational change and should be managed as such. That also necessitates a thorough analysis of the *nature* of a process design, being not a design of a material artefact but of a human action system. As we have seen, the biggest difference between the two is not the design itself but rather the realisation of the design.

4. Developing design knowledge for process design

In this section a number of issues in process design will be presented, for practice to experiment on and for research to explore, to test and to develop insight and evidence. The theory of the previous section has been used to identify these issues. The general objective of the research suggested below, is the development of general design knowledge. Another important line of research is the development of (computer-enabled) tools to support design processes and the design of such processes, but that subject falls outside the scope of this article.

4.1 Design Science and the Science of Design

The choice of research questions and research strategies strongly depends on the ideas the researcher in question has on the mission of academic research. Many academics, both in the natural and in the social sciences, feel that the mission of *all* science is to describe, explain and predict (see e.g. Nagel, 1979 and Emory, 1985). Developing more prescriptive knowledge is in that case seen as rather un-academic.

In the design field the situation is somewhat different. The ambition to develop knowledge that can be used in an instrumental way by designers is seen as academically quite respectable. In this field Cross (1993) distinguishes two research streams: design science and the science of design. The latter refers to empirical, descriptive research on the actual practice of design, aimed “to improve our understanding of design through “scientific” (i.e. systematic, reliable) methods of investigation”. Design science, on the other hand, refers to “an explicitly organised, rational and wholly systematic approach to design”.
While both research streams are clearly recognizable in the publications in the various academic design journals, I would like to give a slightly different interpretation to the concept of design science by putting the distinction of Cross in the perspective of other academic disciplines. One can make a general distinction between “*explanatory sciences*” like physics and sociology, and “*design sciences*”, like medicine and engineering[3] (Van Aken, 2001; Van Aken, forthcoming). The mission of an explanatory science is to describe, explain and predict, so in other words to understand. Students in these disciplines are trained to become researchers. The mission of a design science, on the other hand, is to develop knowledge, which the professionals of that discipline can use to design solutions for the problems in their field. Technological rules are a very important type of research product in these disciplines. Understanding of the nature and causes of field-problems is important, but much research in these disciplines is “solution-focused”, developing and testing types of alternative solutions for types of field-problems. Students in these design sciences are for the larger part trained to become professionals, not researchers.

I propose to regard Cross’ ”science of design” as an explanatory research stream (nothing new), developing knowledge that can be used in a conceptual way, but to regard his “design science” as a research stream in the tradition of other design sciences, developing knowledge that can be used in an instrumental way by designers. This does *not* necessarily mean to impose an “explicitly organized, rational and wholly systematic approach to design”. Research in a “design science” can be aimed at anything useful for designers, including the technical rules to be discussed below and which are not to be used as instructions, but as design exemplars. In this view on design science, the formalization of design processes is not an objective for research, but rather a subject of research: what degree of formalisation and what type of formalization can be useful in (large and complex) design projects.

Research in the science of design can very well complement research in design science, like in the cross-fertilization between the life sciences (explanatory) and medicine (design science) and between the natural sciences (explanatory) and engineering (design science).

4.2 Developing technological rules for process design.

If one aims at the development of prescriptive design knowledge, an important line of research is the development of technological rules for process design.

Of course, the most obvious of those are technological rules for making process designs, which means more elaborate models than the one given in fig. 4. Empirical work would include case studies of recent design processes or action research projects in which researchers develop together with professionals new approaches to process designs. An important part of such empirical work would be the grounding of the technological rules by analysing the mechanisms that produce the desired performance, like the question *why* a stage-gate system would be a better starting point for process design than other approaches. An important subject can be an analysis of the impact of scale on process design, e.g. by comparing cases of large-scale design processes with “smaller-scale” processes.

Technological rules can also be developed for certain sub-processes, like the process of defining the functional specification for the design.

Another subject for research may be the mobilising coalition. For in-house large-scale projects possibly not very interesting (maybe a matter of company politics), but very interesting for large-scale multi-party design projects like in urban development: what can be the role of the various parties, what are the do’s and don’ts in multi-party mobilising and especially what is the grounding of these do’s and don’ts, and – based on such insights – how can the various parties manage that mobilising process.

Also the more general issue of the position structure for the design process could be addressed by developing technological rules for role systems. An important type of issue here are the role systems for multi-party projects.

Still another is process management. Many technological rules for design processes only deal with the undisturbed process, suggesting that the realisation of the design process just involves the execution of the various steps of the process design. It would be interesting to see whether it is possible to develop some general knowledge on the issue of when to schedule iterations and explorations and when to deviate from the process design or to adapt the process design.

To conclude this preliminary list of empirical research issues, an important one is the realisation of the process design. How do designers actually use process designs, how should one transfer the process design to the designers without exciting resistance to the structuring of their work, but motivating them to work according to the process design and to what extent should the process design structure design work beforehand (the issue of minimal specification).

5. Concluding remark

The design of design processes is an important issue and is becoming more and more important as the scale and complexity and the various demands on the design process increase. This is not to say that large and complex design processes should always be fully organised and disciplined. Some process steps may be quite chaotic and allow for ‘free flowing’ creativity and the optimal degree of formalisation of a design process depends on the design situation. Still, some degree of organising and planning of large design processes is always useful. Process design has a somewhat more elusive character than object design and is often based more on experience – evolutionary design – than on experience plus explicit process design, using innovative design exemplars and evidence-based design knowledge. It seems to be worthwhile to do further experimentation in practice and further research in process design in order that that may change.

End notes

1. This position is based on the epistemological starting points of *realism*, see e.g. Sayer, 1984, and Archer, 1995. I follow realism’s contention that there exists a real (material) world, independent from observers and their knowledge. We can develop knowledge of that real world through our senses, even though sensory experiences are concept-laden and are therefore no objective images of the external world. Designs are entities in the immaterial world of knowledge, made to enable the production of artefacts that have a desired performance in the real world.
2. The objective of a design process can also be a process instead of an object, but to keep the discussion simple the following will only mention objects to be designed.
3. It may be somewhat confusing to use in a design journal the label “design science” for a set of academic disciplines, but unfortunately that can’t be helped; this label happens to have been developed outside the design community.

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