# 2. Domain Independent Design Theory

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## 2.1 Summary

This article provides a stepping-stone for the development of domain-independent design theory, based on a study initiated within the framework of the postgraduate Eindhoven design engineer program for Architectural Design Management Systems. This design theory is being developed to support the design of large-scale, complex design processes, such as one has in large building projects. The article will deal with the nature and the content of such theory.

## 2.2 Introduction

The two-year postgraduate design program ADMS (Architectural Design Management Systems) was established in 1997 at Eindhoven University of Technology, more specifically at the Stan Ackermans Institute. The target group for this program consists of building and business engineers. Its objective is to train engineers to design the design processes for large building projects and to support these processes with methods and IT-tools.

Within the framework of the ADMS program work is being done on the development of domain-independent design theory, i.e. design theory that is independent of the domain or discipline related to the entity to be designed. More specifically, this concerns the development of domain-independent design theory to support planning and organizing large-scale, complex design processes. The first results are presented in this article: a discussion of the nature of design theory and of domain-independent design theory, as well as a first sketch of its content. There is no pretence that all of this is new; the discerning reader will recognise much of what is written. The goal is to provide a stepping stone for further development of such theory, which is not only of interest for ADMS but also for engineering design in other disciplines.

At the same time also work is being done on domain-specific design theory, building on a longer tradition of developing such theory. The results of that are presented in Trum and Bax (2001).

## 2.3 Reasons to develop domain-independent design theory

The main issue in ADMS is to produce process designs for large-scale design processes, i.e. processes that are technically and organisationally complex, because they need input from various disciplines and because there are many individuals and parties (i.e. independent organisations) involved.

Process design in building usually is variant design. On the creative-routine scale of design processes (Sriram et al. 1989) they tend to be rather at the routine end. An individual or an architect firm usually operates on the basis of a way of working, developed on the basis of personal experience and under the influence of branch-specific factors (e.g. in the Netherlands the classic BNA model). When given a new assignment, one tends to start working on the basis of a variant of that proven method, using the technical and organisational characteristics of the new assignment and also recent experience to design that variant: what went wrong the last few times and what should we look out for this time, and what went right last time and is worth repeating?

The problem of such a craftsman-like approach is that the process design for the new assignment is not thoroughly thought through (almost all attention is paid to the design of the object). This means that there will be no revolutionary solutions and that there will be no systematic approach to the technical and organisational complexity of the new assignment. Especially for complex, large-scale design processes such an approach has a severe limitation.

ADMS has the ambition to rethink the building design process as a whole and to replace the traditional and experience-related process designs by a more conscious, rational, and theory-based approach. One of the approaches to this is to develop domain-independent design theory.

Each design, but especially craftsman-like designs, contains many implicit design choices, i.e. solutions for certain design problems selected because they seem obvious on the basis of experience or rational thinking, without the awareness of possible alternatives and therefore without an explicit consideration of alternatives. Domain-independent design theory searches for fundamental problems and fundamental design steps in each design process. It is partly developed through the comparison of design processes in various disciplines. Since various disciplines often have different solutions for design problems, these problems then become apparent. The results of such research are 'design science products' (see e.g. March and Smith 1995), which include:

- 'Design language', i.e. a system of concepts or constructs with which design processes can be described and which can be used to make actual designs.
- Design models, which can be used to analyse design processes, but also as exemplars to design such processes.
- Design methods to support certain activities in the design process.
- Specific tools, possibly computer-based, also to support certain design activities.
- Design methodology, i.e. theory on the use of models, methods, tools and general approaches to design.

A domain-independent approach to process design, finally, can also facilitate interdisciplinary communication within complex large-scale design processes.

## 2.4 Design theory

Design processes are nearly as old as civilisation itself; even hand-held rock tools were designed. However, generally they were designed by the user and followed an evolutionary design process: passed on from generation to generation, these tools 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. 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 designing and the realisation of designs and which facilitated innovations in the designs of artefacts. Generally, it is far easier to experiment with new designs on paper than in physical reality.

However, for many centuries the design process itself continued with craftsman-like variant designs. In crafts, building and other engineering disciplines, the design of artefacts was learned through experience and under the guidance of masters and colleagues. Process knowledge (i.e. knowledge about the characteristics of the design process itself) was usually implicit and explicit process designs were seldom used. Process knowledge or design theory first became a field of scientific study in the nineteen-sixties, mainly through British initiatives (Jones and Thornley 1962; Gregory 1966; Glegg 1973; Jones 1980). In this context we may also mention Simon's seminal book "the Science of the Artificial" (Simon 1969, 1980), an important contribution to the development of design science as a field. These pioneers had powerful ambitions and great expectations: 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.

However, up until now there has only been limited success. Theory has been developed, but the impact on actual practice, training, and tools has remained modest. Interesting parallels can be drawn to General System Theory and Cybernetics (Boulding 1956; Ashby 1956; Beer 1972) and decision-making theory (Simon 1960). These too arose in the same period 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 supplemented with results from thorough empirical studies about real-life decision-making processes. General, supra-disciplinary System Theory dissolved into the various mono-disciplines, but did leave traces in the shape of concepts and analytic approaches.

The best road forward for design theory is to use extensive empirical studies on real-life design processes in various disciplines, in order to obtain more fundamental insight into such design processes. Following that, this insight can be used for approaches that are more normative. This article will not take us down this road however. Using knowledge from experience in various engineering disciplines and turning to the literature, an attempt is made from behind a desk to develop a first sketch of domain-independent design theory.

This is not to say that this article is based on a modernist ambition to develop a single all-encompassing General Design Theory (such as general System Theory attempted to do for the formulation of scientific theory in general). There are many possible and useful different approaches to the design process, and the choice depends on the objectives one wishes to serve with the approach. The design process can be viewed, for example, as a problem-solving cycle, as a series of decisions on design problems, as a process of developing successively more details of a description of the artefact to be realized, etc. Every different perspective leads to a different model of the design process and to a different design theory, domain-independent or not.

So there can be many domain-independent design theories. An interesting example is the one of Reymen (2000), who uses a state-transition model for the design process in order to structure it and to develop methods and tools to support it. As said, this article is concerned with domain-independent design theory to be used in planning and organizing large-scale, complex design processes.

## 2.5 Design

A *design* can be defined as a *representation of an entity* (object or process) to be realised, *made as an instruction for the next step* (in the design or realisation process).
A design is a special case of a model; much of the knowledge on model building is relevant to design. A model is an abstraction of reality. Examples of models are schemes, texts, scale models, and computer 3D representations.
The entity to be designed will have a particular physical realisation and must fulfil a particular function for a particular target group. *Designing*, then, *is the process of determining the required function and creating a model of its physical realisation*. One can also say that designing is the development of a *functional specification* of the artefact to be designed, i.e. a specification of the functions it has to perform for its users, combined with the development of its *technical specification*, i.e. a specification of the artefact in such detail that it can be realised, produced by a producing party.
In general, three kinds of design are made: an *object design*, a *realisation design*, and a *process design* (see Figure 2.1).
In the field of building, the object design is the collection of drawings of the building to be realised. The realisation design concerns the plans for actual building and the process design describes the design process itself.
To make an object design, one must have intimate knowledge of the properties of the entity to be designed. This knowledge can be described as *object knowledge*. *Realisation knowledge* (knowledge about the processes needed for the production of the entity) is used to make a realisation design. Knowledge about the design process itself, *process knowledge*, is used to make the process design, i.e. the design of the process of designing. Our research on domain-independent design theory is undertaken to support the development of such process knowledge.

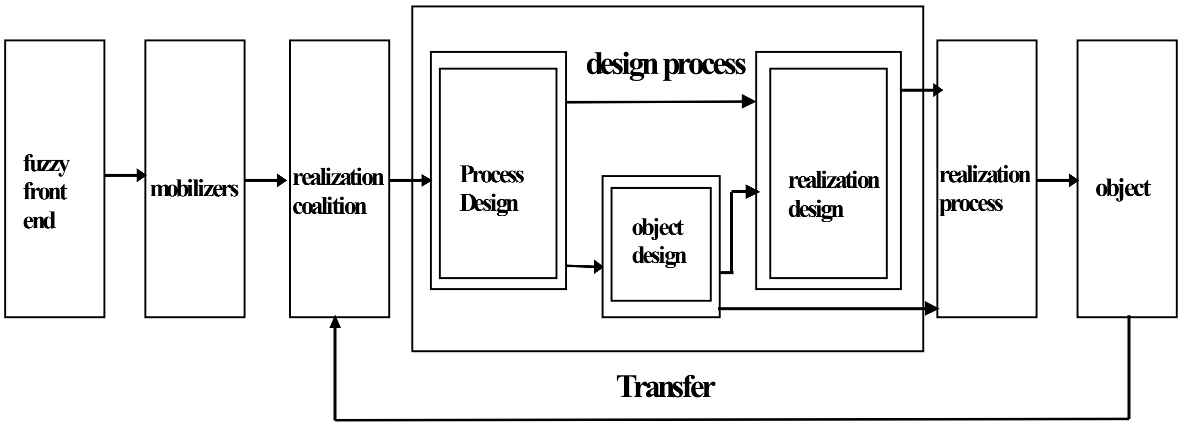


*Figure 2.1: Process, object, and realisation design.*

There are various approaches to the creation of a design process. It can, for example, be spontaneous, evolutionary, or craftsman-like. A spontaneous approach is not guided by process knowledge. Often there is considerable object knowledge and experience with design. In an evolutionary approach, the object design is gradually improved (as discussed in section 2.3). In a craftsman-like approach to the design of a design process, the working methods of teachers are followed. This way of working is often used in smaller building projects. As discussed, an existing method is used and somewhat adapted to a new situation.
In large-scale complex building projects, however, the traditional approach is insufficient. A more professional process design is required, i.e. a more conscious, rational consideration of

alternatives is needed that is guided by scientific process knowledge. As said, such process knowledge consists of design language, design models, design methods and tools, and design methodology.

## 2.6 The design process

In this section, we discuss various aspects of the process design for a physical object:

- Generic step model of a design process.
- Design specifications.
- Basic activities in design.
- Process and task structure.

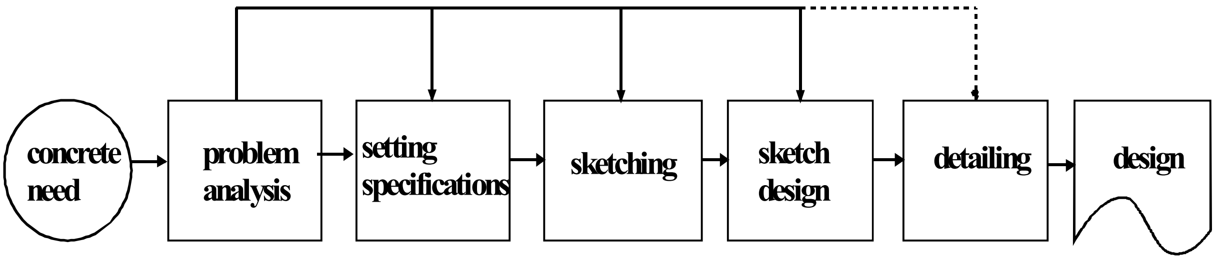


*Figure 2.2: Generic model for a design process*

In the generic model of Figure 2.2 the design process is described as a series of stages with *iterations* - going back to one or more previous stages - and *explorations* - going ahead to subsequent stages in order to explore already the design problems in those stages.
A key element in that process is the *concept design*. This concept design is a design in main lines, which contains all the design decisions with respect to the key design dilemmas. The intention is that many iterations and explorations may take place during sketching and the making of a concept design, but that the concept design should be fixed before the time and money-consuming detailing starts.
The design process is created because of a concrete need among mobilizing parties. These parties consist of the following agents:

- Principal: Decides about the content and has authority over resources.
- Problem-owner: Responsible for the solution of the problem.
- User: The actual user of the object or process to be designed.

### *2.6.1 Design specifications*

The mobilizing parties set down their needs in design specifications in consultation with the designing parties. Managing these specifications is a main issue in the design process. During the design process, these specifications are detailed for the following points:

- Boundary conditions: Must be met.
- Functional requirements: Performance demands.
- User requirements: Perspective of the user.
- Design restrictions: Preferred solution space.

***Examples***

***A. Freezer***

- Boundary conditions: Uses 220 V.
- Functional requirements: Cool space to –2 $^{o}$C.
- User requirements: Easy to defrost.
- Design restrictions: Use the same compressor as in existing types of freezers.

***B. A building***

- Boundary conditions: Building law and building regulations.
- Functional requirements: International appeal, educational function, etc.
- User requirements: Accessibility.
- Design restrictions: Budget and completion date.

### *2.6.2 Basic activities in design*

After problem analysis and the definition of functional specifications, the basic activities of designing are *synthesis-evaluation iterations*: the synthesis of possible solutions to design problems and the subsequent evaluation of those solutions against specifications. Synthesis is achieved through creativity, experience and design examplars. Evaluation is done through testing, calculation and judgement, based on object knowledge. During those synthesis-evaluation iterations the designer searches for alternatives, avoiding 'to marry his/her first design idea'.

### *2.6.3 Process and position structure*

A design process is a special case of a general '*production process'*. A production process is created to produce something, such as a machine, a building or a painting. It can also be created to produce a design.

Every production process has a process structure and a position structure. The process structure is built up of elementary process steps with time relations, such as sequential relations or with iterations and explorations. In each process step a number of tasks have to be performed. Every task can be allocated to a different agent, but usually similar tasks, maybe in different process steps, are allocated to the same agent or position. In this way a set of positions is created. Usually these are not independent from one another, but have certain (static) relations, for instance by again combining related positions into compound positions, thus resulting in a position structure. Next to primary positions there are also control positions, controlling the execution of tasks.

## 2.7 The design of the design process

The objective of designing a design process is to realise an effective and efficient system of activities that produces a design that meets the specifications and expectations of the mobilizing parties.

The process design specifies the process structure, i.e. the what and when (or, in other words, plans the whole design process). And, secondly, it specifies the position structure, i.e. the 'who' and 'where', by allocating these process steps or elementary tasks to certain simple or compound positions. One may compare the process design to a script of a play or movie, specifying actions (text and behaviour) and parts (people with specific characteristics and with certain relations to one another). The script specifies and guides actions, but does not completely determine it: the actors still have some freedom in their interpretation of the script. One can call this freedom the '*realisation freedom*' of the design, i.e. the degree of licence the design allow to those who have to realize it.

In the design of technical objects or processes, like the design of a TV-set or of a manufacturing process, there is usually a clear separation between design (by the development department or by the engineering department) and realisation (by the manufacturing department), while the design usually leaves very limited realisation freedom. In the design of an essentially social process as a design process, however, such a clear separation is undesirable. One needs some degree of involvement of the designers themselves in making the design and the resulting design should still leave those designers quite some realisation freedom.

For the role of the process designer there are at least three design exemplars: he/she can be a technical consultant of the design team, he/she can be the project planner without formal authority and he/she can be the project manager, having specific authority over the people involved in the design process.

The design of a design process entails the decomposition and integration of that process. The decomposition results in process steps and elementary (or compound) tasks or positions. Proper decomposition leads to a nearly decomposable system (Simon 1969): the whole is decomposed in such a way into subsystems that the relations within a subsystem are stronger than between subsystems. Integration is realised through coordination, sometimes supported by the creation of a hierarchical system (again Simon 1969), i.e. a system with a part-within-part structure.

A process structure consists of process steps and time relations. The time relations can be sequential, iterative or explorative. The process steps can be fluid (weak boundaries), transitional (transition phase between steps) or overlapping (limited but without distinct time boundaries). One example of transitional process steps is that you are working on a task that actually belongs to the task of the next process step. The following design exemplars can be used for the design of a process structure:

- The Dutch BNA model for the design process: This is a specific model of a step structure.
- A fluid structure.
- A phase structure: Sequential, defined boundary for each phase, each phase as a black box.
- Step structure: Iterations and explorations, defined in advance or result dependent.
- Concurrent structure: Phases or steps overlap or run in tandem.

The position structure of a design process is conditioned by its structure of *contracting parties*. A contracting party is a group with unity of property, leadership and loyalty. In a multi-party coalition, one has to work with distributed property, leadership, and loyalty. A design coalition has relations with parties outside the coalition. The boundaries of the design coalition are an important issue. Who are the participants of the design coalition and who are only relations?

For the design of a position structure, we can make use of the following design exemplars:

- Traditional tender model: Coalition with relations ('bag of marbles').
- Building team: Design coalition with partnership (one-party model).
- Virtual organisation: Multi-party that is univocal towards the client.
    - With a core partner (main contractor with subcontractors)
    - Without a core partner (balanced network)

Once resources have been made available at governance-level, then a structure for design and management positions can be created on the basis of the following:

- Transformation specialisation (e.g. technical expertise).
- Object specialisation (on the basis of design fields).
- Environment specialisation (contacts with relations).
- Geographical specialisation (for large geographical distances).

People in managerial positions may have the following types of authority:

- Authority to take final decisions.
- Authority to provide advice:
  - Obligatory or facultative advice (from the perspective of the part being advised).
  - Upon request or otherwise (from the perspective of the consultant).

The formal division of decision authorities can deviate from the actual division of powers of decision.

The following design exemplars can be used to organize the design team:

- Chief designer with a team
- Balanced team
  - With self management
  - Without self management
- Modular team
- Design team with sub-teams

## 2.8 Final remarks

This article gave a rough sketch of the content of domain-independent design theory, developed in order to support the planning and organising of large-scale complex design processes, in building or in other engineering disciplines.

Much work and many critical discussions are still needed to develop it in a really useful system of concepts.

## 2.9 References

Ashby, W.R. (1956). An Introduction to Cybernetics, Chapman & Hall, London.

Beer, S. (1972). Brain of the Firm, Allan Lane, The Penguin Press, London.

Boulding, E.K. (1956). General Systems Theory – The Skeleton of Science, Management Science 2.

Glegg, G.L. (1973). The Science of Design, Cambridge University Press, Cambridge.

Gregory, S.A. (1966). The Design Method, Butterworth, London.

Jones, J.C. (1980) Design Methods - Seeds of Human Futures, Wiley, London.

Jones, J.C. and Thornley, D.G. (1962). Conference on Design Methods, Pergamon Press, London.

March, S.T. and Smith, G.F. (1995). Design and Natural Science Research on Information Technology, Decision Support Systems 15, pp. 251-266.

Reymen, I. (2000). Towards a Multi-Disciplinary Framework for Design, Working paper Eindhoven University of Technology, Eindhoven.

Simon, H.A. (1960). The New Science of Management Decision, Harper and Row, New York .

Simon, H.A. (1981). The Science of the Artificial, MIT-Press, Cambridge.

Sriram, D. et al. (1989). Knowledge-Based System Applications in Engineering Design: Research at MIT, *AI Magazine* 10(**3**), pp. 79-96.

Trum, Henk and Bax, Thijs (2001). A Building Design Process Model: According to Domain Theory, in: Achten, H. and Vries, B. de and Hennessey, J. (eds). *Design Research in the Netherlands 2000*, Eindhoven University of Technology, Eindhoven, pp. 19-30.