Modelling the Role of the Design Context in the Design Process
A Domain-independent Approach

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Abstract
Domain-independent models of the design process are an important means for facilitating interdisciplinary communication and for supporting multidisciplinary design. Many so-called domain-independent models are, however, not really domain independent. We state that, to be domain independent, the models must abstract from domain-specific aspects, be based on the study of several design disciplines, and be useful for many design disciplines and for multidisciplinary design teams. This paper describes a *domain-independent* descriptive design model that is developed by studying similarities and differences between design processes in a few design disciplines. The model is based on the general theory of state transitions. We modelled a design situation as a state at a certain moment and a design activity as a transition. We also explicitly modelled the role of the *design context* in design processes. In our empirical studies, we noticed the influence of the design context on the product being designed and the design process and the importance of communication between designers and stakeholders in the design context regularly during the design process. Making designers aware of the role of the design context can improve the quality of both the product being designed and the design process. The role of the design context is, however, often not explicitly taken into account in design models. We modelled the design context as part of the state at a certain moment and interaction with the design context as one of the activities performed by designers.

Keywords: design model, state-transition system, design situation, design activity, design context

INTRODUCTION
For facilitating interdisciplinary communication and for supporting multidisciplinary design, *domain-independent* models of the design process are very important. Because this kind of models abstracts from domain-specific details, it can be used in multidisciplinary teams as a common representation of the design process. The domain-independent concepts and terminology of such a model can be the basis for a dialogue between the members of a design team. The need for domain-independent design theory has been discussed since the beginning of design research. A primary goal of the Design Research Society since its founding in the 1960's has been a domain-independent theory of design within the context of a science of design. A discussion meeting on the question whether the search for domain-independent theory of designing is a reasonable or realistic goal (McDonnell 1995) led to the issue of the aim of design research. The discussion showed a clear division between those who want to study design per se and those who want to improve design practice and design education. We share the second viewpoint: We believe that domain-independent design models are worth developing when they are aimed at improving the design practice and design education in many design disciplines and multidisciplinary teams. This means that the model should have the right generality, i.e., the general concepts used for describing design processes must be recognisable by designers in a number of disciplines. To be domain-independent, design models must fulfil the following three criteria: abstracting from domain-specific aspects, being based on the study of several design disciplines, and being useful for many design

disciplines and for multidisciplinary design teams. Domain-independent models, are, for example, given in (Hybs and Gero 1992), (Korn 1996), (Newell and Simon 1972), (Schön 1983), and (Takeda, Tomiyama, and Yoshikawa 1990).

Many design models, however, are often said to be domain independent but in our opinion do not deserve to be called so. Some theories, for example, do not abstract from all domain-specific aspects and examples given to illustrate these theories are often taken from only one discipline. (For example, Hubka and Eder (1996) take all examples from mechanical engineering and do not consider the existence of non-material products like software.) Many general design theories are also often based on the study of one design discipline or are made with no practical goal in mind. Given the fact that designing in several disciplines has much in common, it must, however, be possible to develop domain-independent design knowledge. Common characteristics of a design process are, for example, the occurrence of design phases and the ill-defined nature of design problems. We have chosen to develop domain-independent design knowledge by studying similarities and differences between design processes in a few design disciplines. This paper describes the resulting domain-independent descriptive design model.

More specifically, this paper describes how we modelled the role of the *design context* in design processes. Based on an empirical study performed in the design practice (Reymen 2001a), we noticed that the design context plays an important role since it influences the product being designed and the design process during a whole design process. The design context determines constraints of the design process like time-to-market and available budget and influences characteristics of the product being designed like function, price, and quality. Factors in the design context that influence the product being designed and the design process are, for example, users, competitors, trends in the market, environmental laws, patents, and the company director. Interaction between designers and parties in the design context is necessary so that designers are informed about important external factors and changes in the design context and to discuss the influence of these factors and changes on the characteristics of the product being designed and the design process. Making designers aware of the design context and its role can stimulate the communication between designers and stakeholders. This may result in an improved product being designed and design process.

The design context is, however, often not explicitly taken into account in design models. In many models, only at the beginning of a design process, some requirements from the design context are taken into account. Also, often a sequence of design activities is discussed, but none of these activities concerns interaction with the design context regularly during a design process. The need for modelling and supporting the interaction with the design context is recently discussed in the literature, for example, in (Dorst and Hendriks 2001), (Glock 2001), and (Mitchell 2001).

In this paper, we propose a domain-independent model of the design process that gives the design context a role in the design process. The paper starts with describing our research approach. It continues with describing the basic theory we used to develop our model. After the model has been described, we discuss its domain independence and its potential usefulness for supporting communication between designers and for supporting interaction with the design context, including some recommendations for further research.

RESEARCH APPROACH

To follow a domain-independent approach, we studied design processes in several design disciplines, namely architecture, mechanical engineering, and software engineering. We chose architecture because it has already played an important role in design research and it is the discipline the first author is most familiar with. Mechanical engineering has also contributed much to design research and is a typical engineering discipline. Software engineering is a new evolving discipline that started to reflect on its design processes. Together, these three disciplines are responsible for a wide range of products and for many different design approaches.

The research question we try to answer is "How to describe design processes in a domain-independent way?". We have chosen an exploratory study because design research across several disciplines is a relatively new approach. We started the research process with a *literature study* in which we explored general design literature and literature specific for the three design disciplines. The goal of the literature study was to find domain-independent characteristics of design processes. We also decided to explore the design practice. For that purpose, we chose qualitative research based on an empirical approach. We performed *case studies* in the three chosen disciplines. We first interviewed six junior designers at the end of the design process of one of their design projects and we analysed the documents made during these projects. In a cross-case analysis, we compared all junior cases. Then, we performed the same activities for six expert designers: interviewing the expert designers, analysing their documentation, and performing a cross-case analysis. More about the performed case studies can be found in (Reymen 2001a). We compared design processes in each of the disciplines for similarities and differences. The similarities found have been the basis for the development of the domain-independent descriptive *design model*. In an empirical study that we performed at the end of the research process, expert designers gave *feedback* on our model in an interview. The feedback was meant to judge the generality (domain independence), the relevance, and the potential usefulness of the model for design practice. At the end of the research process, we performed again a *literature study* in order to position our model.

STATE-TRANSITION SYSTEMS

For modelling the design process in a domain-independent way, we use the general concept of *state-transition systems*. This is a general mathematical theory offering concepts that are independent of a certain discipline; it allows us thus to abstract from domain-specific aspects. A general theory is necessary because similarities between design processes in several disciplines can only be found on a relatively high level of abstraction. State-transition systems are also appropriate to model the similarities we recognised in the case studies. In state-transition systems, a state is defined as the situation at a certain moment in time; a state is changed by transitions. For the field of designing, we translate this as follows: We let a design situation correspond to a state and a design activity to a transition. A design process can thus be described from a static perspective by a design situation and from a dynamic perspective by design activities. We define the design context as part of the design situation. A design situation and a design activity are the main concepts of our model. Both concepts are explained in the next two sections. In this section, the concept of state-transition systems is explained in some more detail.

The concept of state-transition systems is successfully used in, for example, computer science and control theory. Many processes can be described as state-transition systems: for example, workflow processes, logistics processes, and assembly processes. General literature about state-transition systems can, among others, be found in (Lewis and Papadimitriou 1998) and

(Linz 1996) [1]. State-transition systems are a special form of transformation systems: The latter transform something in something else; state-transition systems transform a state into another state. In the design literature, the notion of transformation is widely used: In (Hubka and Eder 1996), a design process is modelled as a process of transforming design information. In (Takeda et al. 1990), a transformation from a functional specification to an artefact specification is suggested. More transformation models in the design literature are summarised in (McMahon, Meng, Brown, and Williams 1995). The concept of state-transition systems is also already used to model a design process. In (Salustri and Venter 1991), a design process is defined as a series of time-dependent actions that transform the information through a series of states. The theory of Salustri et al. was, however, not taken as a basis for our model because it formalises 'design information' rather than concentrating on the description of the 'design process' and it does not explicitly take the design context into account.

We use the concept of state-transition systems to describe design processes in a domain-independent way. Only the externally observable behaviour of designers is described, omitting, for example, the cognitive aspects of designing. Also, only the basic concepts and terminology of state-transition systems (state, transition, state space) are used and translated to design processes; the mathematical notation and definitions of state-transition systems are not used. This basic terminology of state-transition systems is extended with terminology commonly used in technical sciences (like entity, property, factor, representation, relation, and process). To establish a consistent set of definitions, some definitions of state-transition systems are adjusted to the other general definitions used. In this paper, only the main concepts and definitions of our model and those related to the design context are described. In (Reymen 2001), a more extensive description of the design model can be found.

A DESIGN SITUATION

The first main concept of our design model offers a static perspective on the design process, in the form of a design situation. We define a *design situation* at a certain moment as the combination of the state of the product being designed, the state of the design process, and the state of the design context at that moment. In the remainder of this section, we first give a definition of a product being designed, a design process, and a design context. Then, concepts to define the state of a product being designed, a design process, and a design context are discussed.

A *product* is an artefact (that must be designed) satisfying a human need. This need can be defined by the design context. This artefact can be an object or a process. Examples of products are a production machine, a building, a software program, a social process, a design process, a production process, or a logistics process. The life of a product is represented by its *product lifecycle*. This is a representation of the product evolution, starting from a statement about the need of the product, continuing with its design, production, use, and reuse, and ending with its decommissioning. Because the product itself does not yet exist during its design process, we use the terminology of a *product being designed* to indicate the product during the design process.

A *design process* is defined as a finite sequence of design activities, necessary to obtain the design goal. Note that the design goal may change during a design process. One or more designers can execute these design activities, in sequence or in parallel, using one or more design aids, like theories, methods, tools, time, space, and money. A *design context* is described by the set of factors influencing the product being designed and the design process

at a certain moment. Examples of factors are other processes than the design process in the product lifecycle of the product being designed (for example, the production process, the use process), stakeholders (for example, users and suppliers), a company quality handbook, the company culture (image, vision, brand), competitors, laws, patents, new technology, discipline-specific knowledge, and the situation of the market (politics, economy, environment, culture).

The concepts of a factor and of a property are used to define the state of a product being designed, of a design process, and of a design context. A *property* describes a characteristic of the product being designed or of the design process. A property can have a set of values. Examples of properties and their values are 'shape: oval', 'robustness: high', and 'development time: 6 months'. A *factor* describes an external influence on the characteristics of the product being designed or of the design process. A factor has the 'potential' to influence the product being designed and the design process in the present or in the future. A factor can also have a set of values. Examples of factors and their values are 'company colour: red', 'production machines: maximum diameter of 20 cm', and 'environmental law: no coating allowed with ingredient 'X''. The distinction between properties and factors is based on who 'determines' the property or factor and who can 'influence' the property or factor. A designer can determine properties but he cannot determine factors, although he might be able to influence some design factors by interaction with the design context.

The *state* of a product being designed is the set of values for all properties describing the product at a certain moment in time. The state of a product being designed can be seen as a special, second order, property of the product being designed; it describes a characteristic of the product being designed with a set of values as its value. A similar definition can be given for the state of the design process. The state of the design context is the set of values for all factors influencing the product being designed and the design process at a certain moment. In combination, this means that a *design situation* is the set of values of all properties describing the product being designed, the set of values of all properties describing the design process, and the set of values of all factors influencing the product being designed and its design process. The definition of a design situation is illustrated in Figure 1.

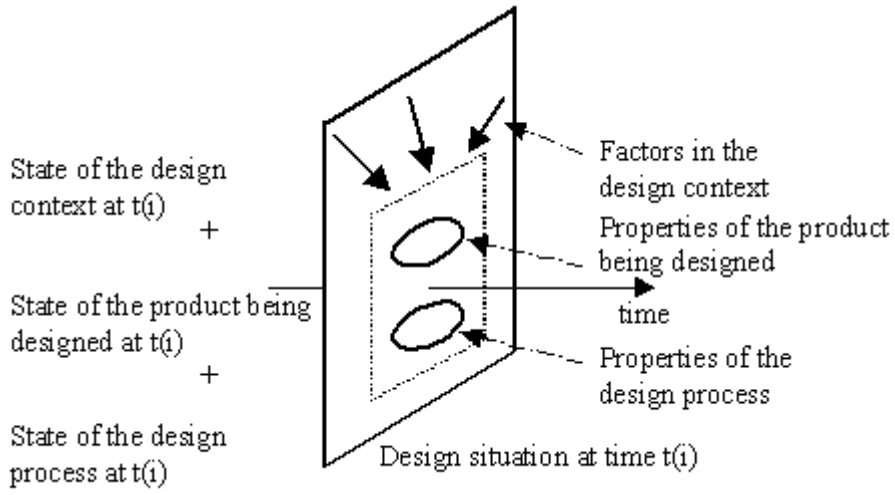

Figure 1: a design situation as a state

DESIGN ACTIVITIES

The second main concept of our design model offers a dynamic perspective on the design process, in the form of design activities. A design situation can be changed into another design situation by one or more actions (causing state transitions). Designers can change the state of the product being designed and of the design process. Stakeholders can change the design context. The design context can also be changed by interactions between designers and stakeholders or it can change autonomously. We model the interaction with the design context as one of the activities that can be performed by designers. In this section, each of these actions is explained in more detail.

Designers are actors executing design activities. Designers can change the properties of the product being designed and of the design process. A *design activity* is a transition towards the design goal at that moment, carried out by a designer, causing a change of the state of the product being designed or of the design process. We define a *design goal* as the goal to create one or more desired representations of the product being designed having a desired state. Multiple representations must be made for communication with several stakeholders, like representations for the realisation process of the product being designed and representations for the marketing department. Usually, the goal of a design process also induces desired properties of the design process, like budget, time, moments for presentation of intermediate results, and guidelines for documentation. A design activity can result in a changed product being designed as well as in a changed design process. The above-mentioned definitions are illustrated in Figure 2. A special kind of activity is *interaction with the design context*, i.e. with stakeholders in the design context; this activity can result in changes in the design context that can also cause changes to the state of the product being designed or the design process.

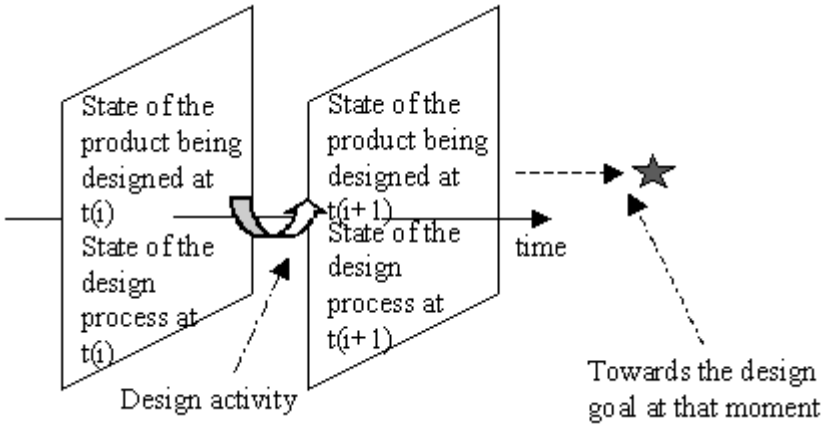

Figure 2: design activities causing a state transition

Stakeholders are actors in the design context. Stakeholders have an interest in the product being designed and/or the design process. They can be part of the company, like the production manager who can buy a new production machine or the logistics manager who can change the concept of distribution of the products, or of society, like customers and users. A stakeholder can change the state of the context; he can influence factors and can interact with the designers. *Transitions in the design context* can be described by transformations or mutations. A transformation can have a goal that may or may not coincide with the design goal. A mutation is an action in the design context with a goal that is independent of the design goal. Mutations take place independently of the lifecycle of a specific product, but can influence this product and its design process. Examples of such mutations are actions of a

competitor and the introduction of a new law. Taking into account the effect of such a mutation on the product being designed and/or the design process is a design activity.

DESIGN MODEL

The concepts of a design situation and of a design activity, described in the previous two sections, are combined into a design model. The purpose of this model is to offer concepts and a terminology for describing design processes in a domain-independent way. To explain our model, we first introduce the concept of a design task and its relation to the design context. A *design task* at a certain moment is a task to meet the design goal at that moment, starting from the current design situation. One or more designers perform a design task by executing design activities. An alternative formulation of a design task is a task to transform the current state of the product being designed and/or the design process into a desired state, taking into account the design context. A design task is often appointed to stakeholders in the design context. Each design task has a specific design context.

Our design model is illustrated in Figure 3. A design process is modelled as a finite sequence of design activities. Designers perform design activities to meet the goal of the design process at a certain moment. To perform their design task, they have to take into account the whole design situation. As explained, a design situation is defined as the combination of the state of the product being designed, the design process, and the design context at a certain moment. A design situation can be transformed by design activities and by actions of stakeholders in the design context. The design context can, however, change the design situation in a direction that does not necessarily conform to the design goal (illustrated in Figure 3 with different 'stars'). Designers can interact with the design context to exchange information about the design situation, i.e., to get to know and to influence important factors in the design context and to discuss desired properties of the product being designed and of the design process.

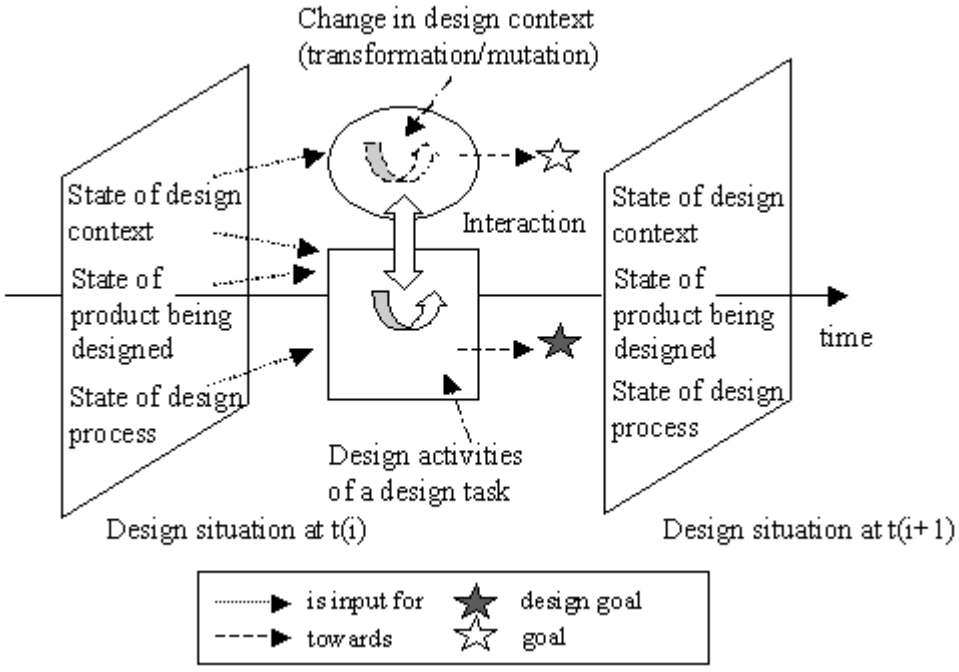

Figure 3: design model

DISCUSSION AND CONCLUSION

Our design model describes a design process from the viewpoint of state-transition systems, which is one of many different points of view to describe a design process. We made the

general theory of state-transition systems suitable for describing design processes by instantiating it with characteristics of design processes like the concept of a design situation and that of a design activity. We also explicitly modelled the role of the design context in the design process to make designers aware of the importance of factors in the design context and of interaction between designers and stakeholders. In (Reymen 2001), a more extensive description of the design model can be found. There, also concepts like a current and desired property, a design alternative, a design relation, a representation of a product being designed, a description of a design situation, a design space, and a definition of designing can be found. Some aspects of design processes in practice, like the designer and the design team and aspects like creativity and intuition, are, however, not explicitly modelled.

Our model is intended to offer a domain-independent description of a design process. To judge if the model is really domain independent, we have to check whether or not it fulfils the three criteria of domain independence we stated in the introduction. The first criterion is met in the sense that our model abstracts from domain-specific aspects. The concepts of our model are understood in each discipline we investigated and are compatible with the concepts in general design theories. Some designers giving us feedback on the model had, however, difficulties with the domain-independent terminology. This difficulty can be overcome by providing examples from several disciplines. We met the second criterion in the sense that we performed research in the disciplines of architecture, mechanical engineering, and software engineering. The third criterion concerns the usefulness for several disciplines and multidisciplinary teams. We found that already only studying similarities and differences in several disciplines is useful for these disciplines, because they have to make explicit their concepts. The comparison of concepts and approaches between disciplines can also offer new points of view for the separate disciplines; a well-known example is software engineering that learns from architecture a way of thinking in design patterns (Gamma, Helm, and Johnson 1995). Our model may be used as a basic representation of a design process both in design practice and design research. In design practice, it can stimulate and improve communication between designers and between designers and stakeholders in the design context. The communication may result in an improved product being designed and a more efficient and effective design process. In (Reymen 2001), our domain-independent representation of a design process is already used for developing domain-independent support for reflection on design processes.

To be really useful for supporting communication between designers (from several disciplines) and for supporting interaction between designers and stakeholders in the design context, the model must be refined and extended. A major extension should be the explicit modelling of the designers and the stakeholders and their characteristics as individuals (like personality and skills) and as groups. For the extension of the design model, further research can be based also on multidisciplinary teams instead of only on individual designers in a number of disciplines as we did. For supporting communication between designers of a multidisciplinary team, support to make a common (domain independent) representation of a design situation would be useful. Further research can concentrate on such prescriptive representations. For supporting interaction between designers and stakeholders, types of interaction and communication between designers and several types of stakeholders in the design context can be studied. A topic of further research can also be the influence of the design team composition on the interactions with the design context.

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[1] Literature about state-transition systems in general (not applied to a specific domain) can be found in books and articles about ‘finite automata’. The definition of finite automata includes all important concepts about state-transition systems.

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