A PROCESS-BASED APPROACH TO DESIGN

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Abstract

The paper presents a process-based design support system to aid the improvement of the mechanical engineering design process. The system requirements have been formulated from the characteristics of design derived from both prescriptive and descriptive design literature, and from an analysis of a design process in industry. The core of the system is a model of the design process, rather than of the product, in order to be able support the whole design activity.

Introduction

In the field of mechanical engineering, both products and the processes of their creation have undergone major changes. Products have become too complex for an individual and so require cross discipline cooperation. Shorter product life-cycles have forced shorter and more efficient development cycles. Tighter requirements and stronger competition have lead to an increased demand for product quality, and therefore a more effective design process. In order to remain competitive, new approaches are needed for effective and efficient projects that are able to deal with these changes.

The research project described in this paper was based on the need to *improve the mechanical engineering design process,* i.e. to increase its effectiveness and efficiency. The various means (such as prescriptive models, methods, computer tools) that have become available to improve the design process were investigated[1,2]. The first conclusion was that they have not had the expected impact on the effectiveness and efficiency of the process as a whole. The second conclusion was that a focus on the *design process*, (the activities) rather than on the *product*, (the deliverables), and on *supporting* rather than *automating* design, would be a more promising approach to improve the mechanical engineering design process. This led to a proposal for a computer-based system developed around a process model of design, that would combine the advantages of computer processing with the knowledge and abilities of designers. The underlying hypothesis that; 'the combination of focusing on the design process and computer support will serve the effectiveness and efficiency of the process' is supported by several empirical studies[3,4,5,6].

The development of the system involved five stages[1]: (1) determination of the characteristics of design; (2) specification of the type of support; (3) development of a set of requirements and functions for the system; and, (4) development of the process model and the system, (5) evaluation of the applicability and usefulness of the model.

Characteristics of design

Several descriptive and prescriptive sources were consulted to find characteristics of design that could be of importance for the development and use of the proposed system. *Descriptive* studies of design offer characteristics of design based on observation. Due to the lack of literature on detailed studies in an industrial context, a design process in industry was observed to find additional characteristics. *Prescriptive* literature suggests ways to improve the design process, such as process models or methodologies, and offers a more complete view of the process than descriptive studies. Both sources were consulted to combine the characteristics of effective and efficient processes suggested by prescriptive sources, with the reality of design practice found in descriptive sources.

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The identified characteristics were classified into 3 groups, based on an analysis of existing computer systems and a personal view on computer support in design. Characteristics *to support* are those that were observed (in descriptive studies) or are expected (in prescriptive literature) to have a positive impact on the design process. Characteristics *to prevent* are those that have or are considered to have a negative impact. Characteristics that have *to be taken into account* are those that might have a negative impact but cannot, or only partially, be prevented. This classification provided a first indication of the system requirements. They were translated in more specific requirements by indicating how a process-based support system could contribute, i.e. *how* the system could support, prevent or take these characteristics into account. Based on this final set of requirements the following main functions of the envisaged system were formulated: supporting a methodical design activity; supporting structured documentation and retrieval of process and product data; supporting communication and teamwork; integrating knowledge, methods and tools; and suggesting knowledge, methods and tools relevant for a specific task.

PROSUS, a process-based support system

The requirements and functions led to a support system, named PROSUS, developed around a model of the design process. PROSUS has three levels (see fig. 1): a primary level, a control level and a support level. The matrices are the working areas of the design team.

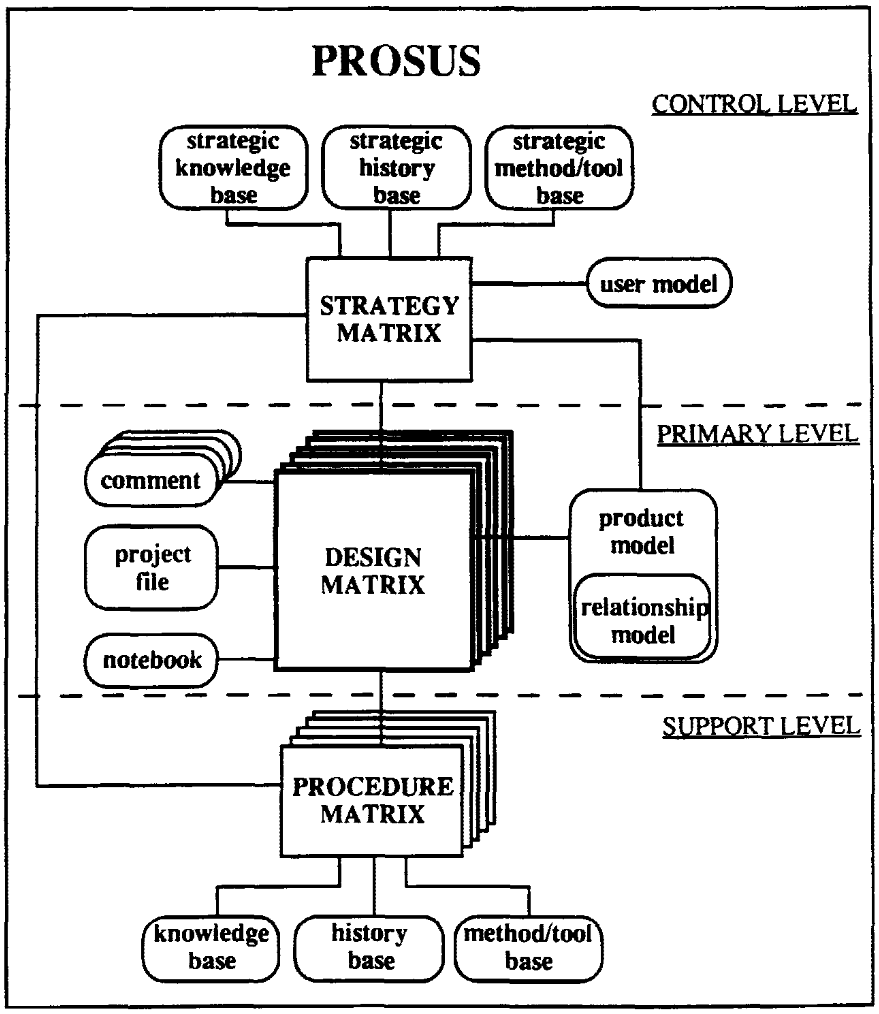

Fig. 1 PROSUS, a process-based support system

The basic building block of PROSUS is the design matrix, which represents the design process as a structured set of issues and activities (fig. 2). This process model does not describe how designers *do* design, nor does it prescribe how they *should* design. It suggests how designers *could* design, by providing a framework for supporting their activities. The design matrix is based on a combination and extension of two models: Methodical Design, a problem-oriented approach to design[7], and the argumentative approach to design proposed by Rittel[8,9].

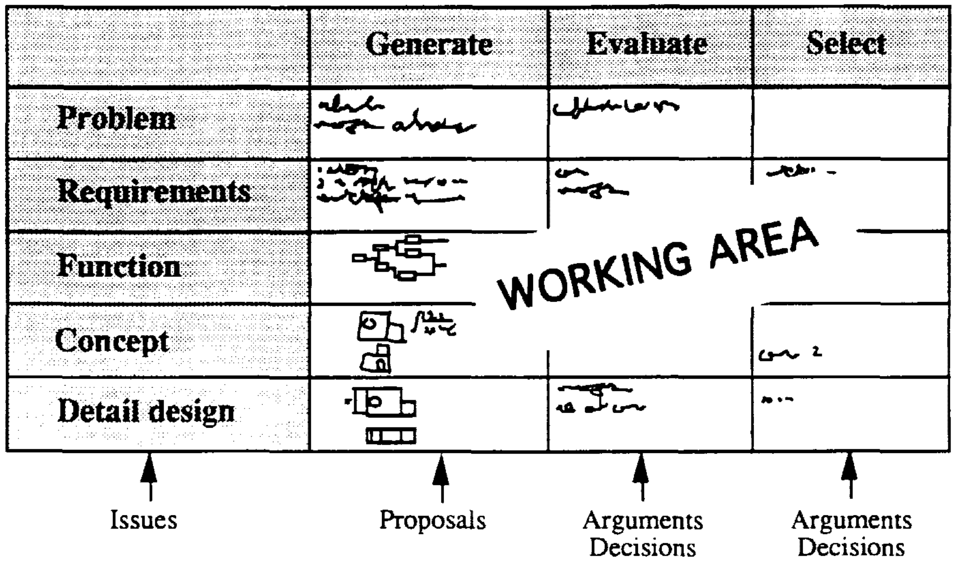

Fig. 2 A design matrix (simplified).

The first column provides the *issues* that are relevant in a design process., They are related to the process stages distinguished in Methodical Design. Issues are solved in three steps: Generate, Evaluate and Select, related to Rittel's approach. Generate results in proposals for the issues concerned. Both Evaluate and Select result in arguments and decisions. They provide the design rationale supporting or opposing a proposal. Evaluate is defined as assessing whether a proposal is promising at all, i.e. could be pursued further, based on a comparison with requirements and other criteria. Select is defined as determining which of the solutions that passed the evaluation is most promising, i.e. should be pursued further.

A design matrix relates to a product, or to one of its assemblies or components. Several matrices are thus used in any one process. Data can be entered in any order; no sequence of addressing cells is prescribed, nor do all cells have to be filled in. A design matrix is, however, more than a structured, passive notebook. The matrix can be used to find knowledge, methods, tools and design histories relevant to the task at hand (the matrix cell). Once completed, a matrix contains a description of the design process of a particular product, assembly or component, providing the rationale that was applied during its creation.

Other elements of the model

The actual *product model* shown in figure 1 is derived from the design matrix. It contains the results of the issues addressed and therefore describes the product, its elements and their relations in terms such as their functions, requirements, and geometry. It extends the official documentation of design projects beyond current practice. *Comments* are remarks, questions or information sent from one project member to another, and related to the contents of one or more cells in the design matrix. Comments enable project members who are not authorized to modify the contents of a specific matrix or cell to react on its contents leading to enhanced communication. Documents such as correspondence, trip reports, management summaries and minutes, that do not relate to a specific product element are stored in the *project file*.

The design matrix does not provide issues related to project member, time and means: "Who solves the issue(s), when and how". This is dealt with in special *procedure matrices*. A procedure matrix links one or more cells of a design matrix with the knowledge base, history base, method and tool base. The history base stores the design matrices, project file and product model of each of previous projects.

A design matrix deals with the different steps in the design process. A procedure matrix deals with the ways to execute a step. A *strategy matrix* deals with the sequence of steps. This matrix aids the designer in finding the current most promising strategy. This interactive process is based on: (1) process status (derived from the design matrices); (2) available resources and means (extracted from the procedure matrices); (3) the product status (stored in the product model); (4) strategic means (in terms of knowledge, methods and history); and (5) a model to tailor strategy proposals to the function of a specific user in the process. The structure of the matrices and their links suggest a default strategy which is based on problem-oriented strategies found in prescriptive literature. A recent empirical study indicates that this type of strategy has a positive effect on the product if applied in a flexible way[4].

Evaluation and conclusions

To evaluate PROSUS, an experiment was executed in which its core, the design matrix, was evaluated against the formulated functions and aims. The experiment compared the design processes and results of designers applying the design matrices with those of designers working without the matrices. The main issues in the evaluation were applicability and usefulness. The findings were considered promising: many typify successful design processes. The designers using design matrices generated more concepts, documented more of their design process including arguments and decisions, assessed their solutions more often and throughout the design process, and were able to apply various approaches. No differences in product quality could be measured, and the design processes of the designers using the matrices lasted longer than the processes of the other designers. Several possible explanations for these two findings were identified that point at the experimental set-up of the evaluation. The overall results of this evaluation, however, were considered to justify further development and implementation of PROSUS. The aim is to have a first prototype available by the end of 1995.

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