Information Management for Integrated Design Environments

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Abstract. This paper identifies requirements for an engineering design information management system. Future CAD systems must support a wide range of activities such as definition, manipulation and analyses of complex product information models. These models represent not only conventional data associated with current CAD applications, but also design information characterizing the correlations between the requirements, functions, behaviors and physical form of the product. Such functionality is important for both the individual designer and the design organization, as the need to manage information as a corporate asset is becoming a critical component of business strategy. This paper explores these needs using two design studies. The first study illustrates some major concepts relative to non-routine design activities, while the second study focuses on the routine design activities relative to organization interactions. These studies were used to elicit high level requirements which serve as the basis for the development of prototype software systems. These prototypes are briefly introduced here.

Keywords. Conceptual design, Design process, Design studies, Engineering information systems, Product data

1. Introduction

Traditionally, documentation of the engineering process has focused on the 'final' product representation to support manufacturing and product serviceability. However, the knowledge associated with the product is usually buried within the product development process and is often not formally captured. Typically, such information is a record of the design process used to create the product: the definition of system level requirements and the setting of targets, mapping system requirements to technological functions, quantifying function to required behavior, designing the physical form and verifying its exhibited behavior. The current emphasis on corporate memory acquisition forces one to consider the information generated during the evolution of the product as an integral part of the product knowledgebase. This is reinforced by the fact that in several industries (nuclear, defense) design information usually outlives the product.

Preserving the knowledge behind a design allows an organization's design process to become more streamlined over time. The data created and the design rationale used by people who are no longer a part of an organization must be available for understanding existing designs and advancing future products. Another equally important consideration is the relationship between a product's design and the organization processes that influence it. Since a complex product is usually a result of a collaborative design process, dependencies arising from such collaborations, and relationships to historical designs must be captured. In this paper, we present design as an information driven process, and identify a comprehensive set of information support capabilities to aid this process. This is based on design studies to understand:

- the interactions between the designer and the design information space (DIS); and
- the interactions between the designer and the design organization

Figure 1 illustrates the evolution of a product starting from the requirements definition stages, through its transformation to functions, associated behaviors, physical implementations of these behaviors, and finally the physical embodiment represented by the physical form and the associated manufacturing process. The boxes shown in Fig. 1 are usually related via many cardinality relationships emphasizing the generative nature of the engineering process that often provides multiple solutions to a problem. Most commercially available
computer aided engineering (CAE) tools tend to address the physical form elaboration, its validation (analysis, simulation), and transition to manufacturing. Product data as modeled by initiatives such as PDES [1] and CALS [2] are currently focused on these stages and usually recognize the existence of applications that service this realm. However, the data associated with the earlier stages of the process are not well formalized. Moreover, there is usually no traceability linking the requirements and conceptual stages of design with the elaboration stages. To fully describe the design information, a more comprehensive view of the design process is needed. The benefits of such an approach are several:

- providing traceability of requirements by understanding the design rationale supporting the product's evolution;
- allowing retrieval and reusability of previous designs on the basis of functional and behavioral information; and
- providing a framework for organizing design data, decisions and rationale that facilitates data sharing and exchange during the design process.

1.1. Background in Design Process Research

Pahl and Beitz [3] categorize design in terms of original, adaptive, and variant design, while Brown and Chandrasekaran [4] classify it in terms of class I, II, III problems. Condoor et al. [5] break up design into original, adaptive, variant, and developmental design. Others [6] offer similar classifications. We have adopted a simple classification in terms of routine and non-routine or creative design. Design process automation has followed prescriptive and descriptive design methodologies. Hubka [7] Pahl and Beitz [3], and other proponents of the prescriptive approach generally argue that the intuitive process of design is best nurtured within the framework of a systematic process. They describe design science as 'a system of logically categorized insights about designing' [7] and have proposed methodologies for doing design. Automation in such cases consists of providing tools to support these methodologies. The descriptive approach, on the other hand, focuses on studies of the design process for the development of cognitive models of the human designer; models that may subsequently help in automating the process of design.

Cross [8] sees design as a technological activity instead of a scientific activity and this is the view we have endorsed in our work. This definition implies that design is naturally explorative and generative, is motivated by solution oriented goals, and often proceeds along ad-hoc lines.

An important property of design information is that it cannot be dissociated from the process used to create this information. Most organizations enforce policies that dictate the evolution path. These policies define how information is to be communicated between groups, how change notices and errors must be handled, how trade-offs must be justified, how product data are managed, how configuration management rules must be applied, etc. At a generic level, the evolution of design information is dependent upon several factors: whether it is a routine or a non-routine design problem, the organizational structure and culture, the type and the size of industry, the complexity of the products generated, the level of expertise and technology involved, etc.

1.2. Focus of Paper

Two facets to the problem of design information management will be discussed in this paper:

- design system capabilities for providing user oriented information representation and manipulation; and
- design system capabilities to provide information access relative to design organizations.

The following sections summarize our findings over a three year period [9–13]. Section 2 of this paper characterizes the cognitive and organizational interactions during the design process by means of a brief literature survey. Section 3 summarizes our observations from the design studies, while Section 4 generalizes these into design system requirements. Section 5 provides an overview of the prototype systems developed to address these needs, and is followed by general conclusions.