

Engineering Design Knowledge Management

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INTRODUCTION

In recent years, greater global competition is pressuring organizations to produce industrial products with the shortest possible lead times, high quality, and lowest costs. The lifecycle of a product includes many phases such as requirement definition, conceptual design, production, operation, maintenance, and so forth. Each phase in the lifecycle would involve the product information, for example, using some information that comes from other phase(s) and generating some new information during the phase. Engineering design knowledge (EDK) of a product consists of the product information related to the design process of the product.

It should be noticed that modern products are complex, and their developments have increasingly become collaborative tasks among teams that are physically, geographically, and temporally separated (Caldwell et al., 2000; Szykman, Sriram, Bochenek, Racz, & Senfaute, 2000). As design becomes increasingly knowledge intensive and collaborative, traditional design databases, which merely provide access to schematics, computer-aided design (CAD) models, and documentation, are inadequate for modern product design (Szykman et al., 2000), and the need for computational design frameworks to support the representation, integration, maintenance, and use of knowledge among distributed designers becomes more critical. The *representation, integration, maintenance, and use* of knowledge consist of the knowledge management of engineering knowledge.

BACKGROUND

Nowadays most engineering design is a knowledge-intensive process undertaken by teams dispersed across multiple disciplines. So it needs to be supported with relevant engineering design knowledge. We call *engineering design knowledge* all the standards, laws, and best practices that need to affect the design decision. Engineering design knowledge attempts to integrate three fundamental facts of artifact representation: the physical layout of the artifact (*structure*), an indication of the artifact's overall effect (*function*), and a causal account of the artifact's operation (*behavior*) (Szykman et al., 2000).

The function-behavior-structure (FBS) engineering design model has been developed in Tomiyama, Umeda, and Yoshikawa (1993) and Tomiyama, Mantyla, and Finger (1995). Based on the model, four categories of design knowledge were basically classified (Li & Zhang, 1999): *artifact functions, artifact behaviors, artifact structures*, and the *causalities* among structures, behaviors, and functions. Function knowledge is about the purpose of an artifact; behavior knowledge is about the changes of states of an artifact; structure knowledge is about a set of components and their relationships; causality knowledge is about design constraints, wishes, physical principles, heuristic rules, and so on.

Corresponding to contemporary engineering design, engineering design knowledge is *structured, distributed, and evolving*. It is generally already formal or can be easily formalized. It essentially consists of sets of constraints with additional references, justifications, illustrations, examples, and other documentation. This knowledge lends itself to a formal, machine-readable representation. Engineering design knowledge is typically distributed because most engineering artifacts involve a variety of domains of expertise (e.g., electrical, mechanical, styling, and manufacturing) and a variety of stakeholders (e.g., manufacturers, suppliers, servicing agents, legislators). The knowledge is distributed in the sense that each area of expertise and each stakeholder authors, publishes, and maintains their own repository. The SAE (Society of Automotive Engineers) handbook and EPA (Environmental Protection Agency) publications, for example, are published and updated independently of each other. Finally, the knowledge is rapidly evolving because it is meant to be a live reflection of the state of the art and the state of the technology relevant to the engineering domain of interest. The knowledge gets updated asynchronously, and the updated information is made immediately available to the user.

Because engineering design knowledge has a large size, rapid pace of growth and evolution, and distributed ownership, it is better managed as an independent resource rather than hard-coded within the CAD systems or their satellite tools. The management of the engineering knowledge entails its modeling (representation), maintenance, integration, and use.

ENGINEERING DESIGN KNOWLEDGE MANAGEMENT

The management of engineering design knowledge entails its modeling (representation), maintenance, integration, and use. Knowledge modeling consists of representing the knowledge in some selected language or notation. Knowledge maintenance encompasses all activities related to the validation, growth, and evolution of the knowledge. Knowledge integration is the synthesis of knowledge from related sources. The use of the knowledge requires bridging the gap between the objectives expressed by the knowledge and the directives needed to support the designer in creating valid engineering artifacts. The management of engineering design knowledge requires an adequate modeling language and an associate inferencing mechanism. So in this short article, we only focus on the modeling of engineering design knowledge.

Knowledge Modeling

Knowledge modeling and the representation of structural information have been prominent issues in artificial intelligence, knowledge representation, and advanced applications of databases. Although the design knowledge representation itself is not a new subject, there is no commonly agreed approach to the problem, and it still represents an active area of research (Vranes & Stanojevic, 1999). A number of solutions have emerged from these domains, and various researchers have developed models that attempt to capture the facts of structure, function, and behavior (Gorti, Gupta, Kim, Sriram, & Wong, 1998; Vranes & Stanojevic, 1999).

An integrated artifact metamodel was developed in BEST's knowledge representation language, Prolog/Rex (Vranes & Stanojevic, 1999). The Prolog/Rex concepts were used to define generic classes and describe the workpiece, which are instances of generic classes; Prolog/Rex relations were used to describe the relationships between the concepts. Then the knowledge used in the design process was divided into declarative and procedural knowledge. Similarly, in Gorti et al. (1998), an object model was developed which formed the basis of the design knowledge representation. Their model consists of objects, relationships among objects, and classes (object class and relationship class). An object-oriented model has been developed and applied for design knowledge modeling (Mili et al., 2001; Ma & Mili, 2003).

Class with Constraints

Knowledge units were basically constraints (Mili et al., 2001). Constraints are always associated with engineer-

ing artifacts, modeled by classes. Instances of a given class are created and modified through the direct setting and update of their parameters. These parameters, because they are the subjects of direct decisions, are called decision parameters. Most constraints on a class do not constrain directly the decision parameters. They generally refer to more complex and more abstract parameters, called performance parameters. This leads to the modeling of a class using the UML notation in which we represent four compartments: The class name in the top compartment identifies the concept of interest. The bottom compartment contains (a reference to) the constraints that class instances are bound by. These constraints typically refer to parameters of the concept. Some of these parameters are attributes directly set by the designer. They are listed under the second compartment. Most of the parameters referred to in the constraints are measures of "performance" of the class. They are not direct decision parameters, but are functions of some decision parameters. The performance parameters are included in the third compartment along with their expression in terms of decision parameters. The decision parameters used are added to the second compartment.

For example, a door panel may be represented as follows:

Door Panel

Decision parameters

length: Real
width: Real
contour: Curve

Performance parameters

top to bottom curvature = curvature
Function (length, contour),
corner angles = corners
Function (contour)

Design constraints

constraint on top to bottom curvature
constraint on corner angles

Constraints

The most interesting elements in this model are the constraints themselves. In fact, we refer to them as constraints even though they are generally complex documents encompassing source, motivation, rationale, consequences, and a log of the various changes and updates they have undergone. Because of this existing and potential complexity, the constraints are represented within their own class. A number of attributes are used to describe the constraints. These attributes can be very useful when it comes to assessing the authority and criticality of a given constraint. For example, a constraint of type standard authored by a trusted authority from the

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