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# A concurrent engineering-oriented design database representation model

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**Abstract**

A concurrent engineering-oriented design database representation model (CE-DDRM) is introduced in this research for supporting various life-cycle aspects in concurrent design. In this model, concepts and behaviors of different design database modeling components, including entities, properties, relationships, tasks, and specifications, are defined at meta-class level. Design database is modeled at two different levels, class level and instance level, representing generic design libraries and special design cases, respectively. A Web-based system architecture is proposed to model distributed design database and allow team-members for different product development life-cycle aspects at different locations to access the design database. This newly introduced approach provides the foundation for developing the next generation CAD systems with concurrent engineering functions.


*Keywords:* Design database; Concurrent engineering; Distributed system

## 1. Introduction

### 1.1. Research background

With advances of computer technologies, many product development life-cycle processes have been automated by the introduction of computer-based systems, such as Computer-Aided Design (CAD), Computer-Aided Process Planning (CAPP), Computer-Aided Manufacturing (CAM), and so on [1]. Many computer-based concurrent engineering design systems have been developed to further improve design quality by considering down-stream product development life-cycle aspects, such as manufacturing, assembly, maintenance, recycle/disposal, etc. at the early design stage [2]. Many distributed systems have also been developed to support product development life-cycle activities conducted at different locations and associate these distributed activities into an integrated environment using multi-agent and Web technologies [3].

Despite the progress, most of the currently developed systems focus on modeling and manipulation of geometric information, such as solid modeling, CNC machining path generation, rapid prototyping, reverse engineering, and so on. Modeling of non-geometric design information, such as design requirements, conceptual design candidates and other product development life-cycle considerations, is not well understood and studied for developing these computer-based systems. Therefore, the computer-based systems that support the entire product development life-cycle, especially the processes at the early conceptual design stage, have to be introduced.

The research to develop systematic approaches to support conceptual design was initiated from the work on design theory and methodology in the 1970s [4]. Since then, many methods have been introduced to model the conceptual design. These approaches include Yoshikawa's General Design Theory (GDT) to map from functional space to attribute space [5], Tomiyama's Extended GDT to accomplish the mapping process through a sequence of meta-models [6], Suh's Axiomatic Design method to maintain the independence of functional requirements and the minimum of information contents [7], Design-for-X approaches to provide design guidelines considering down-stream product development life-cycle aspects [8], and so on. With the advances of computer technologies, especially in Artificial Intelligence (AI), development of intelligent CAD systems was started in the 1980s to support automated conceptual design [9–11].

Among all the conceptual design approaches, modeling of design functions, behaviors, and forms (also called

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structures) has attracted attention of many researchers since the 1980s [12,13]. In recent years, many languages and systems have also been developed for modeling the functions, behaviors, and forms in product design [14–17].

### *1.2. Previous research on design knowledge modeling conducted at the NIST and the University of Calgary*

#### *1.2.1. Design repository modeling project at the NIST*

The Design Repository Project at the National Institute of Standards and Technology (NIST) was initiated in 1996 to model design knowledge using the Function–Behavior–Form database structure for the CONcept GENeration (CONGEN) Project, which aimed at supporting partially automated engineering design [16]. The design repository modeling system was later on improved as a Web-based system that can be accessed through Web browsers [17–19]. Design functions and taxonomy of these functions in modeling design repository were subsequently studied [20]. The design functions were then modeled using eXtensible Markup Language (XML) as a mechanism of knowledge exchange [21]. The design repository model was integrated with other product models developed at the NIST as a Core Product Model in 2001 [22,23]. Two case studies were conducted to model two types of artifacts, an Artifact Transport System and Charters of Freedom Encasements which were developed at the NIST, using the design repository modeling system [24,25].

#### *1.2.2. Design database modeling project at the University of Calgary*

At the University of Calgary, a design database modeling system was developed for supporting concurrent design [26–30]. In this system, the product design life-cycle database is modeled by primitives called features, such as design features and manufacturing features [26,27]. A feature is described by composing features, attributes, qualitative relations among features, quantitative relations among attributes, and geometry. This system was improved as a distributed system by modeling databases at different locations and associating these distributed databases through Internet [28,29]. To allow users to access the distributed system anywhere in the world, the distributed system was further developed as a Web-based system [30]. A multi-level optimization method was introduced to identify the optimal design configuration and its parameter values considering production costs [31].

The objective of this research is to introduce a new database representation model for concurrent engineering design by incorporating the Function–Behavior–Form based design modeling approach introduced in the NIST Design Repository Project and the concurrent engineering based design modeling approach introduced in the University of Calgary Design Database Modeling Project.

## 2. Overview of the concurrent engineering-oriented design database representation model (CE-DDRM)

### *2.1. Requirements for developing the CE-DDRM*

Requirements for developing the CE-DDRM were achieved through extensive studies on commercial computer-based design tools, research prototype systems, and industrial design activities. The major requirements are summarized as follows.

(1) *The model should describe both geometric information and non-geometric information*. Because the methods of developing geometric modeling-oriented computer-based design systems have been widely established and recognized, the CE-DDRM has to support the geometric modeling functions. Modeling of the non-geometric information, however, also plays an important role in different product development life-cycle phases, especially at the early conceptual design stage. Therefore, modeling of non-geometric information and integration of the geometric information and the non-geometric information have to be considered.

(2) *The model should incorporate the results achieved in the research on design theory and methodology to develop tools for supporting design engineers*. Presently the research on design theory and methodology primarily focuses on identifying the behaviors of design activities. Although some algorithms and systems have been developed, their effectiveness for supporting design engineers to improve design quality and efficiency is not well demonstrated. Therefore, formulation of design as a computable model based on the research results in design theory and methodology is required.

(3) *The model should be developed based upon the advances of recent computing technologies*. Many new computing technologies have been developed in the past decade for developing application systems. The object-oriented programming approach can improve the modularity and reusability of computer programs. The distributed object modeling methods allow the programs distributed at different locations to be integrated into the same environment. The multi-agent distributed system modeling methods are used for communication and collaboration among systems located at different locations. These new computing technologies should be considered in developing the CE-DDRM.

### *2.2. Architecture of the concurrent engineering-oriented design database modeling system*

Architecture of the concurrent engineering-oriented design database modeling system is shown in Fig. 1. In this system, the design database is described at two different