Standards for Collaborative Product Development

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Abstract

We are currently witnessing the emergence of an Internet-based engineering marketplace, where engineers, designers, and manufacturers from small and large companies are collaborating through the Internet to participate in RFQs (requests for quotes), create supply chains, and form virtual enterprises to more efficiently satisfy customer needs. The next generation manufacturing environment will consist of a network of engineering applications, where state of the art multimedia tools and techniques will enhance closer collaboration between geographically distributed applications, virtual reality tools will allow visualization and simulation in a synthetic environment, and information exchange standards will facilitate seamless interoperation of heterogeneous applications. In this paper, we discuss the role of standards in the "Internet-based web-enabled knowledge-intensive and seamlessly integrated distributed collaborative design" vision. The paper will discuss various kinds of standards for interoperability among traditional, knowledge-based, and immersive CAD (Computer-Aided Design) systems. Current standards, such as STEP (Standard for the Exchange of Product model data) developed by the International Organization for Standardization (ISO) TC 184/SC4, and future knowledge-based standards for the capture, exchange, retrieval and reuse of engineering product development data and knowledge will be discussed.

1 Introduction

Design of complex engineering systems is increasingly becoming a collaborative task among designers or design teams that are physically, geographically, and temporally distributed. The complexity of modern products means that a single designer or design team can no longer manage the complete product development effort. Developing products without sufficient expertise in a broad set of disciplines can result in extended product development cycles, higher development costs, and quality problems. On the other hand, ensuring comprehensive technical proficiency in a world where trends are toward more multidisciplinary design can become a costly undertaking for a company.

Driven by such issues, companies are increasingly staffing only their core competencies in-house and depending on other firms to provide the complementary design knowledge and design effort needed for a complete product. Designers are no longer merely exchanging geometric data, but more general knowledge about design and the product development process, including specifications, design rules, constraints, and rationale. Furthermore, this exchange of knowledge more and more often crosses corporate boundaries. As design becomes increasingly knowledge-intensive and collaborative, the need for computational frameworks to support a collaborative product development environment becomes more critical. There are several research and development issues that need to be addressed for the realization of such a collaborative design environment. Standards are very important for integrating various heterogeneous applications in this environment. The focus of this paper is on current and emerging standards.

Paper organization. In the next section (section 2), we present a likely scenario for collaborative engineering. In this scenario we envision several categories of computer-aided design/computer-aided engineering (CAD/CAE) applications interacting with each other. We discuss these categories in Section 3. Section 4 outlines the interface specifications relevant for seamless interoperability among various applications. We explore the role of design repositories in collaborative design, including the need for standard representations, in Section 5. Section 6 briefly touches upon product data modelers. Finally (in Section 7), we provide a brief summary of several ongoing research activities at NIST.

1 Keynote Lecture, 8TH ISPE INTERNATIONAL CONFERENCE ON CONCURRENT ENGINEERING: RESEARCH AND APPLICATIONS West Coast Anaheim Hotel, California, USA, July 28 - August 1, 2001
2 A Collaborative Design Framework

Recent trends in computing environments and engineering methodologies indicate that the future engineering infrastructure will be distributed and collaborative, where designers, process planners, manufacturers, clients, and other related domain personnel communicate and coordinate using a global web-like network. The designers may be using heterogeneous systems, data structures, or information models, whose form and content may not be the same across all disciplines. Hence, appropriate standard exchange mechanisms are needed for realizing the full potential of sharing information models. The various applications are coordinated by a work flow management system using a product realization process (PRP); the work flow management system acts as a project manager. They are connected to one another by a design net, which provides the infrastructure for high bandwidth communications. These applications retrieve design data and knowledge from distributed design repositories and the evolving design (or designs) is stored in a database. This database provides various snapshots of the evolving design, with design artifacts and associated design rationale stored at various levels of abstraction. Finally, design applications communicate with other manufacturing applications through various nets, such as production, process planning, and user networks (see Figure 1).

3 Computer-Aided Design (CAD) Application Categories

To successfully implement a computer-supported collaborative design environment, we need to address four areas: 1) applications; 2) standards; 3) infrastructure; and 4) organization. The primary emphasis in this paper will be on interoperability standards between CAD applications and interface standards between applications and design repositories. We set the stage for the discussion of various CAD applications by enumerating the various design phases, taken from Barkmeyer, E. (editor), SIMA Reference Architecture Part 1: Activity Models, NISTIR 5939, National Institute of Standards and Technology, December 1996.

1: Plan Products

Depending on (potential) market needs and customer requirements, develop the idea for a product and characterize it in terms of function, target price range and relationship to existing products of the manufacturing firm. Define cost constraints, performance constraints and other marketability factors. Perform market analysis and cost-benefit analysis. Develop product development and marketing plans.
2: Generate Product Specifications

From the conceptual product specification, formulate an engineering specification for the product. This involves mapping the customer requirements into engineering requirements, and refining the engineering requirements in consideration of the relevant laws, regulations, product standards, etc., and also of the existing patents in the same area. This process may involve determination of the relationship of the new product to the firm's library of existing product designs.

3: Perform Preliminary Design

Decompose the design problem into a set of component design problems and develop the specifications for each component problem. Define the integration of the components into a product and develop a preliminary layout model. This process will be somewhat iterative, as the early phases of the component design will generate new considerations and changes. Primary results are the product layout drawing and annotations and the component design specifications.

4: Produce Detailed Designs

For each subsystem (or component) that is not off-the-shelf (or identical to an existing in-house design), and for the component integration, produce all specifications needed to completely describe the subsystem for manufacture. This includes drawings and geometry, materials, finish requirements, fit requirements and assembly drawings, tolerances, and other relevant information.

CAD applications supporting design, particularly the third and fourth phases listed above, can be categorized into three types -- traditional, knowledge-based, and immersive.

Traditional CAD systems evolved out of an attempt to provide better drafting aids. In these systems, the designer uses a computer to develop either 2D or 3D models of the design. Traditional CAD systems (such as Pro/Engineer) provide comprehensive tools for generating geometric forms, which encourages designers come up with a form first and think about function later (i.e., form-to-function transformation). However, this approach can result in non-optimal and non-competitive designs. Closely related to traditional CAD systems are traditional computer-aided engineering (CAE) packages which primarily focus on analysis, in particular finite element analysis.

Tools for helping a designer think in terms of function need to be developed; form should subsequently result from function (i.e., function-to-form transformation). Knowledge-based design systems implement this paradigm by first focusing on the symbolic aspects of design and later mapping the symbolic structure to a geometric model. They can also capture the various semantic relationships between design objects. Essentially, knowledge-based systems use techniques developed by artificial intelligence researchers to capture the knowledge of expert designers in a computer.

In immersive CAD applications, the human being becomes part of the design by using various immersive environments, including haptic, visual, and speech interfaces. Immersive CAD systems can aid in evaluating manufacturability of designs.

In summary, traditional CAD systems require the designer to completely specify all geometric details, while knowledge-based systems aid in the design generation, and immersive environments allow a designer to interact with and become immersed in the CAD world. With regard to the SIMA design activity model (see Barkmeyer’s report), traditional CAD systems and associated analysis programs (typically called computer-aided engineering or CAE) are used in the detailed design phase, knowledge-based CAD systems primarily assist in the preliminary design phase, and immersive CAD systems can aid in both preliminary and detailed design phases.

4 Standards

CAD applications generally do not use the same format for data input and output. For example, Boeing's customers require that it use engines from different manufacturers, such as GE, Pratt and Whitney, and Rolls Royce. Boeing uses CATIA as the CAD tool, while the suppliers use different CAD systems. Each of these systems has its own unique data format and interoperability is a major concern.

We illustrate the interoperability issue by considering a potential information exchange scenario during the design of the Boeing 777. For Boeing to incorporate Rolls Royce engines into the design, the data format has to be

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2 The design and manufacture of Boeing 777 is well documented in the Public Broadcasting Service’s Twenty-First Century Jet: Video and Book Collection, Item Number: C2375-WEBHV.
converted from Computer Vision’s CADDs (used by Rolls Royce) to Dassault’s CATIA. Similarly, for Rolls Royce to understand changes made by Boeing engineers, the data need to be converted from CATIA to CADDs. Hence, we need at least 2 translators. For three systems this grows to 6 translators and for n systems we need n(n-1) translators. A solution to this problem is to use a neutral format and make all the CAD applications to output into this format. Doing so will reduce the number of translators to 2*n, i.e., for each CAD system we will need two translators — one from the CAD system to the neutral format and the other from the neutral format to the CAD.

A standard of primary interest to design is ISO 10303, also known as informally as STEP (Standard for the Exchange of Product model data) and developed by the International Organization for Standardization (ISO) TC 184/SC4. Its intention is to enable the exchange of product model data between different modules of a product realization system, or the sharing of that data by different modules through the use of a common database. The first parts of STEP to achieve International Standard status were published in 1994, but many other parts have since been published or are under development and will eventually be added to the standard. Recent updates (and other relevant details) can be found at the following website: http://www.nist.gov/sc4.

ISO 10303 (STEP) can be viewed as consisting of several layers. The top layer consists of a set of applications protocols or APs, which address specific product classes and life-cycle stages (e.g., mechanical, electronic, ships, automotive, design, process planning). These application protocols specify the actual data exchange standards and are given the 200 series of numbers. The APs are constructed from a set of modules called integrated resources, which are common for all disciplines. Integrated resources are given the 40 series and the 100 series. The actual transfer of data is achieved in several ways, described by Parts 21 through 26. The language for modeling various STEP entities and their relationships is called EXPRESS. The testing methodology and various test suites comprise the conformance testing methodology framework, which are given the 30 and 300 series numbers, respectively.

The STEP AP most relevant to traditional CAD systems is called AP 203 and is entitled “Configuration Controlled 3D Designs of Mechanical Parts and Assemblies.” This protocol defines the data exchange of geometric entities and configuration control of products. AP 203 defines several levels of implementation — called conformance classes — which deal with increasing levels of sophistication. The original proposal had six conformance classes. A recent update splits each of the conformance classes into two (i.e., a and b), and hence there are 12 conformance classes. CAD vendors who are STEP-compliant, are required to indicate the classes to which they comply. For example, a CAD vendor — selling CADx — may claim that CADx conforms to Class 6, which means it can deal with advanced BREPS (Boundary Representation).

However, the current emphasis of STEP AP 203 is on shape description plus product configuration data. Facilities have been provided for capturing, in standard format, the following representations: 2D drawings, 3D wireframes, surface models, and solid models. This reflects the state of CAD technology as it was when the STEP development effort commenced in the mid-1980s. However, CAD technology has progressed since that time, and most major CAD systems now provide facilities for parametric, variational (including constraints), and/or feature-based design. In addition, many of these systems have facilities to record design histories. These systems generate additional information, beyond the pure shape descriptions created by older systems, and STEP currently provides no means for capturing and transmitting this additional information. The short term parametrics effort (which comes under Working Group 12 of ISO TC 184/SC4) is addressing this problem.

There is another STEP application protocol — Composite and Metallic Structural Analysis and Related Design (AP 209) — that deals with the data exchange between traditional CAD systems and analysis (such as finite element) applications. AP 209 is aimed at integrating finite element analysis programs with design. In addition to product design and configuration data (which is the scope of AP 203), AP 209 includes finite element (FE) data including meshing analysis controls, static stress analysis results and can deal with polymers and composite structures. AP 209 has recently been approved for publication as part of the international standard.

Below, we summarize the various protocols involved in the interoperability between various types of CAD systems and between CAD systems and manufacturing software. Figure 2 shows a schematic view of various interactions, where all communication is routed through two types of information bases: one local to the design applications, and the other acts as an interface between design and manufacturing applications. Also note that the arrows in the figure indicate a two-way communication between various applications.

*Between traditional CAD systems.* The various extensions that could be used with AP 203 would include exchange of feature, constraint, parameterization, and design history information.
Between CAD systems and analysis packages. This would involve a mapping from CAD data to a neutral representation for input to an appropriate analysis package.

Between knowledge-based design systems and traditional CAD systems. Knowledge-based design tools concentrate on the generation of a symbolic structure, using various types of objects and relationships. Any mapping between knowledge-based design and traditional CAD tools should support various aspects of product representation, including form, function, behavior, and design rationale.

Between traditional CAD and immersive CAD systems. Immersive CAD systems generate certain process constraints, such as trajectory and assembly mating constraints. The interface between immersive CAD and traditional CAD systems requires extensions to appropriate STEP standards, such as Part 42 (Geometric and topological representation), Part 44 (Product structure configuration), and AP 203.

The above protocols address intra-design interoperability. Research on the interfaces between design and manufacturing (i.e., inter application interoperability) could include the following:

Solid interchange format for Layered Manufacturing (SIF-LM). This task involves the use of STEP’s generic resources for the development of a standard for the exchange of CAD data with Rapid Prototyping systems, developed for producing physical structures in layers (e.g., 3D Printing).

Between CAD systems and assembly planning systems. This task involves the development of exchange standards for data interchange between traditional CAD systems, immersive CAD systems, and assembly process planning; for clarity’s sake we show only the interface between traditional CAD and assembly planning. Representative data would include the creation of trajectory, component orientation information (process data), swept volumes, and assembly sequencing data that can be merged with part representation.

Between CAD and process planning/manufacturing systems. Considerable research has been performed on mapping traditional CAD data on to process planning systems. However, this work has met with limited success. One problem with the current standards is the lack of integration between CAD data output and process planning input. For example, the primary focus of STEP AP 203 is the interoperability between traditional CAD systems, while the focus of STEP AP 224 (Mechanical product definition for process plans using machining features) has been on input to process planning systems. To achieve truly collaborative design and engineering, exchange representations of both design and process information must support multiple levels of abstraction.

Figure 2: Interfaces between various CAD systems and between CAD and manufacturing software

5 Design Repositories

During the design process, engineers require access to various kinds of design information. Merely providing access to schematics and CAD models of artifacts is inadequate for this purpose. In order to support reuse of engineering knowledge, a representation must convey additional information that answers not only “what?” questions about a design, but also “how?” and “why?” questions. The emerging research area of design repositories is aimed at addressing these industry needs. Design repositories make use of research in knowledge-based design to facilitate the representation, capture, sharing, and reuse (search and retrieval) of corporate design knowledge. It should be noted that although the term design repositories has not yet found its way into daily usage in industry, many companies are migrating from traditional design databases to design repositories.
While companies may still be referring to their corporate knowledge stores as design databases, in many cases these stores would fall under the definition of design repositories as characterized in this paper. Although design repositories can in general terms be thought of as design databases, and indeed will most often be implemented using database management systems, design repositories are distinguished from traditional design databases in several significant ways:

- Traditional design databases are typically more data-centric than knowledge-centric, and contain only a limited representation of an artifact such as drawings and/or CAD models, version information, and often related documentation. Design repositories attempt to capture a more complete design representation that may include characterization of function, behavior, design rules, simulation models, and so on. It should be noted, however, that a fully comprehensive representation of every aspect of a design may simply not be possible.

- Design databases are generally more homogeneous in the kinds of information they contain. In addition to containing images (drawings), file pointers (to CAD models), and unstructured text (documentation), design repositories may contain formal data/information models, structured text (specialized languages for representing function, design rules, logical expressions), mathematical simulation models, animations, video, and other types of information.

- Design databases tend to be static sources of information (though their contents may grow with time). While they are used for storage and retrieval of design data, capabilities for supporting the design process are not built into traditional database systems. Such capabilities might include search for components/assemblies that satisfy required functions, explicit representation of physical and functional decompositions and the mappings between them, simulation of behavior and performance, (partially) automated reasoning about a design, and more. Since design databases have not been designed specifically for these purposes, they are limited in their ability to meet needs for design of large-scale engineering systems.

The design repositories of the future would provide, in addition to catalog data, will also provide images, various information models (including knowledge structures, analysis and design theories,) application notes, and active models. For example, if we were to find out the behavior of a motor, i.e., speed vs torque characteristics, we could simulate it in the computer instead of physically conducting various experiments. Hence interface standards are required for representing form, function and behavior of artifacts.

6 Design Evolution Databases

Product Data Managers (PDMs) are normally used as design evolution databases. Object Management Group’s (OMG) PDM Enablers specifications document, located at http://www.omg.org/arch2/mfg/98-02-02.pdf, provides various object models required to interface with commercial PDMs.

7 Current Research Activities at NIST

In this section, we provide brief summaries of several projects of the Product Engineering Program, which Sriram leads at NIST. These projects address the issues described in Sections 4 and 5. Our overall goal is to help the discrete-part manufacturing industry achieve a 10% reduction in interoperability costs and a ten fold improvement in design exploration capability and product quality, by developing open information protocols for interoperability and knowledge representation schemes for computer-aided design systems, thereby making system integration less of a customized undertaking. Although the primary outcome is a set of interface specifications and representations, we hope that these specifications and representations will facilitate the development of interoperability standards.

7.1 Short Term Parametrics

The CAD data exchange standard ISO 10303 (STEP) lacks the ability to transfer design intent in the form of parametrization and constraint data. This means that CAD models as currently transferred by STEP convey no information regarding what are and are not permissible modifications in the receiving system. The absence of this information makes it hard to edit models for the purpose of design optimization or in response to feedback from downstream processes such as manufacturing. Much time is wasted in industry in trying to reconstruct lost design intent information following current STEP model transfers. The objectives are to provide extensions to the STEP standard as it currently exists. Two different approaches are being taken to cover the methods used internally by different CAD systems for the capture of design intent:
8 Approach 1 works by associating additional information with elements of the types of CAD models that STEP currently transfers. This requires the development of a new ISO 10303 Integrated Resource.

9 Approach 2 uses an entirely different method of representing CAD models, not currently used by STEP, but permitting much greater representational power for the future. In this approach a model is represented in terms of the sequence of constructional operations used to build it rather than, as at present, the end result of that process. New ISO 10303 resources for this purpose cannot be built upon existing resources in the standard, since no suitable ones exist.

The ISO TC184/SC4 Parametrics Group, led by one of us, is tackling the development of the required new resources for both approaches. Progress is measurable against the ISO document development process. New parts of the STEP standard have to go through the phases Preliminary Work Item (PWI), New Work Item (NWI), Working Draft (WD), Committee Draft (CD) and Draft International Standard (DIS) before reaching the International Standard (IS) status.

Approach 1 is now at the NWI stage, and a complete Working Draft of the new resource is almost complete. It is intended to have a Committee Draft ready for the ISO voting process before the end of 1999. The aim is to progress this resource to IS status before the end of 2001. Approach 2 is at the PWI stage. The requirements analysis is complete, and decisions are now being taken on the best way to formulate the new resource documents. The aim here is IS status by the end of 2002.

7.2 Design Analysis Integration (DAI)

In today’s product design process, there is a significant gap between computer-aided design (CAD) and computer-aided engineering (CAE). Typically, the form of the artifact is determined first, down to the minutest geometric feature, using highly sophisticated CAD tools. Only after this step has been accomplished is the behavior of the artifact evaluated, using equally sophisticated CAE tools but requiring major manual effort to generate the analysis model, primarily finite element analysis (FEA) methods. If the observed behavior revealed by analysis deviates significantly from the intended behavior specified by the artifact’s functional requirements, a redesign cycle needs to be initiated. Because of the increased costs and product delivery times involved in such iterations, organizations try to avoid them, typically by designing very conservatively, with very high safety factors, to ensure that the “downstream” CAE activities do not reveal any design inadequacies. In some organizations, designs go to the shop floor for manufacturing at the same time that they go to the CAE group for design verification. The inefficiencies resulting from this approach, in terms of increased material and labor usage, weight of the artifact, energy consumption in manufacturing and use, disposal costs, etc., have not been quantified but are significant. There is, therefore, a major need to improve or “streamline” the design-analysis interface. This project addresses several issues that will result in proper design-analysis associativity, that is, the representation of how the CAE model is related to the CAD model. In doing so, we also wish to define features, or general characteristics of features, that can be proven not to be relevant for analysis and the accuracy of analysis results. If such a list of features can be generated, two modes of CAD-CAE interaction will be possible: (a) in the current, sequential design-analyze mode, the features on the list could be automatically stripped prior to analysis (and the results possibly automatically adjusted for their presence); or (b) in an interactive partial design-analyze-expand design mode, designers could be encouraged to complete the primary geometric design before they add to it any feature on the list.

7.3 Knowledge-Based Systems Interoperability (KBSI)

Recent reports by Forrester Research³ indicate that 40% of information technology budgets ($82 billion in 1998) is spent on application integration. In a manufacturing sector example, according to a 1999 Research Triangle Institute report⁴, imperfect interoperability imposes at least $1 billion annually on the members of the US automotive supply chain. Beyond that, the National Research Council⁵ has identified a major research challenge in embedding knowledge into design and manufacturing applications. Efforts such as STEP have focused on standardizing the exchange of data; however, few efforts have revealed attempts to describe more abstract, knowledge-intensive engineering information. As a result of the confluence of these events, there is both a problem in developing and an opportunity to develop testable knowledge exchange mechanisms (KEMs), where agents - both human and computer - can exchange specific design and manufacturing knowledge in a meaningful way. The technical approach in this work is to develop a

³ See, for example, http://www.openapplications.org/interop/index.html.
knowledge representation that addresses potential interoperability barriers associated with this vision. Specifically, the technical requirements that have been developed are for a formal representation (that includes form, function, behavior, design rationale, and other information) that is not tied to a single vendor software solution, is open and non-proprietary, is simple and generic, is not tied to any one product development process, and captures knowledge most commonly used in product development activities. Achieving the project objectives involves several efforts, including modeling the flow of information through the product development process, information modeling and schema development for product development knowledge, and mapping of generic schemata into implementable formats (such as XML or relational object models).

7.4 Traditional CAD to Immersive CAD Interfaces and Standards (IMCAD):

The emergence of new design support systems has introduced significant interoperability issues as these evolving, innovative systems are not tightly coupled with current CAD applications. Although eventually immersive functionality will be incorporated directly into CAD systems, for the foreseeable future virtual reality systems are being utilized to obtain these capabilities. Virtual reality (VR) technologies seems to be a natural extension to the current CAD systems yet each of these systems use very different methods to visualize and manipulate the underlying product model. This results in data and information that can not be shared easily or reliably with other engineering and manufacturing systems. This incompatibility is further highlighted when engineers, working with the product model in an immersive system, generate valued information that assists in defining assembly processes or results in desired modifications to the product model. At present, this valued information has to be exchanged manually or through some ad hoc method that is typically labor intensive and error prone. In addition to these concerns, successful application of immersive tools and technologies in industry that demonstrate significant economic impact can be shown is lacking. Until these barriers are addressed and solved there is little likelihood that industry will accept these tools. The technical approach in developing improved interfaces between traditional CAD and Immersive CAD is to extend current standards and leverage existing representations where appropriate. The goal is to validate the resulting interfaces by establishing a close working relationship with an industry consortium.

Tolerance design is the process of deriving a description of geometric tolerance specification for a product from a set of specifications on the desired properties (performance) of the electro-mechanical assemblies. Existing approaches require detailed knowledge of geometry of assemblies and are mostly applicable during the advanced stages of design, leading to a less than optimal design process. Significant gains can be achieved by effectively using evolving assembly and tolerance information to influence the design of an assembly. In order to carry out early tolerance synthesis and analysis in the conceptual stages of the product design, we need to devise techniques for representing function-behavior-assembly models that allow the tolerance analysis and synthesis, even with the incomplete data set. The primary goals of this project are as follows. The first goal is to advance tolerancing decisions to the earliest possible stages of design. The second goal addresses the appropriate synergistic use of available methods and best practices for tolerance analysis and synthesis, at successive stages of design. Pursuit of these goals will lead to a definition of a multi-level approach called design for tolerancing (DFT) that will enable tolerancing to be addressed for the entire design life. Finally, we intend to develop an integrated, comprehensive, and neutral object architecture for function-assembly-behavior model.

7.6 Solid Interchange Format for Layered Manufacturing/Rapid Prototyping (SIF-LM)

Rapid Prototyping (RP) is emerging as an important manufacturing technology. The current data interface to most commercial RP systems is through the STL (stereolithography) de facto industry standard data format. There are several disadvantages of the STL format, including redundant data within the file, little product intelligence (e.g., no knowledge of geometrical features, part surfaces, or topology), large file size for complex parts, no accommodation for multiple materials, colors, or material properties, no mechanism to apply tighter tolerances at critical part features, and lack of a true geometrical part representation. Hence, there is a need for a new CAD-RP interchange format that addresses above issues. The goal of this project is to improve current data transfer capabilities from computer-aided design (CAD) systems to rapid prototyping (RP) systems, in particular for layered manufacturing, through development of a proposed alternative to the existing CAD-RP interface.

7.7 Design and Process Planning Integration (DPPI)
In current industrial practice, conceptual design, process/resource selection, time/cost estimation, detailed design, and process planning are performed independently, without integrated software tools. This is primarily because conceptual design systems, detailed design systems, cost estimating systems, and process planning systems are not designed for interoperability. Design and manufacturing data and messages cannot be efficiently sent from one system to another. Due to this information barrier between design and manufacturing systems, errors made during the early stages of design cannot be timely discovered and tend to exponentially contribute to the cost of the final product. For example, an error that costs a thousand dollars to fix in the early design stage may require nearly a million dollars to rectify in the production stage. Hence, there is a need for developing an infrastructure and associated protocols for integrating design and manufacturing information throughout the design-manufacturing life cycle. The long-term goal is to develop systems interface specifications for integrating design and manufacturing throughout the entire product development cycle. The short-term goal is to develop specifications and prototype systems to enable manufacturability analysis in conceptual product design.

7.8 The NIST Design Repository (DR)

While advances in the area the area of Internet computing have improved the means for sharing and exchanging information, the more significant barrier to product development is not the problem of providing distributed access to distributed information, but of finding the information that’s needed. The need for rapid retrieval and subsequent reuse of knowledge, driven by pressure to reduce product development times in industry, has resulted in an increased focus on methods for representing and storing engineering artifact knowledge. Traditional design databases, which merely provide access to schematics, computer-aided design (CAD) models, and documentation, are inadequate for this purpose. The emerging research area of design repositories is aimed at addressing these industry needs. The overall goal of this project is to develop an information modeling framework to support the creation of design repositories, the next generation of design database. This project is driven by industry needs for technology to support the increasing role of knowledge-based design, including the representation, capture, sharing, and reuse of corporate design knowledge. We are currently implementing a prototype design repository tool that aids in editing and creating design artifact knowledge. This tool suite consists of web-based interfaces, a client/server-based architecture, and example design repositories to demonstrate the functionality and utility of the design repository concept.

8 Acknowledgments

In this paper we have described a framework for a web-enabled collaborative design environment. To successfully implement such a web-enabled collaborative design environment, we need to address four areas: 1) applications; 2) standards; 3) infrastructure; and 4) organization. The primary emphasis in this paper was on interoperability standards between CAD applications and interface standards between applications and design repositories. We described several on going standards related research in our Product Engineering program. Current funding for our work is provided by NIST’s SIMA program, managed by James Fowler. Past funding was provided by NIST’s ATP program and the Defense Advanced Research Program Agency. The project leads for the various programs in FY 2001 are: Kevin Lyons (DFT, IMCAD, SIF-LM), Mike Pratt/Ram Sriram (STP), Shaw Feng (DPII), Steven J. Fenves (DAI), Simon Szykman (DR). The others current members of the Product Engineering Program are: Sylvain Archibault (DR), Robert Allen (KBSI), Guilhem Assant (DR), Amba Bhatt (SIF-LM), Young Choi (DAI), Balan Gurumoorthy (DAI), Young Hyun Han (IMCAD), Hua Jiang (STP, DAI), Jean-Christophe Julien (DR), Hiromichi Obara (DAI), Yuyin Song (DPII), Rachuri Sudarsan (DFT), Khahn Trieu (DR), and Fujun Wang (KBSI). In addition, we are also collaborating with several universities (University of Maryland, Carnegie Mellon University, Syracuse University, University of Michigan) and industry consortia (PDES, Inc., Washington State University VADE, CAM-I, OMG).

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