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Final Report

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A Survey of Applications and Research In Integrated Design Systems Technology

NASA Ames Research Center Grant

NAG 21114

Submitted by:

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Frame of Reference for the Study

Each of the persons and organizations who were asked for information in connection with this study were provided with a description of the frame of reference of the study, as follows:

NASA Ames Research Center has identified several applications focus areas within the scope of their responsibilities as the NASA Center of Excellence for Information Technology. We are working on one of these, Integrated Design Systems. One of our tasks is to conduct a review of research, development and applications in integrated design environments in academia, industry and government. We have taken a broad view of this area, to include consideration of the entire product realization process.

We are interested in learning how industry and government are using advanced information processing technology in integrating the different tools and processes that comprise the engineering of complex systems. There has been a lot of work done in automating different parts of the process, such as CAD, CAM, virtual reality, requirements analysis, product data managers, integrated product databases, company legacy databases, formal design architectures, model and simulation-based design, verification and validation, etc. These have evolved into what some have called "islands of automation." We would like to find out what is being done to integrate these islands into a comprehensive design and product realization environment.

We have been asked to report to NASA on our findings from this review. In addition, we have been asked to prepare two papers in the open literature. One is a paper to be given at the AIAA Aerospace Sciences meeting in Reno, January 1998. The other is an invited article in the IEEE Spectrum magazine. The main topic of these papers will be some research we are involved in called MADA (Multi-Agent Design Architecture), which is an approach to use of intelligent agents in collaborative design and analysis. We have been asked to include in these papers some background material on how integrated design systems are being developed and used in industry and government.

We point out the open papers so that you will keep us advised of any sensitivities about proprietary data.

In addition to the introductory material quoted above, we provided each of our contacts with the following document that briefly explains the genesis of our research project tasking from NASA.

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Overview
NASA Ames Research Center
Center of Excellence Plan: Information Technology

Ames Research Center (ARC) has been designated as the NASA Center of Excellence (COE) for Information Technology (IT). The primary objective of this COE is to develop advanced information technologies to support NASA's four strategic enterprises (aeronautics, space science, human exploration and development of space, and mission to planet Earth). COEs are charged with the responsibility of establishing partnerships with government, academia and the private sector.

Ames has identified seven enabling discipline-based technologies in IT to support the strategic enterprises (modeling and simulation, database and information management, human/computer interaction, automated intelligent decision making, smart sensor systems, software technology, high-performance computing, networking, and storage).

Ames has also identified five applications focus areas that it regards as drivers of the COE-IT requirements (integrated design systems, large-scale information management and simulation, aviation operations, space systems operations, autonomous systems for space flight).

We are working with Dr. Charles Smith, Chief, Aeronautical Technologies Division, ARC, on the integrated design systems (IDS) applications focus area. NASA's interest here is in leading the development of advanced systems engineering design tools for aerospace applications, through the use of new information systems technology. The overall objective of the effort is to develop systems design tools that will help reduce design cycle time and costs. Some specific objectives are 1. enable the functioning of dispersed virtual design teams, 2. increase the efficiency of interactions within the design process, 3. improve the early introduction of advanced technology into a system design cycle.

We are doing three tasks for ARC. We are tasked to survey industry, government and academia to see who is doing work that is related to IDS. In addition, we are doing two specific applications tasks: smart processing of test data between the wind tunnel and the designer, and development of an integrated design and analysis framework for High Speed Civil Transport engine nozzles.

SURVEY APPROACH

The initial part of the study was begun with a combination of literature searches, World Wide Web searches, and contacts with individuals and companies who were known to members of our team to have an interest in topics that seemed to be related to our study. There is a long list of such topics, such as concurrent engineering, design for manufacture, life-cycle engineering, systems engineering, systems integration, systems design, design systems, integrated product and process approaches, enterprise integration, integrated product realization, and similar terms. These all capture, at least in part, the flavor of what we describe here as integrated design systems.

An inhibiting factor in this inquiry was the absence of agreed terminology for the study of integrated design systems. It is common for the term to be applied to what are essentially augmented Computer-Aided Design (CAD) systems, which are integrated only to the extent that agreements have been reached to attach proprietary extensions to proprietary CAD programs. It is also common for some to use the term integrated design systems to mean a system that applies only, or mainly, to the design phase of a product life cycle. It is likewise common for many of the terms listed in the last paragraph to be used as synonyms for integrated design systems.

We tried to avoid this ambiguity by adopting the definition of integrated design systems that is implied in the introductory notes that we provided to our contacts, cited earlier. We thus arrived at this definition:

Integrated Design Systems refers to the integration of the different tools and processes that comprise the engineering of complex systems. It takes a broad view of the engineering of systems, to include consideration of the entire product realization process and the product life cycle. An important aspect of integrated design systems is the extent to which they integrate existing "islands of automation" into a comprehensive design and product realization environment.

As the study progressed, we relied increasingly upon a networking approach to lead us to new information. The departure point for such searches often was a government-sponsored project or a company initiative. The advantage of this approach was that short conversations with knowledgeable persons would usually cut through confusion over differences of terminology, thereby somewhat reducing the search space of the study. Even so, it was not until late in our eight-month inquiry that we began to see signs of convergence of the search, in the sense that a number of the latest inquiries began to turn up references to earlier contacts. As suggested above, this convergence often occurred with respect to particular government or company projects.

SOME KEY OBSERVATIONS

U. S. INDUSTRY

Boeing (formerly McDonnell Douglas Space and Defense Systems, Huntington Beach), developed an integrated design infrastructure to provide engineering tools and processes to support their integrated product teams (Hart Humphrey,1997). Their motivation is to improve design integration during the early conceptual phase, when sensitivity to new technology and design changes is greatest.

The Boeing concept is based upon using a browser server to provide access to various analysis tools and enterprise databases. The browser environment can be accessed from workstations and PCs throughout the company, from any location. This environment also provides email capability for coordination of engineering decisions and actions. The CAD tool provides a master solid model database, which is accessed by all other elements of the system. STEP standards are being applied to the geometry data. A virtual reality facility provides the capability of accessing the geometry database for fly-through inspections to check clearances, form, fit and function. The Boeing system also provides a product data management system, with access to legacy databases such as material and parts libraries. Workflow analysis is included too, providing configuration and interface control, and versioning and sign-off capability for design changes.

Under development is a capability for unified interaction of the CAD and finite element/structural analysis tools. One of the future goals of these developments is to extend the design environment to include manufacturing processes. Simulations will be used to verify fabrication and assembly processes.

Contact: Twila Hart Humphrey, 714 896 6057, twila.s.harthumphrey@boeing.com

Boeing Information , Space and Defense Company, Seattle, through its participation in the **DARPA RaDEO** (Rapid Design Exploration and Optimization) program, is developing an Integrated Product Data Environment (IPDE). This is an evolving integrated design environment that is intended to be independent of proprietary formats. It links interacting design tools through a common, object-oriented database that emphasizes standardization of database and data exchange formats, such as STEP. The objective of the program is to demonstrate, in a series of prototypes, how diverse analytical tools, including CAD, fluid mechanics and structural analysis, as well as non-analytical information, such as requirements traceability and manufacturability, can be integrated into a standards-compliant, application-neutral object-oriented design environment.

The operation of the system involves translation of the application-unique outputs of the various tools into a neutral, object oriented data format that is stored in a common data base. These data objects can be recalled by other analysis applications. Upon receipt of such a request, the data object is then translated into a form that can be used by the requesting application. Through the supervision of the database control program, diverse applications can exchange information. An example given in an early demonstration started with a CAD representation of a wing section, performed successive iterations between a CFD tool and a static stress analysis tool, then converged after a few iterations to produce the revised geometry, stress and pressure distributions of a wing in flight. Future demonstrations will incorporate the non-analytical elements, which have been written as a STEP application protocol.

A related project, using similar approaches to the IPDE project is referred to as the Vehicle Synthesis System (VSS). This development is internal to the company, and is considered somewhat more sensitive than the IPDE development. The work is supported in part by Langley Research Center.

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Boeing, St. Louis, is developing an integrated design environment. They have conducted a series of internal studies of approaches to integration of existing capabilities. In early summer, 1997, this environment comprised two main elements, a Configuration Synthesis Workstation and the Design, Manufacturing and Producibility Simulation (DMAPS).

The Configuration Synthesis Workstation is used during the requirements definition and conceptual design phases of a system project. It primarily uses linear analysis models and cost estimation tools.

The company is also conducting simulation-based trade studies that will lead to integration of the Configuration Synthesis Workstation with a common user interface, analysis tools (structures, aerodynamics), process models, cost models, geometry models and an object-oriented database structure. This will lead to real-time linking of all elements in a collaborative design environment. Internal company studies are underway to integrate these functions with the Vehicle Synthesis System at Boeing, Seattle.

DMAPS is an established, and evolving, collection of tools, processes and company practices that is intended to bridge the design-manufacturing gap. Its goal is to improve the product realization process by integrating design, analysis and manufacturing tools in a virtual environment. Company experience has demonstrated cost and schedule savings through early insertion of technology, rapid modeling and analysis using an integrated structures, loads and geometry tool set.

DMAPS has also developed virtual tools for the manufacturing environment. Feature based design techniques have been used to design smart components for virtual manufacturing process evaluation. Virtual shop floor simulations have been used to develop work instructions, manufacturing process flows, and assembly instructions.

The DMAPS environment provides browser access to all information sources by integrated product team members, thereby providing a collaborative environment for design, analysis, and manufacturing.

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James E. Cupstid, 314 232 4941, (configuration synthesis)
David A. Koshiba, 314 233 7754 (DMAPS)

Boeing Defense and Space Group, Helicopter Division, Philadelphia, is conducting research under DARPA program MADE Smart. The goal of the project is to improve the design process for large scale systems by providing a distributed concurrent environment.. The technology they are applying includes:

- Intelligent agents
- Lexical concept structures
- Multi-disciplinary optimization

Their concept involves a web-based interface that is used to specify design and analysis parameters to intelligent agents, which carry out design tasks. This agent architecture provides a foundation for the integration of design tools and processes for use in design of aerospace structures. Another project objective is improving computational efficiency in performing design optimization.

Contact: Thomas M. Barrett, 610 591 4083

Lockheed Martin Tactical Aircraft Systems is developing a comprehensive integrated design environment to support their participation in the Air Force Joint Strike Fighter program, (Aviation Week 10-6-97).

Their Virtual Product Development Initiative (VPDI) is developing a virtual modeling, simulation and design environment that has the goal of improving competitiveness in the initial phases of the affordability-driven DOD acquisition environment. This initiative is directed to the improved functioning of a multidisciplinary product team. The company recognizes that a major impediment to effective performance by a product team is lack of ready access to all the needed information, particularly in the critical early phases of a design cycle.. Thus, a major component of the IPDE is a central database, a product data manager, which is accessed through a common browser interface. Analysis tools are being integrated in an open architecture to link with the common database. This architecture will also include visualization tools, and access to enterprise knowledge available at many other company locations, such as company best practices in design engineering.

The Lockheed Martin development approach for the VPDI is to make maximum use of commercial, off the shelf, components through integration, while minimizing in-house software development. They are exploiting their long-term experience with CATIA computer-aided design software by integrating it into their common database architecture. In addition, they are integrating manufacturing simulations into the virtual development environment, so that production operations may be included in the overall product development virtual environment.

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Lockheed Martin Missiles and Space Company, Palo Alto, under the DARPA-sponsored **Simulation-Based Design** (SBD) program, has developed a generic, object-oriented, domain-independent structure for computing, communication and information management in collaborative, integrated design. Users can construct their integrated design environment by building upon the SBD architecture and programming interfaces.

The SBD environment provides a browser interface for user interaction with the core information-processing element, the Smart Product Model (SPM). The user is presented with a workbench interface to the SPM. The user is able to browse, find, and invoke elements of a uniform object data structure in the SPM. The use populates the generic object structure of classes, folders and instances with user-specific design objects and methods. The SBD environment provides communication and a logical database structure, which the user supplements to build an integrated design environment. Information processing within the SPM is CORBA-compliant, but the user does not see the internal details of the SPM.

As indicated above, the SBD environment, as delivered to a user, is not a stand-alone application. In the specific applications for which SBD has been demonstrated, the linking of user environments with the SBD environment, has been done with languages based on KQML. At present, this imposes a substantial programming burden on users. Work is continuing to provide a friendlier, graphical interface for users. The issue of standards for information exchange between analysis tools , such as the STEP standards, has not yet been addressed by the SBD project.

Demonstrations of the SBD environment have been done by Newport News Shipyard on a Navy surface combatant ship, and by Lockheed Martin Missiles and Space Company on a satellite. Future demonstrations are planned for aircraft (Boeing, St. Louis), and for an electric car (University of Iowa).

A somewhat different application of the SBD approach is being considered in the Office of the Secretary of Defense. They contemplate using the SBD infrastructure in the front end of the DOD system acquisition process, during the decision/authorization phase of a program. This proposed used of a virtual, collaborative, simulation and modeling environment in the early stages of a program is consistent with recent emphasis upon affordability as a major consideration in DOD program decisions. It is also consistent with DOD policy of recent years requiring that programs provide a digital model of their systems, along with hardware deliverables.

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Lockheed Martin Missiles and Space Company, Advanced Technology Center, conducts a research project titled Context-Integrated Design. The goal of the project is to create a flexible design environment. Their approach is an agent-aided design process in which agents work through a hypermedia, shared project notebook. The agent approach is used to mitigate the computationally burdensome problem of developing a full product design model. Each agent handles only a modest amount of information and requires only a limited model of part of the total product and process model.

This project is sponsored by the DARPA RaDEO program.

Contact: N. Narasiman: http://aims5.parl.com/cid

Lockheed Martin Electronics and Missile Systems Company, Orlando, FL, is leading a research project, Integrated Gimbal Design. The goal of the project is to develop an interactive gimbal design system that will allow for the efficient integration of system requirements, system models, optical and mechanical designs, structural analysis, stabilization models and manufacturing processes.

A generic solution is sought through use of the Adaptive Modeling Language (AML), a knowledge-based language developed by TechNisoft, Inc., to capture the knowledge and methodology associated with the design-simulation-manufacturing sequence. Use of AML provides an interactive design environment, and facilitates design automation.

This approach uses an object-oriented part model to represent part geometry, materials, processes and a finite element model. The design knowledge capture capability allows the capture of information on both design process and design artifacts. This permits creativity in design, while at the same time building a model of process and designed artifacts.

An element of this project is the development of a standardized gimbal database that is compliant with the STEP standard.

This project is supported by the DARPA RaDEO program, under contract with the U.S. Air Force, Wright Laboratory.

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General Electric, Aircraft Engines, Military Engines Programs, with support from GE Corporate R & D, is developing capability in the integration of tools and databases to support collaborative product realization. Several years ago they decided upon 3-D modeling as their basic archival reference for product geometry and topology. Having a 3-D model helped to remove ambiguity in the production process, and helped improve quality. They have joined with several of their hardware partners in establishing STEP as a standard for their solid modeling activity.

GE is particularly concerned with logistic support for their products. They emphasize the importance of coding and archiving field experience for use in providing logistic support and in redesign of products. They recognize that data formatting for this application is a difficult problem

GE is active in working with the OSD CALS office in the area of supply chain integration, consistent with their interest in system logistics.

In their research and development, GE has recognized the importance of object-oriented data management approaches, using CORBA standards, as a key to reusability of information. They also recognize both the importance and the difficulty of incorporating legacy database information into an object-oriented data structure. They have conducted studies of the application of intelligent agents in building integrated product environments.

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The **Industrial Technology Institute, Ann Arbor, MI**, is conducting research under project RAPPID, funded by DARPA's RaDEO program. RAPPID is described as a community of agents (active software objects with varying degrees of intelligence) that help human designers manage product characteristics across different functions and stages in the product life cycle. Agents represent not only design tools and humans with a stake in the design (including designers, manufacturing engineers, and marketing and support staff), but also the components of the design itself, and the characteristic of each component. These agents trade with one another for design constraints, requirements, and manufacturing alternatives. The resulting marketplace provides a self-organizing dynamic that yields more rational designs faster than conventional techniques.

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http://iti.org/cec/rappid/

The **MITRE Corporation** has developed the Collaborative Virtual Workspace (CVW). This is a prototype collaborative computing environment, designed to support temporally and geographically dispersed work teams. From a user's point of view, CVW provides a persistent virtual space within which applications, documents and people exist in rooms, floors and buildings. From a technical point of view, it is a framework for integrating diverse collaborative capabilities.

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The **Microelectronics and Computer Technology Corporation (MCC)** has developed a system called InfoSleuth. It is described as a system that implements a community of cooperating agents that discovers, integrates and presents information on behalf of a user or application, for which it provides a simple, consistent interface. The information sources it accesses are distributed and heterogeneous, for example, the types of information available through an intranet in a large corporation, or on the World Wide Web. InfoSleuth information processing conforms to an agreed ontology of a particular domain of information. The agents in the system are intelligent, in the sense that they may possess domain knowledge or inferencing capability.

The user of InfoSleuth queries information in a simple and uniform way, unaware of the complexity of the underlying information. It appears to the user that the entire domain of information the user accesses is a static database whose terms and relations reflect the user's perspective of the knowledge domain. InfoSleuth communicates with agents by use of KQML, layered on top of TCP/IP or the HTTP protocol.

Contact: Marek Rusinkiewicz , (512) 338-3733, http://www.mcc.com/projects/infosleuth/

Scientists at **Blackboard Technology**, are studying the use of multi-agent systems as an element of knowledge-based design. They point out that, while knowledge-based design systems are partially successful in automating expert knowledge sources in design, the rapid evolution of standards, technologies, and the competitive marketplace, require a high degree of adaptability in the employment of expert knowledge in the design process. They argue that the multi-agent paradigm is appropriate for knowledge-based design in this new environment.

They point out that, in addition to potential improvements in managing information flows in design, and in managing the design process, the multi-agent approach may provide an improved theoretical foundation (presently considered weak) for the application of expert knowledge in large-scale projects.

These matters are discussed at length in a recent article in IEEE Expert by Susan E. Lander (Lander, 1997).

Contact: Susan Lander, lander@bbtech.com, www.bbtech.com

The **National Industrial Information Infrastructure Protocols(NIIP) Consortium,** led by IBM, is a consortium of government, industry, and academic institutions that are cooperating on open software protocols for information exchange among product developers. The purpose of this effort is to enable formation of virtual enterprises, which are temporary groupings of companies in joint enterprises.

The vision of NIIIP is to improve competitiveness through improved collaborative computing and communication environments. They plan to take advantage of such recent advances as object information technology (exemplified by CORBA), STEP standards for product data definition, and improved communication through the Internet.

Contact: http://niiip.org

US GOVERNMENT

The **Defense Advanced Research Projects Agency (DARPA), Defense Sciences Office, RaDEO (Rapid Design Exploration and Optimization)** program has the vision of creating a flexible and responsive design environment in which it is possible to evaluate an order of magnitude more design alternatives than is possible now. This would enable producers to optimize product characteristics and quickly prototype complex products and processes.

RaDEO project support falls under these major categories:

- Design Exploration and Advanced Design Representation
- Multi-Disciplinary Optimization and Simulation
- Integration Frameworks
- Designers Interface

The RaDEO program supports many projects in industry, academia and government. A number of projects described elsewhere in this report are noted as having DARPA support under the RaDEO program.

Contact: Kevin W. Lyons, klyons@darpa.mil, 703 696 2314

The **National Institute of Standards and Technology** (NIST) provides a rich source of information on integrated design systems. Their Engineering Design Technologies Group, Manufacturing Systems Integration Division, has the goal of becoming a world leader in the development of technology and standards in support of design (product, process and enterprise) environments needed for U. S. industry to maintain preeminence in the global market place. Their areas of research interest include:

- Computing architectures for collaborative design environments
- Product and process model representations for communicating across disciplines
- Visualization and virtual reality in design environments
- Modeling and simulation-based approaches in design
- Database technologies for complex, data-intensive computer-based design environments
- Use of the object-oriented paradigm for encoding and storing design information
- Integration of design tools to permit synchronous collaboration in design
- Integration of non-analytical information (such as design rationale) into design systems

NIST is also developing standards for integrated design systems, such as the STEP standards for exchange of product data., to include extensions to STEP to accommodate non-analytical, non-geometric information. One of their major interests is standards for exchange of data between proprietary applications that must apply in collaborative design environments.

The NIST Design Repository Project is developing a modeling framework for the representation of artifacts in a design database (Murdock, et al, 1997). This emphasis on an object-oriented, applications-neutral representation scheme for product data in an integrated design system is consistent with the recognition in industry of the centrality of the product and process information base. This project provides an object-oriented modeling language that transcends the traditional geometric modeling format to include form, behavior and function. Their work acknowledges that standards for geometry representation (STEP AP 203) are much further advanced than standards for non-geometric information. They provide language formalisms to describe data objects, and a representation language that links these objects to artifact models.

The NIST development also includes a suite of tools for implementation of the object-oriented design database concept, including commercial object-oriented databases, an information browser for a user interface and visualization capability.

Contact: Dr. Ram D. Sriram, sriram@cme.nist.gov, 301 975 3507

The **Office of the Secretary of Defense (OSD), Computer-Aided Acquisition and Logistic Support (CALS) Office** plays a major role in establishing and overseeing DOD policy for information management. They perform a number of functions, such as:

- Run the DOD data management program
- Harmonize Military Standards with STEP standards
- Provide life cycle configuration management guidance
- Implement object-oriented database technologies, CORBA standards
- Implement digital product data practices to support weapon systems development

Historically, OSD data management has centered on contract deliverable "tech data", such as operations and maintenance instructions. Now this OSD function also emphasizes product and process data associated with the identification, design development and support of weapons system. This is consistent with OSD policy of the past few years, which requires the delivery of a digital system model along with the hardware products of a system program.

A new initiative for this office is an extension of the DARPA/Lockheed Martin Simulation-Based Design (SBD) virtual, collaborative design environment into the domain of the top-level OSD decision makers. The purpose of this initiative is to use, at the beginning of the acquisition decision process, the tools of simulation, operational analysis, technology assessment and conceptual design, in a virtual environment, to reduce risk, shorten cycle time, cut cost, and improve the probability of success.

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Dr. Gary Jones, DARPA, gjones@darpa.mil, 703 696 2351

The **U. S. Navy, Assistant Secretary for Acquisition, Office for Acquisition Reform** has developed a Navy Acquisition Center of Excellence (ACE) at the Washington Navy Yard, Washington, DC. This facility provides decision-makers in the Washington area with product and process models to help in the acquisition decision process. This environment can also be used by program managers to support integrated, multidisciplinary product and process teams during system development, thus insuring early and continuous life cycle planning. It provides a browser interface for all program stakeholders to share project information. It exploits the capabilities of the DARPA Simulation-Based Design (SBD) project in integrating tools, processes and data in a standards-compliant, processor-neutral environment.

The ACE project features world-class practices, including concurrent development, integrated product and process development and simulation-based acquisition.

Contact: Mike Roberts, roberts_mike@acq-ref.navy.mil, 703 602 5506,
http://www.acq-ref.navy.mil/ace/ace.html

The **Naval Surface Warfare Center (Dahlgren Division)**, has, for several years, conducted the Engineering of Complex Systems (ECS) Technology Project. The objective of this project has been to develop an engineering environment that supports the design and development of large-sized, complex, and real-time systems. Recognizing that development of large-scale, mission-critical systems involves a complex mix of hardware, software, data resources and human operators and decision-makers, the ECS project seeks to automate and integrate these elements. The project also seeks to integrate the application of domain knowledge, in the form of best practices, analysis, expert advice and heuristics.

The ECS Project has developed a number of tools and prototypes, including tools for

- Requirements analysis
- Object-oriented design evaluation
- Object-oriented design resource capture
- Object models for constraint analysis
- Re-use of legacy code
- System-level optimization
- System simulation
- Reliability estimation
- Reliability assessment

A major element of the ECS project has been a series of workshops entitled *Annual Workshops on Engineering of Systems in the 21st Century (WES 21)*. While these workshops focussed on integrated systems engineering capabilities for mission critical needs of Navy platforms, they also had the broader vision to "revolutionize the understanding and practices of engineering complex systems". These workshops were held in 1994, 1995 and 1996. Additional workshops are planned.

Contact: Dr. Harry Crisp, hcrisp@relay.nswc.navy.mil, 540 653 8902

The **U. S. Air Force, Wright Laboratory, Avionics Directorate,** has started a new initiative in integrated design systems entitled Collaborative Engineering Environment (CEE). It contemplates the use, and extension, of the results of the DARPA/Lockheed Martin Simulation-Based Design (SBD) program in an integrated, collaborative environment for use by all of the directorates in Wright Laboratory. Its goal is to enable all of the Directorates to:

- Facilitate collaborative R&D (across directorate disciplines)
- Integrate technologies
- Participate in system concept studies
- Perform technology evaluation
- Accomplish technology transfer
- Perform investment analysis in support of acquisition decisions

The CEE data structure will use the SBD Smart Product Model, hence will be a CORBA-compliant, object-oriented database. The CEE processing baseline will be based upon intelligent agents. The CEE will build upon the SBD infrastructure by integrating tools and processes from the laboratory environment. The CEE will comply with OSD guidance on data standardization, and this will include compliance with STEP.

The CEE project is just getting under way (Sep 97). Contract support to Wright Laboratory is being provided by Ball systems, supported by Lockheed Martin, the developers of SBD. DARPA is supporting the effort.

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The **U. S. Air Force, Wright laboratory, Manufacturing Technology Directorate (MANTECH)**, conducts a comprehensive program of research in topics related to integrated design systems. Their research projects are listed in annual project books, under *Manufacturing and Engineering Systems.*

http://www.wl.wpafb.af.mil/mtx/index-n.html

Several of these MANTECH projects are summarized below:

- **Integrated Product Processing Initiative**

The objective of IPPI is to implement a complete product information thread using PDED/STEP (Product Data Exchange using Standard for the Exchange of Product Model Data) information models at all product-based (computer-aided design and manufacturing) workstations. A second objective of the IPPI program is to use lessons learned in an actual production environment to provide guidance for current and future program activities.

Raytheon Electronic Systems is working under the direction of Wright Laboratories to bridge the gap between design and manufacture by developing IPPI. The first step is to transfer product information between design and manufacture. The second step is to have this information support most of the manual operations of the manufacturer's environment, and prepare for the emerging automated manufacturing of the future.

Contact: Jeff Ashcom, WL/MTIM (937) 255-7371

- **Advanced Collaborative Open Resource Network (ACORN)**

The objective of this effort is to provide network-based engineering and design software tools that can be used on the emerging national information infrastructure. Two high-level, network-based software toolkits which will be able to identify, locate, and catalog acquisition parts, and provide for the design, rapid prototyping, and acquisition of cast and/or machined parts,

In addition, this network seeks to provide three essential elements: access to the ACORN technology by a wide range of organizations, including small businesses, tools to facilitate search, acquisition, design, and prototyping, and training to assure that the skills needed to use ACORN technology are available to all.

This work is funded by DARPA, through Carnegie Mellon University

Contact: Brian Stucke, WL/MTH, 937 255 7371

- **An Adaptable Enterprise Integration Platform for Flexible Manufacturing**

This program has developed the Platform for the Automated Construction of Intelligent Systems (PACIS), which is a logic-based knowledge representation system, integrating new and existing information systems. PACIS was used to build reference models of the data systems in which the information resided and to make information retrieval from multiple systems transparent to the user. PACIS can also be used to explicitly define complex relationships between data, such as composition, spatial, and temporal relationships. Using this ability to define complex relationships, PACIS has defined the relationships between the bill of materials for manufacturing, engineering, purchasing, and logistics support.

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- **Flexible Environment for Conceptual Design, Geometric Modeling and Analysis and Assembly Process Planning**

This program will develop a prototype design system that supports multiple linked representations along with unique analysis and generative planning modules. It will couple a parametric model-based design representation (which is most appropriate during conceptual design and for integrating multiple disciplines) with a geometrically centered design representation.

The project is funded by DARPA

Contact: Daniel Lewallen, WL/MTIM 937 255 7371

- **Context Integrated Design**

Context Integrated Design (CID) consists of a set of software agents, each handling a modest information manipulation task, that work through a hypermedia shared project notebook to organize, interpret, and coordinate information in the context of the task at hand. (This project was discussed earlier as a research project of the Lockheed Martin Advanced Technology Center.)

This project is funded by DARPA under the RaDEO program.

Contact: James Poindexter, WL/MTIM, 937 6569223

- **Multiphase Integrated Engineering Design**

The overall objective of the project is to develop engineering tools and information integration capabilities that could be used to evaluate an order of magnitude more design alternatives than is possible today in an attempt to optimize several product characteristics, and quickly prototype complex products and processes. The objective is to provide for the development of key enabling technologies and tools to support integrated products from early stage design through manufacture for electro-mechanical parts.

This project was sponsored by DARPA under the MADE (later RaDEO) program, through the University of Utah.

Contact: (see U. Utah)

- **Integrated Knowledge Environment - Integrated Product Management**

This effort demonstrated the concept of an Integrated Knowledge Environment (IKE), Integrated Product Management (IPM) framework which provides a process-oriented environment with encapsulated tools, methods and techniques that enable affordable analysis. The IKE provides a variety of capabilities that allow the user to graphically develop a process model. It also provides a tool for the manipulation of forms that enables the user to graphically create, edit and fill in electronic business forms and to map data to and from local or remote databases.

Contact: David Judson WL/MTI (937) 255-7371

The U.S. Department of Energy (DOE), Oak Ridge National Laboratory (ORNL), Project TEAM (Technologies Enabling Agile Manufacturing), leads an inter-laboratory research effort to develop an integrated product realization environment,. This work involves ORNL, Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL) and Sandia National Laboratory (SNL).

The *vision* of the TEAM effort is to develop manufacturing enterprises that can succeed in environments of dynamic change. The *mission* of TEAM is to develop and demonstrate enabling technologies to implement agile manufacturing. The *goal* of TEAM is to integrate design and manufacturing by providing modular tools that maximize the use of enabling technologies.

The product realization environment that TEAM contemplates developing will provide a computing and communication framework for collaboration on shared data, in a distributed, object environment, based upon a CORBA-compliant information repository. In addition to analysis and visualization tools and communication modalities, they expect to encapsulate non-analytical legacy applications by providing object wrappers for the data objects.

The TEAM project technical activity is organized according to five *thrust areas:*

- **Product Design and Enterprise Integration**
  - Requirements definition
  - Design tools
  - Support for concurrency
  - Tools for concept development and rapid prototyping
  - Release control procedures
  - Design data control

- **Virtual Manufacturing**
  - Modeling and simulation tools
  - Integrated systems to model life cycle processes
  - Integrated software tools

- **Manufacturing planning and control**
  - Apply STEP (ISO 10303) standards
  - Develop automated systems to support agile manufacturing

- **Intelligent closed-loop processing**
  - Imports product definitions via STEP standards
  - Captures process information needed for control

- **Integration**
  - Communication and information transfer
  - Technology standards
  - Architecture for communication and information processing.

The DOE **Kansas City Plant**, operated by Allied Signal Corp., develops prototype demonstrations of TEAM technology.

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TEAM@ornl.gov, 423 574 1884 (Program Office)
http://www.eng.ornl.gov/, (Concurrent Engineering WWW server)
http://java.ca.sandia.gov/itml/, (Sandia National Lab)
http://www.lanl.gov/projects/TEAM/, (Los Alamos National Lab)

ACADEMIA

Stanford University, Department of Mechanical Engineering, Center for Design Research, is active in research, development and teaching in integrated engineering environments. Their research includes:

- Collaborative processes and information sharing
- Design rationale capture
- Agent infrastructure for collaborative design
- Indexing, modeling and retrieval of design knowledge
- Virtual, collaborative design environments

The Mechanical Engineering Department demonstrates the application of collaborative design among dispersed teams in their design course ME 210.

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Prof. Mark Cutkosky, cutkosky@cdr.stanford.edu, 650 725 1588

Stanford University, Department of Civil Engineering, has formed a Center for Integrated Facility Engineering for research and teaching in integrated design. Their research includes

- Integrated computer systems to link modelling tools in collaborative design
- Computer techniques for integrated facility development in the architecture-engineering domain.
- Methods and tools for integrated life-cycle engineering in building construction.

The center conducted the Virtual Design Team (VDT) research under NSF sponsorship. This project developed modeling and approaches for use in analyzing work process and communications in concurrent engineering design teams. (Levitt, 1997)

This Center also conducts courses in collaborative architectural design and engineering, involving dispersed participants from several remotely located organizations.

Contact: Prof. Raymond Levitt, rel@cive.stanford.edu, 415 723 2677
Dr. Renate Fruchter, fruchter@cive.stanford.edu

Stanford University, Department of Computer Science, Center for Information Technology, has developed an information infrastructure that is being applied to a regional collaborative engineering environment in the Silicon Valley. This center has previously done work on agent-based frameworks for integration of tools in computer-based product engineering.

Contact: Prof. Michael Genesereth, genesereth@cs.stanford.edu, 415 723 0324

Stanford University, Department of Computer Science, Knowledge Systems Laboratory, conducts research on collaborative environments, including knowledge representation, shared knowledge bases and knowledge-based systems for engineering. Under sponsorship of the DARPA RaDEO program, they conducted a project entitled "How things work," the goal of which was to develop a collaborative modeling environment for tools, languages and devices, and model-based reasoning capabilities to enable distributed teams to develop and coordinate their design work.

Contact: Prof. Adam Farquhar, Adam_Farquhar@ksl.stanfor.edu, 415 723 9770

Carnegie-Mellon University, Institute of Complex Engineered Systems, has several groups and projects doing research on computing technologies in systems engineering. Two are of particular interest for this study:

The **Engineering Design Research Laboratory (EDRL)** was established over a decade ago under NSF sponsorship. The **Institute of Complex Engineered Systems** is an extension of the capabilities developed by the EDRL to a broader range of topics. Research and teaching in the EDRL has included

- Collaborative design and manufacturing environments
- Information management in design and manufacturing
- CODES (Collaborative Open Design Environments) project
  - Funded by DARPA , RaDEO
  - Focussed on integration of people, tools and information in collaborative design environments
- Knowledge-based expert systems in electrical design
- Software environment for early phases of building design (SEED) ,(Garrett, 1997a, 1997b)
- Rapid Design through Virtual and Physical Prototyping (RDTVPP), a project consortium with Stanford University (Center for Design Research), and UC Berkeley.
- A sophomore course on rapid prototyping, using the RDTVPP approach.
- The Asynchronous Teams Project is developing theory and practice of computational networks of agents and shared memories that can deal with difficult and complex problems by combining algorithms for cooperative problem solving. They have applied these developments to electromechanical and building design problems.:

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Professor James Garrett, garrett@cmu.edu. 412 268 5674
Professor Susan Finger, Susan.Finger@cmu.edu (RDTVPP)
Professor Sarosh Talukdar, snt@erdc.cmu.edu, 412 268 8778 (A-Teams)

The Georgia Institute of Technology, Aerospace Systems Design Laboratory, conducts research in theory and implementation of environments for concurrent, life-cycle design of complex systems. (Hale, et al, 1996)

Their project DREAMS (Developing Robust Engineering Analysis Models and Specifications) produced an architecture that supports a Decision-Based Design paradigm. This involves formally partitioning and modeling the design process to support the decision makers, with the goal of minimizing impact of early design decisions on product changes, cost and risk.

The design process architecture has been implemented in a computing environment called IMAGE (Intelligent Multidisciplinary Aircraft Generation Environment)., which represents both the design process and the associated information management processes. Developments in the IMAGE project includes:

- Graphical browser interface.
- Design process modeling to organize design tasks to support decision-making.
- Research on design information management requirements for representation of design artifacts and processes. This work is using object-oriented and feature-based design approaches. It provides an object structure and object-oriented virtual database for integration of information on design artifacts and processes.
- Use of an approach called *schema evolution* to provide design data descriptions, instead of a central data model. Schema evolution permits a design object to have multiple variable sets, corresponding to different stages of design and differing perspectives held by different engineering disciplines.
- "Plug-n-play" mechanisms for integrating analysis tools.

- Agent collaboration facilities to support running codes on multiple machines.

The Aerospace Systems Design Laboratory conducted a related conference in May, 1997: *An Industry Perspective on Integrating Frameworks*

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Dr. Mark A. Hale, mark.hale@aerospace.gatech.edu, 404 894 9810

The **Georgia Institute of Technology, Engineering Information Systems Laboratory** (EISL) conducts research in Design-Analysis Integration (DAI). They have done a number of projects in which analysis tools were integrated in specific design domains. Examples are CAD/CAE integration for electronic packaging and printed wiring assemblies. They are also working on extending STEP standards to engineering analysis by developing STEP application protocols.

The director of the EISL, Professor Robert Fulton, also has responsibilities for the coordination of data exchanges among CAD packages, on behalf of the OSD CALS office, the office that manages the DOD data management program.

Contact: Professor R. E. Fulton, Director, robert.fulton@me.gatech.edu, 404 894 7409
Professor Russell S. Peak, Deputy Director, peak@cad.gatech.edu

Massachusetts Institute of Technology, Center for Innovation in Product Development was established recently to advance the theory and practice of product development in US industry. Their vision statement includes increasing effectiveness in product development through:

- Better project team organization
- Improved decision making
- Improved communication infrastructures

One of their major research thrusts is in the area of Information-Based Product Development. Their objectives include:

- Identifying key information for product data management
- Representing and managing product and process information

Contact: Professor Stephen Eppinger, eppinger@mit.edu, 617 253 0468, http://web.mit.edu/cipd/

The **Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, Intelligent Engineering Systems Laboratory**, has the objective of improving engineering of large-scale systems, using advances in systems engineering, information technology and cognitive sciences.

Professor Feniosky Pena-Mora is continuing earlier work on project DICE (Distributed and Integrated environment for Computer-aided Engineering) involving SHARED (a shared, object-oriented workspace for product model information) and DRIMS, (Design Recommendation and Intent Management System). This research involves design rationale capture and conflict mitigation in a collaborative environment.

Professor Pena-Mora is also conducting research, under a project titled *the DaVinci Initiative*, to explore computer support mechanisms for distributed design change negotiation. Such mechanisms would include computer-aided design tools, distributed communications, design knowledge sources, intelligent change management and an artifact object model. The base element of such a system would be an object database providing a unified product and process model. A communication facility would enable multiple participants to access the design database, thereby providing the ability for design and coordination tools to interact with the design knowledge base.

In June, 1997, the Intelligent Engineering Systems Laboratory Hosted the IEEE Sixth Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE 97). This workshop was co-sponsored by the IEEE and the Concurrent Engineering Research Center at West Virginia University.

Contact: Professor F. Pena-Mora, feniosky@mit.edu, http://ganesh.mit.edu/feniosky/
http://www.cerc.wvu.edu/WETICE/WETICE97.html/

The **Massachusetts Institute of Technology, Department of Mechanical Engineering, Engineering Design Research Laboratory**, is conducting a project: *Imprecise Concurrent Engineering Design Environment.* This project aims to develop computational algorithms and software for multiple agents to share imprecise constraints arising from design tools and processes used by collaborating designers on a large design project. The goal is to allow collaborating engineers to observe and interact with the constraints imposed by other engineers, to refine the restrictions through iteration and obtain a design solution.

Contact: Professor Kevin. N. Otto, knotto@mit.edu, 617 253 8199, http://design.mit.edu

The **University of Iowa, College of Engineering, Center for Computer Aided Design (CCAD), Information Integration Project** is conducting a research program whose goal is to develop a simulation-based concurrent engineering environment to support distributed, collaborative product development operating over a network.

They describe this work as being based upon two emerging technologies: product data exchange using the STEP standards, and the simulation-based design approach, as developed by the DARPA-Lockheed Martin Simulation-Based Design program.

To demonstrate the feasibility of building such a collaborative concurrent engineering environment, this project will use the High Mobility Multipurpose Wheeled Vehicle (HMMWV) as a prototype. They propose to develop an information network that will permit prime contractors and suppliers to work collaboratively in product development.

Contact: Professor Kyung Choi, Director CCAD, kyung-choi@uiowa.edu, 319 335 5668
http://www.ccad.uiowa.edu

The **University of West Virginia,Concurrent Engineering Research Center** (CERC) is an interdisciplinary research facility. In DARPA-sponsored research that was completed last year, they studied computer support for virtual product teams, using the World Wide Web to provide common workspaces for virtual team members.

The goal of this work was to provide Web access to data repositories , permitting information sharing and project coordination. They developed an Information Sharing System (ISS), which provides communication protocols and database software to enable product teams to access distributed databases using heterogeneous data formats. In addition, they have several other projects dealing with collaboration and communication issues in system development.

The CERC will co-sponsor, with IEEE, the 7th Workshop on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE 98) at Stanford, CA, in June 1998.

Contact: Ms. M.Carriger, info@cerc.wvu,edu, 304 293 7541
http://www.cerc.wvu.edu/index.html/
http://www.cerc.wvu.edu/WETICE/WETICE98.html/

The **University of Wisconsin, Department of Mechanical Engineering, I-CARVE Laboratory**, is conducting research in the area of Virtual Design and Virtual Prototyping to support Computer-aided Concurrent Design. They are developing computer-based methods to support the generation of product designs. Product designs are generated by virtual shape design tools and features-based design tools. For the analysis of product designs, research focuses on computer tools that support design for manufacturability, toolability and disassembly. The analysis is based on a unified methodology by which design features are mapped to process-specific shape features. The latter form the basis for the various types of analysis.

Contact: Prof.Rajit Gadh, gadh@engr.wisc.edu, (608) 262 9058, http://icarve.me.wisc.edu/I-CARVE.1.html

The **University of Utah, Department of Computer Science**, is carrying out a project MIND (Multiphase Integrated Engineering Design), based on the concepts of feature-based design. MIND seeks to develop an integrating domain and enabling technology to support integrated product design by geographically dispersed participants, across design phases and disciplines, throughout the product life cycle.

Their specific design objectives include:

- Design Assistants, sets of algorithms for design processes
- Design Area Encapsulations, encapsulating rules for parts design
- Linked Design Alternatives, collections of design variations to be used in exploring the design space
- Early Stage Features and Flexible Elements, to facilitate evolution of an integrated design representation

Through this approach, they aim to incorporate more information on engineering design into the CAD system, providing multiple levels of abstraction for design representation and permitting teams to cross discipline boundaries.

This project is supported by DARPA, under the RaDEO program

Contact: R. F. Riesenfeld, riesenfeld@cs.utah.edu, 801 581 7026

The **University of Southern California, IMPACT (Improve Manufacturing Productivity with Advanced Collaborative Technology)** Laboratory, is developing an advanced collaboration technology for improving design and manufacturing productivity. Their research on new information technologies includes:

- Behavior and methodology
- Collaborative infrastructure
- Enabling tools
- Modeling systems to trade model accuracy with computation time

A goal of this work is to develop a System Workbench for Integrating and Facilitating Teams.

Contact: Professor Stephen Lu, 213 740 6667, http://impact.usc.edu
http://pisces.usc.edu/swift/swift.html

At the **University of Southern California, Marshall School of Business,** research in human factors in the development of concurrent engineering (CE) tools concluded that more attention should be given to these factors (King 1996). The researchers studied a number of cases of concurrent engineering tool development and found that many assumptions about the interactions of humans with tools and information in the CE environment were not consistent with human cognitive and behavioral models. They concluded that greater attention should be paid to human factors during the development of CE tools, recommending that:

- CE tools be "user-centered"
- Human factors be included in tool design
- CE tool designs should be different for early and later design phases

Contact: Professor Ann Majchrzak, 213 740 4023, amajchrz@marshall.usc.edu

University of Arizona, Department of Electrical and Computer Science faculty members are engaged in research related to our study of Integrated Design Systems.

Professor J. Rozenblit does research in knowledge representation for concurrent engineering (Rozenblit, 1995), object-oriented design methodologies, and complexity issues in the design of complex systems. Some of this work is reported in the volume edited by Professor Rozenblit (Rozenblit 1997a), reporting the proceedings of the 1997 Conference and Workshop on Engineering of Computer-Based Systems. Professor Rozenblit also studies computer-aid support for the engineering of complex systems (Rozenblit 1996).

Other research at Arizona is directed to theoretical issues involved in the engineering of complex computer-based systems. In a survey article (Rozenblit 1997b) Professor Rozenblit discusses:

- The complexity issues in computationally hard problems in design
- Model-based engineering, the use of unified, formal representations in the co-design of hardware and software.
- Formalization of the engineering process through process modeling

Professor Terry Bahill does research in model-based systems engineering and design (Bahill 1992), (Bahill 1993).

Professor B. Zeigler does research in modeling and simulation in design. He was the organizer of a Symposium on Modeling and Simulation: Foundation for Design and Acquisition, at the 1997 Summer Computer Simulation Conference, sponsored by the Society for Computer Simulation (SCS). (Zeigler 1997)

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T. Bahill, , 520 621 6561, terry@sie.arizona.edu

George Mason University, Center for Information Systems Integration and Evolution, conducts research in the integration of computing and communications in large-scale systems, such as engineering design and manufacturing. Their work includes:

- integration of heterogeneous computer systems
- support of legacy data systems
- integration of off-the shelf applications in information systems
- development of product data models
- development of collaborative environments
- integration of information from multiple, heterogeneous sources

The Director of the Center, Professor Larry Kerschberg, presented an invited paper, *Information Structures to Support the Intelligent Enterprise* at the Tenth Annual IEA/AIE Conference, June 1997. (Kerschberg 1997)

Contact: L. Kerschberg, 703 993 1640, kersch@isse.gmu.edu

The **University of Maryland, School of Engineering, Institute for Systems Research, Systems Engineering and Integration Laboratory**, conducts research in modeling of complex systems. In their *Virtual Manufacturing Project: A Decision-Making Assistant for Integrated Product and Process Design*, they have established these objectives:

- tool integration for product and process design
- integration of object-oriented and legacy databases

The technical challenges identified in this project are:

- mapping legacy relational databases to object-oriented databases
- applying multi-objective optimization techniques to the manufacturing domain
- developing client-server software for the IPPD environment
- developing object-oriented modules and libraries for virtual manufacturing applications
- system integration of heterogeneous databases, communication and computing architecture, and tools
- integration of different data models

Contact: Professor John S. Baras, baras@isr.umd.edu, 301 405 6606,
http://www.isr.umd.edu/Labs/SEIL/seil.html/

At the **University of New Orleans, Department of Mechanical Engineering**, Professor Norman Whitley is developing an object-oriented approach to computer-aided design in the shipbuilding industry. This approach focuses on the fact that a three-dimensional product model, containing geometry, topology, materials information, manufacturing processes, and other life-cycle information, is key to the creation of a central database to support integrated product and process design .

A recent paper (Whitley) discusses an object-oriented computer-aided design development based upon the Matra CAS.CADE package. This paper also gives a summary of current issues in information technology for integrated design systems, and provides a perspective on the object-oriented paradigm applied in engineering design.

Contact: Professor Norman Whitley, nlwme@ucc.uno.edu, 504 280 7120

Rensselaer Polytechnic Institute, New York State Center for Advanced Technology, Robotics, Automation and Manufacturing, Laboratory for Industrial Information Integration, has the mission of improving the efficiency of distributed collaborative engineering. They seek to accomplish this mission by doing research on:

- Information models for product design
- Systems to build products
- Software tools for controlling the product development process

Some specific research areas include:

- Modeling languages and standards for information exchange, such as STEP
- Object-oriented programming tools
- CORBA-based computing tools
- Communications tools for collaborative environments

Rensselaer has also developed a design conference room for academic instruction in collaborative design.

Contact: Professor Martin Hardwick, 518 276 2712, hardwick@rdrc.rpi.edu
http://www/rdrc.rpi.edu
http://www.dcr.rpi.edu (design conference room)

The **Stevens Institute of Technology, Design and Manufacturing Institute**, has developed an automated concurrent engineering system (ACES), which they have applied to the design and production of polymer and composite parts and assemblies.

ACES is a knowledge-based, constraint-based, feature-based software system that integrates with existing CAD systems (Pro/E), databases and analysis tools. It provides a graphical interface. Constraints are applied through capture of dependencies in the knowledge base. Feature-based design allows objects to share common information, through object-oriented software implementations. ACES is adaptable to multi-platform and processor environments.

ACES:

- Integrates knowledge about product design and manufacturing
- Provides reasoning and decision-making capabilities
- Addresses the entire product life cycle
- Provides concurrent development of product and process
- Captures and integrates specialized discipline knowledge
- Automates the concurrent engineering process

Contact: Professor Souran Manoochehri, 201 216 5673, souran@dmc.stevens-tech.edu,
http://www.dmi.steven-tech.edu/

The **Arizona State University, School of Management, Management Information Systems**, conducts research in collaboration in manufacturing environments. Professor Stephen Hayne was an organizer and participant in *the Sixth International Conference on Data and Knowledge Systems for Manufacturing and Engineering (DKSME 97).* The proceedings (Hayne 1996) contain a number of papers related to Integrated Design Systems:

- Knowledge-based systems
- Applied data-base techniques in design
- Hypermedia support for integrated environments
- Object-oriented systems for engineering applications
- Applied artificial intelligence techniques in design and manufacturing

The conference also included a panel session*: Database Issues for Distributed and Virtual Manufacturing*, moderated by Ram Sriram, National Institute for Technology and Standards.

Contact: Professor Stephen Hayne, 602 543 6256, hayne@asu.edu

Ohio State University, Center for Integrated Design, is a proposed project that will seek to address the current and future integrated design needs of universities, government and industry.

In addition, the Center is currently teaching a number of courses on integrated design subjects to various engineering disciplines.

Contact: Professor M. Waldron, 614 292 2896
http://chopin.bme.ohio-state.edu/~cid/

ACTIVITIES OUTSIDE OF THE USA

The ESPRIT (European Strategic Research Programme for Research and Development in Information Technology) program encompasses a large number of research and development projects, involving many members of the European community. Several projects of particular interest in this review of integrated design systems are categorized under the heading *Integration in Manufacturing.*

- The **ATLAS** (Architecture, Methods and Tools for Computer-Integrated Large Scale Engineering) is a project with the goal of enabling electronic exchange of information between applications in a design environment. The project envisions an open and non-proprietary approach to information exchange, compliant with ISO STEP standards.

- The **Improving Compatibility of Design Data** project has developed GEM (Generic Engineering analysis Model) which provides
  - Standards for transfer of analysis data, based on STEP
  - A standard model for exchange of data between analysis and simulation tools

- The **Manufacturing for the Future** project has developed the SCOPES (Systematic Concurrent design Of Products, Equipment and control Systems) environment, which:
  - Provides a suite of concurrent engineering tools for integration between phases of the production process.
  - Integrates CAD/CAM tools with shop floor process control systems

- The **System Support for Concurrent Engineering** project has developed ADVANCE (Advancing common basic services for distributed concurrent engineering applications), an environment for the integration of design tools. It provides:
  - An object-oriented data model
  - An inter-tool communication facility
  - A shared memory facility

Contact: http://www.prosoma.lu

The **University of Toronto, Department of Industrial Engineering, Centre for Computer Integrated Engineering (CCIE)** conducts research in enterprise modeling and computer integrated manufacturing.

Their **Enterprise Integration** project involves research in:

- Enterprise modeling to provide generic, reusable data models for design and analysis
- Smart databases
- Intelligent software advisors
- Multi-agent systems for virtual collaboration
- Information architectures to support automated distribution of information in a distributed environment.
- Knowledge representations to support sharable models

The **Computer Integrated Manufacturing - Open System Architecture (CIM - OSA)** project is an extension of work that originated in the ESPRIT program. CCIE describes CIM as "a new manufacturing paradigm", the objective of which is the integration of enterprise operations by efficient information exchange.

Contact: Professor Mark S. Fox, msf@ie.utoronto.ca, 416 978 6823
http://www.ecf.utoronto.ca/ccie/

The **Key Centre of Design Computing, Department of Architectural and Design Science, University of Sydney**, carries out a comprehensive program of research and teaching in the area of design computing. They are the organizers of the biennial International Conferences on Artificial Intelligence in Design (AID), (Gero and Sudweeks, eds., 1996). The next AID conference will be held in Lisbon in August, 1998.

The Centre also publishes a monthly *Design Computing Newsletter*, which is available on the Web.

They have announced the publication of a new journal: *International Journal of Design Computing*, edited by Mary Lou Mayer (Mayer, 1997). This is an electronic journal, available on line.

Contact: John Gero, john@arch.usyd.edu.aus
http://www.arch.usyd.edu.au
http://www.arch.usyd.edu.au/kcdc/dcn (newsletter information)
design-request@arch.usyd.edu/au (subscribe to newsletter)

The Tokyo Institute of Technology, Process Systems Engineering Laboratory is conducting research that aims at developing methodologies to support life cycle engineering of process, plants and products. Because of the wide scale in both time and problem size of the project, standard techniques such as Quality Control (ISO9000), Environmental Audit (ISO14000), and STEP (ISO10303) have been used whenever possible to ensure the usefulness of the research results. For example, STEP (ISO standard for exchange of product model data) is used for data sharing and database building.

Based on the concurrent engineering concept, the research attempts to create a comprehensive methodological framework to cover the whole life cycle of plant and product.

Currently, prototypes have been developed and studied for (1) the pilot plant of a distillation column with a heat pump in the laboratory, and (2) a part of a hydrogen desulfurization plant.

Contact: Prof. Yuji Naka, ynaka@pse.res.titech.ac.jp, +81(45)924-5248,
http://www.pse.res.titech.ac.jp/

The **Mexican Society of Concurrent Engineering, Concurrent Engineering Research Group (CERG)** provides a Web page that describes research and teaching in their program, which is conducted by staff and faculty of the Manufacturing System Center of the Instituto Tecnologico de Estudias Superiores de Monterrey (ITES). Their research (students at the Masters level) includes:

- Computer architectures for concurrent engineering
- Information modeling tools for product life cycle integration
- Object models in concurrent engineering

The Society Web page also posts a Concurrent Engineering Information Center, which provides links to the Manufacturing Systems Center, and to sites in other countries, including the USA, that are doing work in concurrent engineering.

Contact: http://www.mor.itesm.mx/EVENTOS/CERG/

The **University of Singapore, Department of Information Systems and Computer Science**, conducts a project INPROSE (Integrated Process Planning for Simultaneous Engineering). The objective of the project is to develop an integrated process planning methodology to facilitate sharing, decision support and collaboration in engineering design and development.

Contact: W. Hsu, whsu@iscs.nus.edu.sg, www.iscs.nus.edu.sg

CONCLUDING COMMENTS

This limited review of developments and applications of integrated design environments leads to some general impressions of activities in the field:

1. Companies in the aerospace hardware business are acutely aware of the competitive value of owning an effective integrated, collaborative environment for product development, manufacture and support. Accordingly, they are sensitive about revealing details of their implementations, including technology, status of development, and application to particular business enterprises, such as a major competitive government system contract.

2. There is a considerable range in the degree to which companies seek to push the envelope in advancing the technology of computing, communication, and database development. At one end of the spectrum are efforts like the Boeing IPDE development, which has an ambitious set of technology goals. At the other end of the spectrum are the practical developments in integration of owned and commercially available components into a collaborative facility that use up-to-date, but not cutting-edge, technology. Examples of the latter case are the Boeing (formerly McDonnell Douglas), Huntington Beach, and Boeing (formerly McDonnell Douglas), St. Louis. It is noteworthy that the IPDE project is a DARPA-funded project, while the latter two projects are largely company-funded.

3. Several technical and management issues appear repeatedly in the development and applications that we reviewed. These suggest some areas of basic and applied research.

- Scalability, particularly in computing, but also in communications and data structures, is recognized as a problem that must be better understood.

- Data formats, data conversion and translation between object-oriented data environments and more conventional structures, is considered by many to be a hard problem.

- Tool integration has been a primary effort in integrated design environments, especially the integration of analysis tools with CAD systems. CAD purveyors have attempted to meet this need by building families of extensions on their proprietary data formats. Wide recognition of the need for application-independent tool sets has led to some success in the effort to standardize geometry data in STEP.

- Less clear is the extent to which developers will succeed in integrating into their design environments the "legacy" data that is vital to an operating company. This information includes such relatively mundane things as parts catalogs, materials lists, best engineering practices, requirements analysis and tracking, design rationale, design history and so forth.

- Companies that are busy with day-to-day development and production of hardware find it difficult to maintain the software development capability necessary to do such things as implementing STEP standards, establishing CORBA-compliant database and data processing environments, and programming Java applications for their networked collaboration facilities. Some people surveyed reported a certain cultural incompatibility between the two classes of activity, leading to difficulty in recruiting and maintaining the appropriate staffs..

- Concurrent engineering techniques are being applied to complex systems that contain both software and hardware components, but the systems engineering practices in these two domains are quite different. For example, in the software domain, where a designed artifact is executable, verification and validation is straightforward, because the virtual world and the physical world coincide. In the hardware domain, testing provides a counterpart to verification and validation in the physical world. There would seem to be need for formalizing the verification and validation of virtual models of physical artifacts. Structures such as shape grammars suggest an approach to this issue.

- Formal methods are not much discussed among the developers of the integrated design environments. Some formal studies would appear to be necessary, in order to answer questions about scalability and reusability of software to be used in these environments.

- Human factors in the development of design environments have not received a lot of attention. The paper by King and Majchrzak, cited earlier, points out the need to consider the compatibility of humans with the high bandwidth information systems that are being contemplated for integrated design environments.

- We have not yet seen a comprehensive assessment of the potential role for artificial intelligence techniques, such as expert systems, "designer's assistants" and "smart databases." Such concepts could presumably be implementing by embedding intelligent processing objects in an object-oriented product and process database.

- An alternative to the "smart" database concept is the use of intelligent, independent agents to provide active, intelligent information processing in the integrated design environment. Examples of such developments are the DARPA-Lockheed Martin Context-Integrated Design project discussed earlier, and the Multi-Agent Design Architecture for Integrated Design Systems at FAMU-FSU College of Engineering that is being reported separately under this research grant.

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