A Hybrid Manufacturing System Modeling Environment Using VRML

Krishnamurthy, K. Rangan,
Industrial and Systems Engineering Department
Virginia Polytechnic Institute and State University,
Blacksburg, VA 24060
Email: krangan@mail.vt.edu

Shewchuk, J.P.
Industrial and Systems Engineering Department
Virginia Polytechnic Institute and State University,
Blacksburg, VA 24060
Email: shewchuk@vt.edu

McLean, Charles R.,
Manufacturing Systems Integration Division,
National Institute of Standards and Technology
Gaithersburg, MD 20878
Email: mclean@cme.nist.gov

A Hybrid Manufacturing System Modeling Environment Using VRML

Abstract

Manufacturing systems are complex entities, comprised of people, processes, products, information systems and data, material processing, handling, and storage systems. Because of this complexity, systems must be modeled using a variety of views and modeling formalisms. In order to design and properly integrate system functions, the multiple views and models must often be considered simultaneously. However, no single tool or computing environment currently exists that allows this to be done in an efficient and intelligible manner. Virtual Reality Modeling Language (VRML) provides a variety of features which make it attractive for use in developing such environments. In addition, VRML is attractive because it is an ISO standard, ISO 14772. This paper describes how a team at Virginia Polytechnic Institute and State University (VPI) and the National Institute of Standards and Technology (NIST) is using VRML as a hybrid manufacturing-modeling environment. Different manufacturing scenarios that are being investigated with the environment and future research directions are also discussed.

Keywords

Manufacturing Systems Modeling, VRML, Multi-dimensional Models, Virtual Reality.

1 INTRODUCTION

Manufacturing systems are complex—they are comprised of people, processes, products, information systems and data, and material processing and handling systems. In order to design effective and efficient systems and integrate the various components, manufacturing systems modeling is required. Because of system complexity, however, systems must be modeled using various views, e.g., functional, informational, physical, control, etc. Models in each view can be developed using one or more software applications employing various modeling formalisms. Some examples of modeling formalisms include the Integrated Computer Aided Manufacturing Definition functional modeling method (IDEF0), EXPRESS (Schenck, 1989), flowcharts, 2D and 3D simulations, system and data flow diagrams, plant layouts, part designs, virtual prototypes, program logic and code, organization charts, process plans, Gantt charts, and various text specifications. New representation schemes and formalisms are being developed all the time. In order to properly integrate system functions, these multiple views and models must be considered simultaneously. At present, no single tool or computing environment exists that allows an arbitrary set of views and models to co-exist and be used together in an efficient, intelligible way. Additionally, many applications are not intended to work together and hence file formats are often incompatible. As a result of these deficiencies, users are often forced to deal with multiple tools simultaneously, switching from one application to another as required. The use of modeling tools in this manner is both inefficient and detrimental to the decision-making process, and seriously impacts the time it takes to design manufacturing systems and products. A software environment is needed that allows different representations to be combined and shows the various relationships between different models, and which can deal with incompatible file formats.

This paper describes the work underway by a joint team at Virginia Polytechnic Institute and State University (VPI) and the National Institute of Standards and Technology (NIST) to use Virtual Reality Modeling Language (VRML, pronounced "vermel") to tackle these problems. VRML is a scene description language, which can be used to describe 3D environments over the Internet (VRML 2.0, 1997). Because of its inherent flexibility, portability, and open structure, and the fact that it is an ISO standard (ISO 14772 – VRML 2.0, 1997), VRML may provide that common environment for integrating multiple views and models of manufacturing systems.

2 BACKGROUND

A review of the literature shows that a wide range of modeling techniques have been developed and adopted over the years. Vernadat (1996) states that an important part of modeling manufacturing systems is to consider the various aspects: functional, informational, resource and organizational. Additionally, there should be a way to view the various data at different abstractions and in different modalities (Mize *et al.*, 1992). The majority of work dealing with simultaneous consideration of multiple views and models in manufacturing has been performed through research on manufacturing (enterprise) architectures. Various architectures, such as the Computer Integrated Manufacturing – Open Systems Architecture (CIM-OSA – AMICE Consortium, 1992), the Purdue Enterprise Reference Architecture (Williams, 1992), the Graphs with Results and Activities Interconnected (GRAI) model (Doumeingts *et al.*, 1992), and the Integrated Enterprise Modeling (IEM) approach (Mertins *et al.*, 1991) propose different views and models for modeling manufacturing systems throughout their life-cycles. Very little work has been performed, however, directed specifically at the development of software environments for dealing with the multiple views and models that result simultaneously.

Three-dimensional interfaces like VRML present a promising approach for tackling this problem. This approach is advocated by He *et al.* (1996), who point out that the development of generalized models and an open-system architecture are essential efforts that should go into the future development work for virtual manufacturing. Despite its potential, however, the use of VRML in manufacturing to-date is limited. Most of the work done using VRML has covered applications in the sciences. The few reported engineering applications of VRML have been in such fields as civil engineering and architecture (Dodge *et al.*, 1997; Smith *et. al.*, 1997). Some work has been performed to show how VRML can be used to access manufacturing data (Ressler *et al.*, 1997) and illustrate pick-and-place capabilities of robots (VRML, 1997).

Recently, researchers have started focusing on object-oriented technology to solve the issues facing manufacturing systems modeling. In addition to introducing modularity into the modeling environment, object-oriented technology might be a better way to solve the problem of configuration-on-demand (Mills *et al.*, 1992). But again, the object-oriented languages, which exist in the market today, are usually restricted to the two-dimensional frame-of-reference. Though VRML itself is not object-oriented, it allows for the incorporation of other object-oriented or scripting languages, such as Java and JavaScript.

3 USE OF VRML FOR MANUFACTURING SYSTEMS MODELING

3.1 What is VRML?

Just as Hypertext Markup Language (HTML2.0, 1995) is a file format that defines the layout and content of 2D pages with links to more information, VRML is a file format that defines the layout and content of 3D worlds with links to more information. The links can be either to HTML pages or to other VRML worlds. Unlike HTML, however, VRML worlds are spacious and inherently interactive - filled with objects that react to users and to each other.

VRML is a platform-independent language, which makes it portable across platforms with no difficulty. Some of the other features of VRML include specification of camera positions (called "viewpoints"), turning visibility of objects in the VRML world on and off, the ability to employ animated objects, provisions for database connectivity, and the ability to incorporate multi-user options. Viewpoints are one of the more powerful features of VRML. They allow the user to be transported to specific camera positions within the virtual world. There are no restrictions on the number of viewpoints in a VRML world. VRML also provides the ability to attach animations to viewpoints. This feature is useful if one intends to view animation from a particular camera position. The user also has the ability to move around in the virtual world ("cruise") on his/her own. Finally, objects can be included as “billboards” into virtual worlds. These objects can be either two-dimensional or three-dimensional and have the ability to orient themselves to the user as the user moves through the virtual world. Caution should be exercised in using this feature, however, as seeing only the front face of the object might not be the intention of the user.

3.2 Relevance of VRML Functionality to Manufacturing Systems Modeling

As previously described, manufacturing systems are extremely complex entities, which must be studied using multiple views and models. The sheer amount of information, variety of information types, and relationships that exist for such systems make it extremely difficult for any user to obtain an accurate, detailed understanding of the system via two-dimensional models developed using stand-alone applications. At the same time, the incompatibility of the various file formats used for different applications hinders the ability to develop integrated modeling environments. VRML is able to tackle both of these problems simultaneously.

Through extensive use of three-dimensional modeling features, VRML is able to give users a much clearer picture of the manufacturing system via different views and models. Objects in different models can be linked with each other using "hot links" in a similar manner to HTML web pages. The links can be used to connect to different types of modeling artifacts (e.g., physical object, function box, information flow, etc.) via the use of different modeling formalisms (e.g., layout diagram, activity network, data flow graph, etc.). Multiple viewpoints allow the user to "move" to particular locations within a model, and to then view the various objects in the model from that position, using various orientations. Additionally, multiple viewpoints can be used to move the user between different models as desired. Animation can be employed to show system behavior over time, while turning visibility on and off can be used to effectively isolate select models and/or objects, bringing them to the foreground.

The incompatibility problem is addressed via the platform-independent nature of VRML. Because of its neutral file format, many of the formats employed by different modeling packages can be translated to VRML. This allows for easy and efficient use of various modeling formalisms in the same VRML world.

3.3 Application of VRML to Manufacturing Systems Modeling

To integrate the various views of manufacturing systems, each view is represented as one or more levels in the environment. Since the quantity of views may vary according to the user’s perception of the system, the quantity of levels in the environment is variable: users can add/remove levels (views) as necessary. Features like changing the spacing between the levels, changing the orientation of the levels, and providing a fly-through of the environment can also be provided. These will allow the user to “customize” the presentation to suite his/her taste. Different types of manufacturing system objects, models, and data can be displayed on each level. The physical view for instance, could consist of a single level containing a three-dimensional model of the facility, with objects representing the various machines, conveyors, storage facilities, etc. The animation capability of VRML can be used to illustrate the machining operations being done at this level. Models at each level can be represented according to one or more modeling formalisms: the representation used depends on the application and requirements. IDEF0 and EXPRESS are commonly used for functional and information modeling. If more than one modeling formalism is to be used at a given level, the resulting models can be located adjacent to one another in different segments of the same level. A further enhancement might be to consider representing the various models via graphs, with each model as a separate node. To study the different views and models, the user can cruise at a particular level, viewing the level from any desired orientation and position. An improved approach is to provide viewpoints, allowing the user to move to a particular location to view the level. One of the advantages of providing viewpoints is that the user can always track the way back in case he/she loses place in the three-dimensional virtual world. In addition to moving at a particular level, the user can move between levels as well.

An important problem in manufacturing system modeling is to show the mapping between various views and the activities. The ability to provide hot links in VRML worlds can be used to advantage for mapping functions between the various views. Apart from the above features, the flexibility and ease of programming of VRML makes it ideal for building the hybrid-modeling environment.

4 PROTOTYPE APPLICATION

4.1 Application Description

The prototype VRML environment for manufacturing systems modeling is being developed for the domain of fabrication facilities, with the focus on machining processes. The environment consists of three levels: physical processing systems (physical view), information systems (physical view), and systems architecture (functional view), as shown in Figure 1. A brief description of the various levels is given below. For additional details, readers are referred to Krishnamurthy *et al.* (1997). This work is on-going, hence some of the features mentioned are still under development.

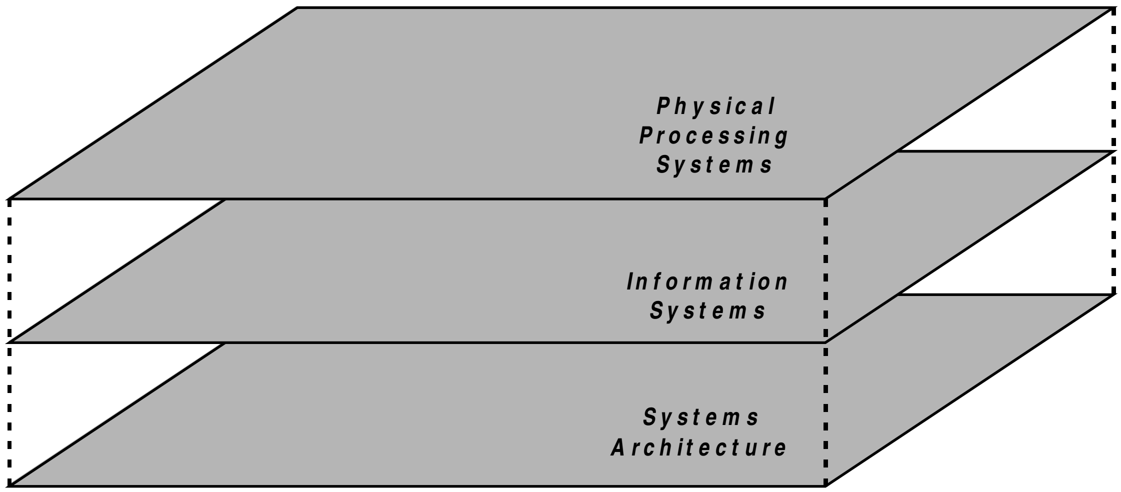

Figure 1 Levels in the Virtual Manufacturing System.

4.1.1 Physical Processing Systems Level

The physical processing systems level is used to model the items and facilities used for executing physical processing (manufacturing) activities. A single model is currently employed, the *physical processing systems model*. This model contains three-dimensional models of the various items found in machine shops, including production machines, material handling devices, engineering workstations, fixtures, tooling, raw materials, Work-in-Process (WIP), and finished-goods storage areas. Production and support personnel are modeled as well. The various parts that flow through the facility can also be shown. Figure 2 presents a partial view of this model.

4.1.2 Information Systems Level

The information systems level is used to model the items and facilities used for executing informational activities. The two models employed are the information systems model and the software applications model.

The *information systems model* contains three-dimensional models of computers, monitors, printers, plotters, communications networks, and various peripheral devices (e.g., bar code scanners, etc.). Electronic documents and messages travel on communications links, which are modeled as U-shaped channels, pipelines, or wires. The pipelines represent network connections between the computers in the engineering department, shop management offices, product data management (PDM) system, database management systems, shop machinery, and the shop floor. Data document icons move along the pipelines to illustrate data transfer among the different systems. The monitors show the interfaces to the various software applications employed.

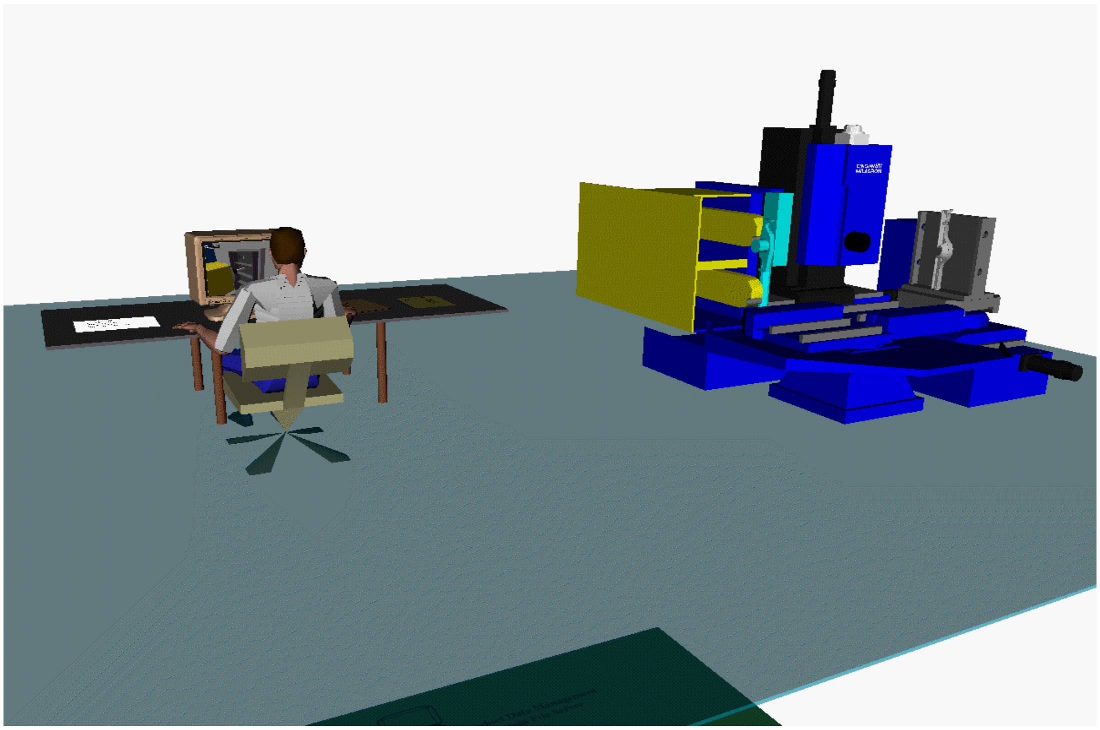

Figure 2 Partial view of physical processing systems model.

The *software applications model* shows the software applications resident on each computer system in the facility. Applications considered at this point include those used for design and analysis, process planning, numerical control (NC) programming, machine control, scheduling, shop floor data collection, tool management, inventory control, product data management, order entry, and shipping and receiving. The applications are represented as various artifacts: manuals, flowcharts, application output (e.g., graphic display), etc.

4.1.3 System Architecture Level

The system architecture level is used to model the functional architecture of the manufacturing system. A single set of models is employed, the *manufacturing activity models*. These are IDEF0 models of the various activities and processes used in manufacturing facilities, based upon the System Integration for Manufacturing Applications

(SIMA) Reference Architecture (Barkmeyer *et al.*, 1996). Activity model nodes are located under the appropriate physical or information system where the activity is carried out.

Figure 3 shows the virtual manufacturing system comprised of VRML models as described above.

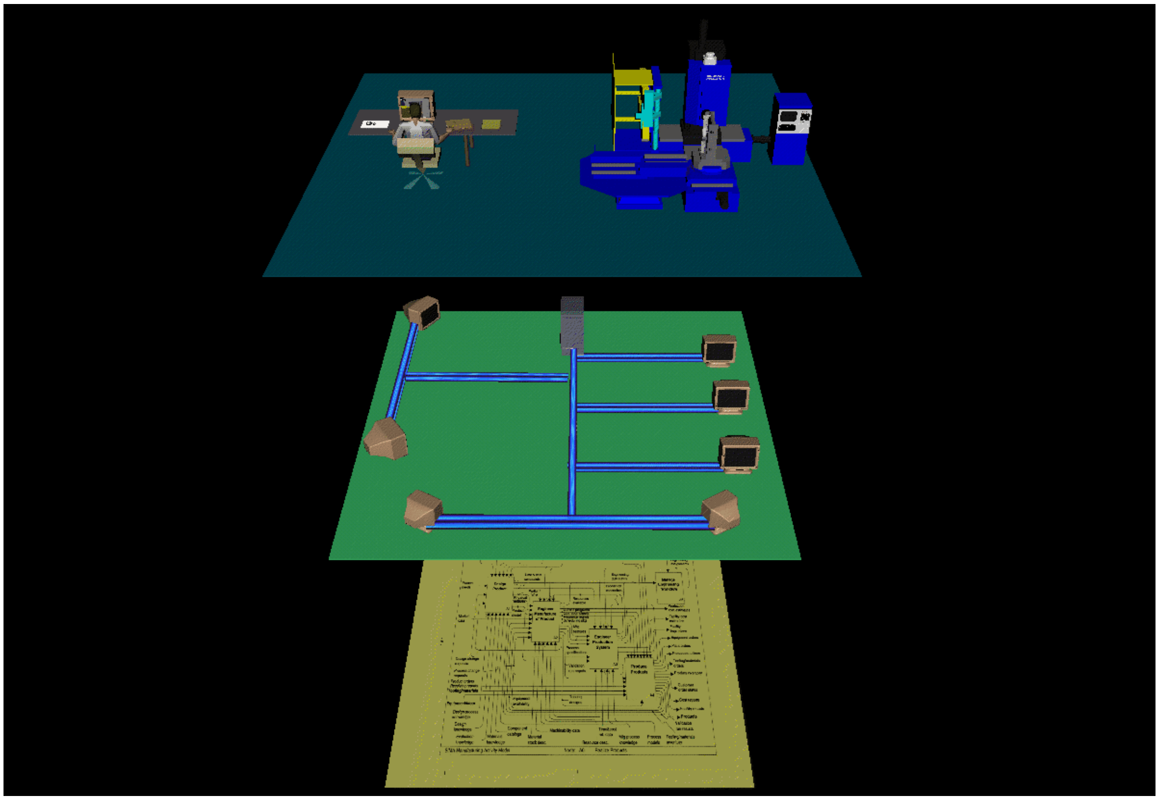

Figure 3 Virtual Manufacturing System comprising of VRML models.

4.2 Application Scenarios

To demonstrate the applicability and utility of the proposed approach, various scenarios are being developed. Scenarios are different manufacturing problems/questions for which solution information would be obtained via the VRML modeling environment and system models. A variety of scenarios are under investigation at present. Three examples are as follows.

Scenario #1: Determination of Activities Performed at Machines

Each machine in the facility performs a variety of processing activities. In order to establish which activities are performed by which machines, the activities must be mapped between the physical and functional views. This is done by using hot links at the physical processing systems level. Clicking on a machine in the physical processing systems model pops-up the functional activities (IDEF0 nodes and/or diagrams) which are performed at that machine.

Scenario #2: Identification of Equipment and Applications Associated with Item Production

In order to analyze production flow in the shop, it is necessary to know what products follow which routes in the facility, machine utilizations, supporting information requirements, etc. This information can be provided via hot links, visibility, billboards, and overlaying of information. Clicking on a part in the physical processing systems model pops-up the product's route sheet (possibly via a menu of selections). At the same time, the visibility of all machines not on the part's routing is turned off. A set of directed arcs appears, superimposed over the facility (in three-dimensional space) to show the routing, with arc color, thickness, etc. showing the proportion of flow intensity accounted for by that product. Billboards appear over each machine on the routing, showing the capacity required for production of that product, required NC programs, etc. By cruising through the facility, the user can study what is required to produce the product in the facility.

Scenario #3: Analysis of Information Flows

A large variety and amount of information is required to support the manufacturing process. This information flows between various pieces of equipment (e.g., servers, computers, databases, NC controllers, etc.) during the production process. The user can study the flow of information by moving to the information systems level and clicking on a button to "start" the production process. Animation is then used to show the flow of information (i.e., documents, parameters, code, etc.) through the various communications channels and media (e.g., pipelines).

5 CONCLUSIONS AND FUTURE RESEARCH

There is a clear consensus among researchers that an open environment is needed for manufacturing systems modeling. VRML appears to be an excellent candidate for satisfying this need. Even though it is not as powerful as some other languages, it does provide many features that are lacking in other environments, and is well-suited to the requirements of manufacturing systems modeling. VRML 1.0 [VRML 1.0, 1995] was restricted to representing static 3D worlds. VRML 2.0 [VRML 2.0, 1997] offers several improvements and can be used to represent dynamic environments.

This research is an on-going effort to provide an environment for integrating the various views and models used in manufacturing systems modeling. Work is being planned to develop an interface where the user will be able to interact with the system in a high-level language. Additionally, work is being carried out to develop the capability to perform simulations in VRML worlds.

Work described in this paper was sponsored by the NIST Systems Integration for Manufacturing Applications (SIMA) Program. No approval or endorsement of any commercial product by the National Institute of Standards and Technology is intended or implied. The work described was funded by the United States Government and is not subject to copyright.

6 REFERENCES

AMICE Consortium Report. (1992) *ESPRIT Project 5288*, Milestone M-2, AD2.0, 2, Architecture description, document RO443/1, Consortium AMICE, Brussels, Belgium.

Barkmeyer, E.J., Christopher, N., Feng, S.C., Fowler, J.E., Frechette, S.P., Jones, A., Jurrens, K., Lyons, K., McLean, C.R., Pratt, M., Scott, H.A., Senehi, M.K., Sriram, R.D. and Wallace, E.K. (1996) *SIMA Reference Architecture: Activity Models*, NISTIR 5939, National Institute of Standards and Technology, Gaithersburg, Maryland, USA.

Dodge, M., Smith, A. and Doyle, S. (1997) “Visualising Urban Environments for Planning and Design,” Graphics, Visualization and the Social Sciences Workshop, 8-9th May 1997, Loughborough, UK.

Doumeingts, G., Fénié, P., Régnier, P., Larrechea, M., Vallespir, B., Zanettin, M. and Chen, D. (1992) GIM, *GRAI Integrated Methodology*, Version 1.1, unnumbered report, LAP/GRAI, University de Bordeaux I, Bordeaux, France.

HTML 2.0 (1995) *http://www.w3.org/MarkUp/html-spec*, November 1995

He, H., Xiong, Y., Yang, S. and Wu, B. (1996) “Virtual Manufacturing System and Environment,” *IEEE International Conference on Industrial Technology (ICIT96)*, pp. 13-24.

Krishnamurthy, K.R., Iuliano, J.M. and McLean, C.R. (1997) *Development of Manufacturing Systems Models Using VRML*, NISTIR 6093, National Institute of Standards and Technology, Gaithersburg, Maryland, USA.

Mertins, K., Sussenguth, W. and Jochem, R. (1991) “Integrated Information Modeling for CIM: An Object Oriented Method for Integrated Enterprise Modeling,” *Computer Applications in Production and Engineering:*

Integration Aspects, Doumeingts, G., Browne, J. and Tomljanovich, M. (Editors), Elsevier Science Publishers B.V. (North-Holland), pp. 315-323.

Mills, J.J., Huff, B., Criswell, T., Graham, J. (1992) "The Virtual Manufacturing Workstation," *ASME International Conference on Design Theory and Methodology*, Arizona, USA, Vol. 48, pp. 35-39.

Mize, J.H., Bhuskute, H.C., Pratt, D.B. and Kamath, M. (1992) "Modeling of Integrated Manufacturing Systems Using an Object-Oriented Approach," *IIE Transactions*, Vol. 24, pp. 14-25.

Ressler, S., Wang, Q., Bodarky, S., Sheppard, C. and Seidman, G. (1997), "Using VRML to access Manufacturing Data," *Proceedings of VRML97 Second Symposium on the Virtual Reality Modeling Language*, Monterey CA, USA, Feb 26, 1997.

Schenck, D., ed., Information Modeling Language Express: Language Reference Manual, ISO TC184/SC4/WG1 Document N362, May 1989.

Smith, A., Dodge, M. and Doyle, S. (1997) "Virtual Cities on the World-Wide Web Towards a Virtual City Information System," *GIS Europe* (to appear).

VRML (1997) *http://cosmosoftware.com/galleries/2dgallery_eng.html*, August 1997.

VRML 1.0 (1995) *http://cosmosoftware.com/developer/moving-worlds/Overview.html#Introduction*, November 1995.

VRML 2.0 (1997) *http://cosmosoftware.com/developer/moving-worlds/index.html*, April 1997.

Vernadat, F.B. (1996) "Enterprise Integration: On Business Process and Enterprise Activity Modeling," *Concurrent Engineering: Research and Applications*, Vol. 4, Number 3, pp. 219-228.

Williams, T.J. (1992) "The Purdue Enterprise Reference Architecture," *Instrument Society of America*, Research Triangle Park, North Carolina, USA.