Assessment of Current Trends in Computer-aided Design and Manufacturing In The Furniture Industry

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Abstract

As part of a project sponsored by the Furniture Manufacturing and Management Center at North Carolina State University, an assessment of the use of CAD/CAM in the furniture industry in North Carolina and neighboring states was undertaken. The woods-based furniture industry, an important component of the North Carolina economy, is a manufacturing intensive activity for which CAD/CAM can provide great benefits. The project covers six stages: 1) An initial survey of the industry to facilitate the development of questionnaires and checklists, 2) site visits, 3) assessment of current industry practices, 4) assessment of current computing tools available for use by the furniture industry, 5) preparation of a written report outlining the current state and recommendations for future directions, and 6) holding workshops for furniture industry professionals. This report outlines the results of the project.

Project Goals

The 1980's and early 1990's saw a revolution in how information pertaining to the manufacture of projects is generated and managed. Computer-aided Design (CAD) and Computer-aided Manufacture (CAM) are two of the most commonly used computer-based tools in use in industry to help manage the manufacturing process. Increasingly, CAD/CAM has come to mean not only graphic-based information, but also includes the integration and management of text and numeric-based information at an enterprise-wide level.

Though there is a wealth of information on CAD/CAM practices and trends, there is very little material pertaining to the implementation and integration of CAD/CAM into the furniture industry in general and the woods-based furniture industry of North Carolina and surrounding states in particular. Developments in CAD/CAM have led to the creation of tools such as CNC machine control, parametric design, automated production documentation, 3D modeling, and advanced rendering. There is not, however, specific information as to how these tools could be implemented in the furniture industry. There is also no centralized source of information on what tools CAD/CAM specific vendors offer and how they could be integrated to provide industry solutions.

Many furniture companies have implemented CAD and/or CAM at some level. What is often lacking is a source of information of how their current tools might be improved or what other tools are available to enhance their impact. Consolidation of information pertaining to CAD/CAM practices both from within and outside of the furniture industry could be used to provide both base level information on computer-based tools and recommendations for future directions.

Certainly one of the strongest contemporary trends in manufacturing can be put under the general heading of concurrent engineering. This term has been articulated through a series of studies conducted by government and industry that looked into issues of keeping U.S. industry competitive in the global marketplace. Concurrent engineering is less a single idea as it is a grouping of concepts and techniques aimed at reducing product cycle time, improving quality, and lowering cost. These goals — as old as manufacturing itself — have both taken on new possibilities and new urgency with the introduction of computer technologies to all facets of the manufacturing operation. These concepts are used to help assess the current state of the furniture industry and to look at how engineering graphics curriculums can evolve to help train engineers and technologists to participate in the manufacturing workplace of the twenty-first century.

Site Visits

During the summer of 1994, site visits were made to nine different furniture companies along with phone contacts with a number of other companies. The product produced by the factory visited varied considerably (Table 1) but all produced furniture using wood as the primary material. On the whole, the companies visited produced furniture for the medium to high end market, primarily for residential use. The exceptions to this were two facilities which produced office and contract furniture and one which produced kitchen cabinets. All of the companies would be considered medium to large size and consisting of at least six separate manufacturing plants. Some were privately held, others publicly held, with some of these part of larger corporate conglomerates manufacturing related products such as other home furnishings, floor coverings, or plumbing fixtures.

Table 1 - Products produced at site visit locations

Product Manufactured	Number of sites visited manufacturing this product
Casegoods and Seating	5
Contract furniture and Office systems	2
Upholstered seating	1
Kitchen cabinets	1

There was a variety of CAD and CAM systems being used at the sites visited (Table 2). In quite a number of cases the systems being used had changed during the last three years. Sometimes the driving force behind the change in CAD software was changes in computer hardware, but in many cases it was the lack of capabilities in the software. All sites visited were using both mainframe/mini computer systems and PC's. In some cases workstations were also being used, usually because the chosen CAD software demanded their use. All of the sites except one were using CAM software to some degree, many of them quite extensively.

Table 2 - CAD systems used during the last 3 years at site visit locations

CAD System	Number of sites visited having used this system
AutoCAD	5
CADAM/MicroCADAM	4
Pro/Engineer	2
SDRC-IDEAS	1
Cadkey	1

Product Cycle

The residential furniture industry is unlike many other manufacturing industries in that their product development cycle is driven by twice yearly trade shows (markets) held in the fall and the spring. In addition, it is not uncommon for a medium sized company to premiere 50 new designs at one of the markets, 25 of which may end up going into production. Though groups of furniture pieces are likely to contain similar stylistic elements (i.e. be part of a suite), each one needs individual development by engineering and its own set of manufacturing documentation.

This sort product cycle also means low production volume, especially for medium to higher end priced pieces. Those pieces which go into production are likely to only have runs of 50-150 units. The result is a company may produce 50-150 units of 25 different new designs in addition to continuing to produce strong sellers from previous markets. In addition, in some market segments such as contract furnishings, custom orders are the norm. The result is a low volume production

environment with very complex product development, scheduling, and production needs. This sort of low volume production environment is also very common in high-tech industries such as defense or medical instrumentation. The difference is that there is considerably more price sensitivity in the furniture industry and little tolerance for missing production deadlines.

A flexible manufacturing environment has been achieved in the furniture industry not so much from investment in high-tech robotics as in a highly skilled workforce that operates in an environment akin to an oversized custom cabinet shop. One of the greatest challenges is to find ways in which CAD/CAM tools can be successfully integrated in a cost-effective manner in such an environment. The skilled workforce and general purpose manufacturing equipment employed in the industry means the shop floor is usually quite flexible to changes in production requirements. What is typically less responsive is the product design and manufacturing information needed for production. An important goal is to find ways of making the enterprise more capable of responding to increasing demands for more timely and accurate generation of the information needed for production of new furniture pieces.

Information Exchange

One way to facilitate production is to improve the flow of manufacturing information through an enterprise. Though computers played a central role in all of the sites visited, like most industries, computers have been introduced in phases into different aspects of the operation (Figure 1). In most of the operations visited, mainframe or minicomputers were introduced some time ago for use in business accounting, materials requirement planning, and production scheduling. More recently, PC's and/or workstations were introduced in engineering operations for product development and manufacturing. The result has often been two sets of computer systems using operating systems and software which do not allow an easy exchange of product or manufacturing information. This situation is often aggravated by the fact the mainframe/minicomputer system is usually managed separately from the engineering computing systems. The result is both organizational and computer hardware/software barriers to efficient information exchange.

One example of this information bottleneck centers around information pull off from the detail drawing of the furniture piece. The production specification sheet is usually manually generated either on paper or on a spreadsheet. This information becomes the source of both materials requirement planning and scheduling but, because these functions are usually served through the mainframe/minicomputer system, the information often has to be hand keyed back in. This not only takes time, but also introduces another source of potential error in information generation. Because the scheduling is typically being done on a system incompatible with the CAD system creating the parts drawings, merging the two types of information onto a route sheet can also be a challenge. Expensive custom software and/or hand manipulation with printers and photocopiers are often used to achieve this merger.

Database software, when it is used, is also typically located on the mainframe/minicomputer system; this has meant parts coding done on the bill of materials must be manually associated with the parts drawings and other part and product specific information. On PCs, the most common method for managing CAD files is through file naming conventions. For example, a directory would be coded based on the type of piece and the furniture suite it belonged to. Individual parts files would be named based on a common part naming convention. This would mean that two similar pieces from different suites would have files in their respective directories named exactly the same. Comments were made by engineers and detailers that it was not uncommon to pull up or print the wrong drawing because they did not realize they were in the wrong directory. When asked how they made sure they were working with the most current version of a part design, the reply was that they simply made sure they always erased old versions of the part files.

The extensive use of freelance designers has meant a divergence in the level of computerization. By and large, the designers have been much slower to adopt computer tools than the product engineers with whom they work. CAD tools have, for the most part, concentrated on supporting engineering documentation and have not provided affordable tools to support work in the early stages of the design process. What systems do exist that might support early phases of the design process are typically expensive and often not wholly compatible with the CAD systems used by the product engineers. This situation is aggravated by the fact that many of the established designers are in their 40's and 50's and are reluctant to change their creative processes at this point in their careers. The result is that product engineers are usually responsible for creating detail drawings either from 1/8 scale or full scale drawings and sketches. Regular meetings are usually required to confirm that the engineer correctly interprets the designer's drawings.

Another reason designers have shied away from the use of CAD tools has been the lack of support for complex curves. On higher end furniture lines, the curved lines of carvings and/or moldings often become the signature for the pieces. Designers have found the spline curve and surface tools in CAD packages to be constraining to their design process. These curves are typically sketched by hand by the designer and then digitized into the CAD system for tooling documentation or into a CAM system for programming CNC routers.

The Potential for 3D Modeling

Though a number of the companies visited were using 3-D modeling software, most of these companies had only been using 3-D for a short time and were still doing pilot studies with it. Certainly the single biggest factor companies using or considering the use of 3-D modeling were concerned with was productivity: would they be able to produce the required documentation for production as quickly as they had either by hand or using 2-D CAD methods? Secondary (but still important) considerations were the cost of the hardware and software, training costs and time requirements, and compatibility with current computer systems. One company had moved directly from hand drawing to 3-D solids modeling two years ago and definitively said they had no interest in going back. On the other hand, another company had been working with a 3-D wireframe modeling system and were not convinced that it had improved their productivity over 2-D CAD. The other users of 3-D solids modeling systems were too early in the piloting stages to be able to come to a definitive conclusion. These newer users of 3-D were, by and large, extremely

excited about the promise of 3-D solids modeling. In one case, 3-D solids modeling was the centerpiece of a two year development effort that was to completely revamp the way in which products were developed and engineered within the company.

Based on what was seen in the companies visited and from information gathered from other sources, the potential for 3-D modeling in the furniture industry centers around:

- speeding the initial generation of product information through the use of 3-D modeling tools, standard parts libraries, and parametric tools
- eliminating redundancy of information entry through better electronic data management and exchange
- reducing errors induced by the necessity of 'interpreting' 2-D documentation

In summary, the result of these improvements is increased agility in responding to customer demands for design changes; time to produce the necessary engineering information is more predictable, costing is more reliable, and quality control is more manageable.

The initial generator of product information used in the manufacture of the furniture pieces is typically product engineering. This division would also be the ones most likely to be spearheading the introduction of CAD and 3-D modeling into the company. The above mentioned goals, in some cases, means cooperation of individuals and divisions outside of product engineering, but to some degree can be implemented without changing the product development process external to its division.

The shorter term goals for 3-D modeling can be restricted to involve only changes in the product development process contained within the product engineering division (Figure 2). The 3-D model database of the furniture piece can be linked to an information/document management system either internal or external to the CAD system to become the center of product development activity. By treating the 3-D CAD model as, in essence, a spatial database of product information, information necessary for manufacture can be linked to parts of the 3-D model. Rather than creating a separate product specification sheet, all the information normally contained on this sheet is either explicitly or implicitly attached to the individual parts. Explicit information might include species information or special manufacturing information. Implicit information might include dimensional information of the part. As necessary, all of this product information can be extracted for printout or linking with other operations such as materials requirement planning or scheduling. Ideally, the model will be built to finished dimensions and the rough dimension information generated using hand calculation and automated 'rules of thumb' embedded in macro routines.

Part of the reason so many designs can be produced for a single market is that most furniture factories use their own standard construction methods. A new piece may only vary from a previous design in the veneer wood species, overall proportions, and finish trim. For that reason, there is tremendous potential for the use of standard parts libraries. One of the difficulties of using standard parts libraries in the past has been that almost all parts in a piece of furniture are interrelated and changing the dimensions of one part dictates altering many others. Parametric tools hold the potential for simplifying the use of standard parts by relationally linking parts in the furniture piece so that when the dimensions of one part are changed, all other parts are also updated. More robust parametric tools can use rule-based instructions to automate other drawing tasks. For example, a rule can be defined to add another dovetail in a drawer side anytime more than an inch in height is added to the drawer.

One of the concerns of using a 3D modeling system is whether the time spent creating the 3D model is simply added to the time needed to create the multiview drawings of individual parts. For the most part, considerable time is saved in the creation of parts drawings. Views of the 3D model are 'captured' and documented with the appropriate dimensions and notes. If a multiview drawing is created, there is no longer a concern that an 'impossible' part is created by incorrectly drawing a view. In addition, there are no longer any constraints on the creation of pictorial views of parts since the 3D system can capture one projection as easily as it can any other. Pictorial views are often easier to interpret for assembly and some machining operations. If the parts drawings are also linked to the 3D model, they to will be dynamically updated if the model is altered. This can lead to considerable savings in drawing time if the design needs to be changed after market introduction or during engineering.

Since product engineering is often in charge of generating CNC code for manufacturing, a more robust CAD system may allow faster, more accurate generation of code (Figure 3). Tighter integration of the CAD and CAM side will mean less hand digitizing from drawings and the elimination of unnecessary paper documentation. Currently, most CNC work is limited to 2 and 2-1/2-axis routers. Though this is adequate for casegoods work, 5-axis routers are needed for sculpted parts such as chair legs or backs. More advanced 3-D modeling systems which support complex surfaces using NURBS (Non-Uniform Rational B-Splines) or similar techniques show the potential for streamlining the production of these expensive parts.

Ease of generation and manipulation of both planar and sculpted surfaces are necessary for the system to be fully integrated into the initial design work of a furniture suite. Both advanced modeling and parametric tools will ease the ability to generate multiple iterations of a design for viewing. Parametric tools will allow the exploration of proportions of functional and decorative elements on the furniture piece. Libraries of past pieces and individual parts will ease the mock up of new designs. The existence of shaper profile libraries eases the creation of moldings in the model using these shapes and encourages use of existing tooling.

The logical extension of creating a product database which serves just product engineering is to create a enterprise-wide database which can serve the complete product cycle (Figure 4). Much of this database would still originate as product engineering data in product development but would also be used in other aspects of the organization. One of the most important contributions of integrating product data on an enterprise-wide level would be to increase the coordination of materials requirement planning and scheduling with product development. If the scheduling/planning software is to continue to largely reside on mainframes or minicomputers, better data communication with the CAD data residing on PCs or workstations is critical to facilitating data exchange. The elimination of hand-keying of part information would save a step in data generation and eliminate costly keying errors.

Part of the setup of an enterprise database would be the inclusion of computer terminals on the shop floor. Tighter integration of the scheduling system with the CAD system would also simplify the process of generating route sheets for parts. One possibility would be to have routing information and parts drawings available on the computer terminals, making the most current data available on demand on the shop floor. In the cabinet room, access to the 3-D model of piece might answer questions about assembly not easily answered from parts drawings or pictorial assembly drawings. For training new workers, simple animations generated from the 3D model could be used to demonstrate assembly operations. Access to 3-D models on the shop floor could also be used in the sample shop. By having the sample pieces being made by workers querying the 3-D model directly for dimensions and assembly, the need for 'interpreting' a 2-D detail drawing is avoided. This also means that design changes can be made in the piece right up until the last minute before construction by simply altering the 3-D computer model.

Scheduling would also benefit from better data exchange with marketing, especially for special orders. One company noted that special orders made up close to one third of their production volume, generating a critical revenue flow, but causing considerable paperwork headaches. Marketing could benefit from better data exchange with the furniture designers by allowing them to render 3-D models of furniture designs. These rendered images could be used for exploring potential designs with target audiences, creation of promotional materials of released products, or working up special orders with customers.

From these initial site visits there was clear indication that CAD/CAM and related computer software tools is playing an increasingly important role in furniture companies of all sizes and product lines. Less clear was exactly what role it will play. A number of companies were staking a claim on 3-D modeling having solutions to many of their problems. Though some of the plans were more modest and involved localized change in the product development process, other plans were much more bold. Probably one of the biggest roadblocks to developing plans at any scale were difficulties in developing a plan of action which crossed many departmental lines and required numerous managers to buy into and agree to cooperate with the plan. A related difficulty is to convince those managers who control the budgets that these changes will indeed be cost-effective, both in the short term and the long term.

Survey of Furniture Companies

In order to supplement the information gathered during the site visits, a survey was conducted of approximately 100 wood-based furniture companies. These companies were chosen based on one or more of the following criteria:

- They manufactured wood-based furniture
- They were listed in the furniture trade press as being in the top 25 companies with U.S. operations.

In addition preference was given to:

- Larger size (based on estimated or actual yearly sales)
- Companies having factories in North Carolina or neighboring states
- Companies primarily manufacturing residential furniture

Of the 100 companies surveyed, 34 companies responded. The survey, found in Appendix A, consists of questions pertaining to the type of computer software and hardware used in the major phases of the furniture development and manufacturing process. Though there was not an opportunity to ask in-depth questions on the specifics of current and planned use of CAD/CAM and related tools, the survey did help give a snapshot of how these tools were being used today.

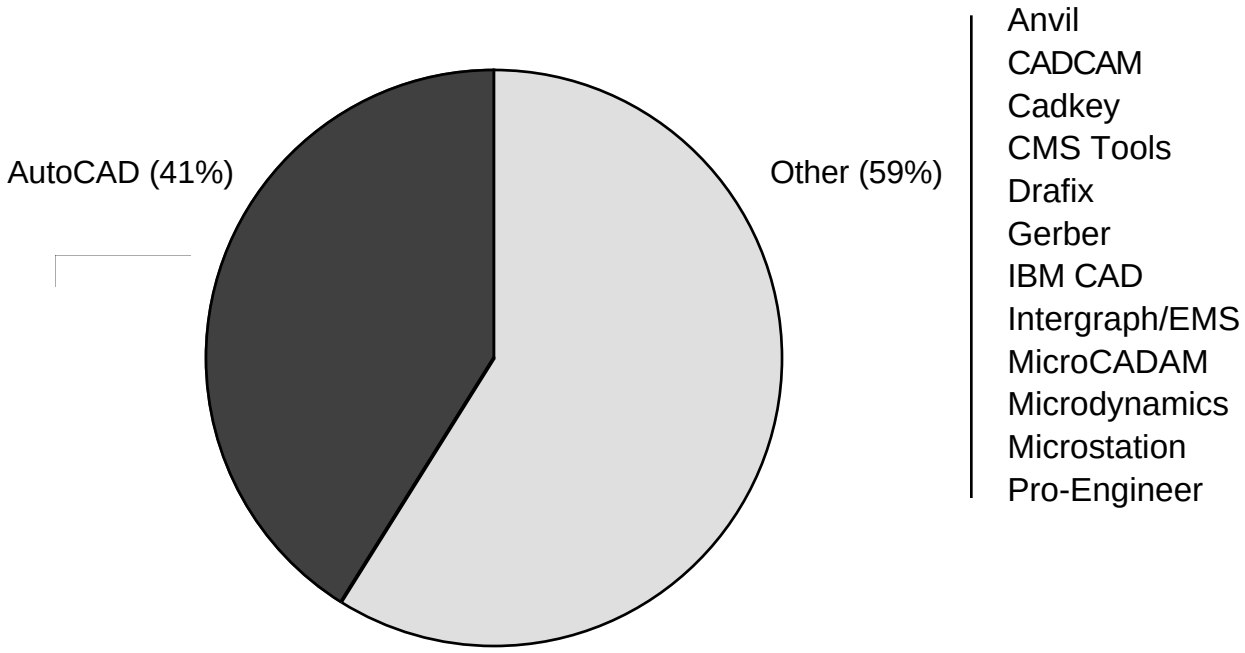
There was a clear diversity in size of the companies though a majority of them had over 50 million dollars in sales and very few of the companies considered themselves regional (Table 3). The average number of employees for these companies was 1644.

Table 3 - Demographics of responding furniture companies

Annual sales	**Percentage of companies**
Under 50 million	29%
50-100 million	29%
100-300 million	22.6%
300-500 million	12.9%
Over 500 million	6.5%
Base of operations	
Northwest	2.3%
Northeast	4.7%
Southwest	2.3%
Southeast	7.0%
National	34.9%
International	48.8%

Thirty-four companies reported using some type of CAD software for design and product engineering functions. AutoCAD had a clear plurality (Figure 5) but still only accounted for 41% of the companies responding. There were fifteen other packages being used by the remaining companies. Fifteen companies reported using 15 different bill-out software packages with similar trends for manufacturing scheduling, materials requirement planning, and document management software tools. Twenty-eight companies reported using CAD/CAM tools with a slight preference being shown for packages allied with AutoCAD (i.e., SmartCAM, QuickCAM, CMS Tools).

Figure 5 - CAD software used by responding furniture companies



Of the companies responding, there was a clear favorite for PCs and mainframe computers (Table 4). DOS was clearly the operating system of choice for PCs with only one company reporting using OS/2 and none using the Macintosh operating system. All of the respondents using workstations were using Unix whereas the mainframe and minicomputers used a variety of operating systems.

Table 4 - Computer hardware used by responding furniture companies

Computer Hardware	**Number of companies (percentage)**
PCs	46.3%
Mainframes	32.1%
Workstations	11.1%
Minicomputers	10.5%

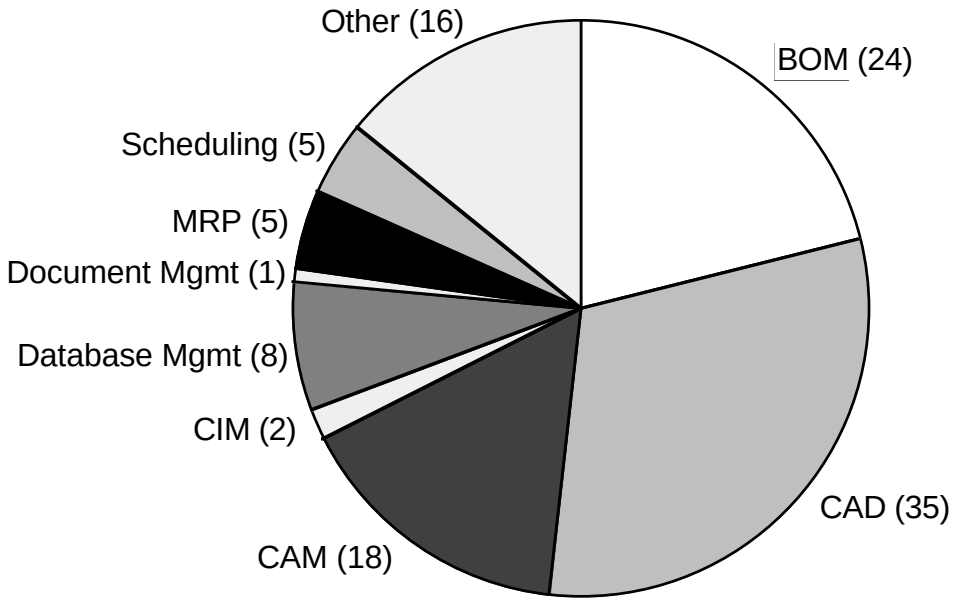
The most popular pairings of computer usage were PCs and mainframes or minicomputers, with PCs dominating the design, product engineering, and CAD/CAM categories, and mainframes and minicomputers dominating the manufacturing and materials requirement categories. Other categories were uniformly split.

The results of the survey largely paralleled what was seen at the site visits, with AutoCAD and associated packages running on PCs holding a plurality of the market for design, product development, and CAM functions. Also seen was a clear preference for using mainframes and minicomputers in scheduling and materials requirement planning. It was telling that for many of the areas outside of design and product development, there was significantly less usage of computer tools.

Survey of Software Vendors

In addition to sending out of the survey to furniture companies, letters were sent out to 143 software vendors requesting information on software products they either develop or distribute. Software with potential application in the furniture industry was identified through trade journals, software industry research publications, and the results of the site visits and surveying of the furniture industry. A total of 114 vendors responded either to the initial mailing or follow-up phone calls.

Figure 6 - Software vendor respondents (by category)



The information entered into the software vendor database provides a method for furniture companies to match their needs against currently available software. Once potential software is identified, the software literature mailed by the vendors can be reviewed. Of course, the vendors or their local representatives can also be contacted directly for more information. A summary of the information contained in the database is listed in Appendix B. The first part of the Appendix shows a checksheet which matches the vendors to the major categories of functionality. The second half of the Appendix lists all of the information entered for each of the vendors.

Benchmark and Workshop

Interaction with both the furniture industry and with software vendors clearly indicated there was often a large gulf of understanding in what current design and manufacturing software could offer to the furniture industry. To help them make an educated analysis of these tools, a benchmark was developed which embodies many of the potential applications of 3D modeling and related techniques discussed in this report. This benchmark (see Appendix C) is based on a generic casegoods design and was given to a select number of CAD software vendors as the basis for demonstrating a specific set of techniques. The vendors (and their flagship software package) participating in the workshop are:

- Parametric Technologies Corporation (ProEngineer)
- EDS Corporation (Unigraphics)
- Autodesk Corporation (AutoCAD)

Though the benchmark is going to only be demonstrated on a select number of software packages, the information contained in the database created through the software vendor survey can be used to match capabilities of software packages to the techniques demonstrated in the benchmark.

In bringing together some of the leading software vendors and furniture industry professionals to view and discuss a furniture-specific benchmark, it is hoped that some of the misinformation of what these and other software tools have to offer the industry can be dispelled. The advantage to the participating furniture companies is that they will be able to make better short-term and long-term decisions on how these tools can be successfully integrated into their operations. The advantage to the participating software vendors is that they will be better informed as to the specialized needs of the furniture industry and, therefore, be in a better position to service this client base.

Summary

The initial site visits to nine furniture manufacturing operations gave a good snapshot of the current status of CAD/CAM tools in the industry. These visits, reinforced by a mail survey of the furniture industry, has pointed towards many areas where software tools could improve the speed and accuracy in which product data is generated and communicated within a furniture company. The recent introduction of 3-D modeling tools in some of the companies visited has indicated the potential of these tools — combined with parametrics and product database tools — to increase the efficiency in the product development process. These site visits, combined with engineering and manufacturing trends in other industries, also highlight the potential of a 3-D model as a starting point for the development of an enterprise-wide product database. One of the primary purposes of this all-encompassing database is to better leverage the information generated during the product development process in planning, manufacturing, and marketing.

The benchmark developed around techniques and technologies outlined in this report will be used as the basis of a workshop in which some of the leading design and manufacturing software vendors and furniture industry professionals can educate each other as the state of their respective industries. This workshop should have an impact beyond the participants of the workshop as the participating software vendors demonstrate their benchmark to other furniture companies and participating furniture companies request other software vendors to demonstrate

some of the techniques demonstrated at the workshop. A future goal will be to build on this benchmark to incorporate software tools and techniques that encompass more of the potential applications of an enterprise-wide product database, as shown in Figure 4.

Appendix A

Appendix B

Appendix C