

From Geometric Modeling to Product Data Models: Collaboration Between Engineering, Computer Science, and Industry at Leeds University

Daniel E. Whitney, Liaison Scientist, Manufacturing

Summary

The Computer Aided Engineering Unit in the Mechanical Engineering Department at Leeds University has built its expertise on increasingly sophisticated geometric modelers over the last 15 years. From this base, two main trends have emerged. The first is increased sensitivity to the need for structured data to represent products as a whole, not just their geometry. The second is a broadening view of design beyond creation of geometry to include concurrent engineering.¹ In both cases, the Unit has established strong ties with the Computer Science Department and has also hired individual staff who combine engineering and CS backgrounds. These ties give the Unit's research a quite different character from that of most other CAD/CAE labs, especially the German ones. Most research has industrial partners. The test cases they provide are "really challenging."

Some results from this lab have had practical consequences. One is an institute devoted to standardizing data formats and promoting data interchange. The other is active participation in the PDES/STEP² process; a member of the Unit is the editor of STEP Part 41, which defines product configuration data.

Recent research has focussed on a product data editor. This is an interactive software tool for designing product data descriptions. The implication is that product data represent a generic need but each product will require its own structure. An important issue is how to define the appropriate structure in each case. Right now the editor creates essentially elaborated, hierarchical parts lists with links to important design algorithms and references to relevant data. The structures contain information about single parts but no information about assembly or other technical interrelations between parts other than set membership. STEP Part 41 has the same character.

New research with UK government and industry funding is dealing with defining product data models that will support concurrent engineering. Both fabrication and assembly will have to be dealt with. The work is just starting and no definitive results are available.

The Unit's past and current research is strongly influenced by industry and by long term government funding patterns. University budgets are now based in part on matching funds from industry. Research projects in manufacturing must be structured like concurrent engineering activities: the users of the research must be part of the research project from the planning stage to the time when the "results" are "delivered." Because of the sweeping influence of these funding patterns on universities at large as well as on manufacturing research, the article begins with a discussion of these trends. The Unit's director, Prof. Alan de Pennington, has had a key role in advising the UK government on design and manufacturing research policy. In the mid-1980s he was a Program Director in the NSF Division of Design and Manufacturing. This discussion benefits from his insights.

Background

Prof Alan de Pennington is the director of the CAE Unit, still colloquially called the Geometric Modeling Project for historical reasons. He is one of six professors in the Mechanical Engineering Department, the others being mostly in traditional ME areas like tribology and fluid mechanics. Before coming to Leeds, de Pennington was at the Philips Production Automation Department at Eindhoven. There he met Prof Herb Voelcker, a pioneer in solid modeling, and took inspiration to develop CAD models. He has been at Leeds since 1979 and is now a leader in this field as well as a member of several influential UK government committees that plan research. He therefore offers interesting perspectives on such matters as

- ° how funding trends and reorganization of the UK university system affect what research topics are pursued as well as research projects' balance between basic research and research that must be transferrable to industry within the life of a single research project

- ° how computer science can be combined with engineering and design and what kind of research emerges

- ° how each of these issues is reflected in the balance between "top-down" and "bottom-up" in design research

(See separate ESNIB article Government Funding Policy for British Universities and University Research, where these topics are discussed in detail.)

History of the CAE Unit's Research

In 1979 the first of a series of geometric modeling projects began. These resulted in commercial CAD modelers and in phase II some computer capabilities in numerical control based on solid models. Spurred by some of its industrial partners, the unit began in 1983 to work on CAD data interchange. The CAD-CAM Data Exchange Technical Centre, an industry-funded consortium, is one result. de Pennington feels that phase II was somewhat ahead of its time for both the researchers and the industrial partners. The ideas of concurrent engineering were in the future, and the partners did not understand the potential of solid modeling to capture important design and engineering information. In particular, they resisted his attempts to include assembly modeling in the project because they thought assembly was not itself a cost-driver for manufacturing. Also, the researchers did not produce a modeler with a good user interface, preventing the users from appreciating it. Yet the users blocked Leeds from working on UI, thinking there was no research issue there.

By 1987 the Unit stopped direct work on solid modelers, since very good commercial ones were becoming available. Instead, it launched phase III of the GMP with an effort to provide Information Support Systems for Design and Manufacture. The result of this project, in collaboration with the Computer Science Department, was the product data editor, about which more below.

Starting this year, the group is working on "Exploiting Product and Manufacturing Models in Simultaneous Engineering." It is just starting up and has not produced any firm results. The goals are to extend the idea of product data, addressing such questions as

- what is a specification for a product?
- what is an assembly data model?
- what is a manufacturing model?
- how can conflicts between specialists on concurrent engineering teams be resolved?
- how can different specialists' models be harmonized?

The industrial partners include a high tech systems house, a food packaging machine maker, and a materials handling equipment maker. This mix is intended to provide a variety of products whose data needs are different.

The Product Data Editor

"Product data model" is new terminology since the mid 1980s. While the Unit's appreciation for such data goes well beyond geometry, in practice the research deals mostly with geometry. In that context, a product data model organizes geometric data, provides a hierarchy for it, and provides hooks for applications that will work on it. Typical applications check for intersections between solids, define or check relationships between entities (e.g., parallel to...), annotate drawings with dimensions and tolerances, calculate tolerance stackups, plan inspection programs for coordinate measuring machines (actually plan the approach path for the inspection probe), and plan numerical control machining.

The goal of the product data editor is to permit creation of organized and coordinated data structures that allow the applications to get the information they need from one central database. This contrasts with current commercial capabilities in which data are created and structured during the design process by the CAD software. The resulting data structure suits the CAD process but not much else. The data must often be massaged or converted to a new form before a new application can work on it.

While recent object-oriented data structure efforts have produced hierarchical trees, the Leeds structure editor creates directed graphs. In order to support recursive structures like {products contain parts or subassemblies which contain parts or subassemblies}, the graphs can be cyclic. They thus can support a "part" which is actually an assembly of parts.

In other respects, the Leeds structures resemble objects: they can contain slots³ with attributes or methods. Substructures can be generated as instances of master structures. These are called patterns. Some of these patterns can be generated with parameters that will get their values later, thus permitting decisions to be deferred.

Given the capability to define arbitrary structures, the question becomes: what kinds of structures and patterns would best support product descriptions? Several of these patterns have been identified:

{name|attributes|comments}

{name|abstraction|comments} (abstraction is just a collection (COL) node in the graph onto which other nodes are hooked)

{specification or requirements | definition or design seeking to meet the requirements | actual or as-made instances of the design}

I was shown the proposed general structure, a portion of which appears in Figure 1) Three data structures with major similarities are outlined. At the top is the most general structure, which describes the product. Below are two dependent structures describing assemblies and individual components. The arrangement and content of each of these structures is the same, except that, at key points, the word "assembly" or "component" is used in place of "product."

Interestingly, the structure contains "FEA analysis" as one of a collection (COL) of nodes fairly near the top of the hierarchy, indicating that a finite element model was presumably needed at the "product" level. This is quite unusual. (Note in this figure the repeated occurrences of FEA analysis at the "assembly" and "component" level.)

It is necessary to point out that this structure was carefully made and not arbitrary, but did not represent a tested model of a real product. Yet the inclusion of the FEA node at this unexpected place provides an irresistible opportunity to ask where such structures might come from in the future. All the previous data models I have seen in industry are in some sense mimics of a product design/development process. Hence they contain essential elements of time and logical precedence, indicating data that are needed first, then second, and so on, plus the data flows as inputs and outputs.

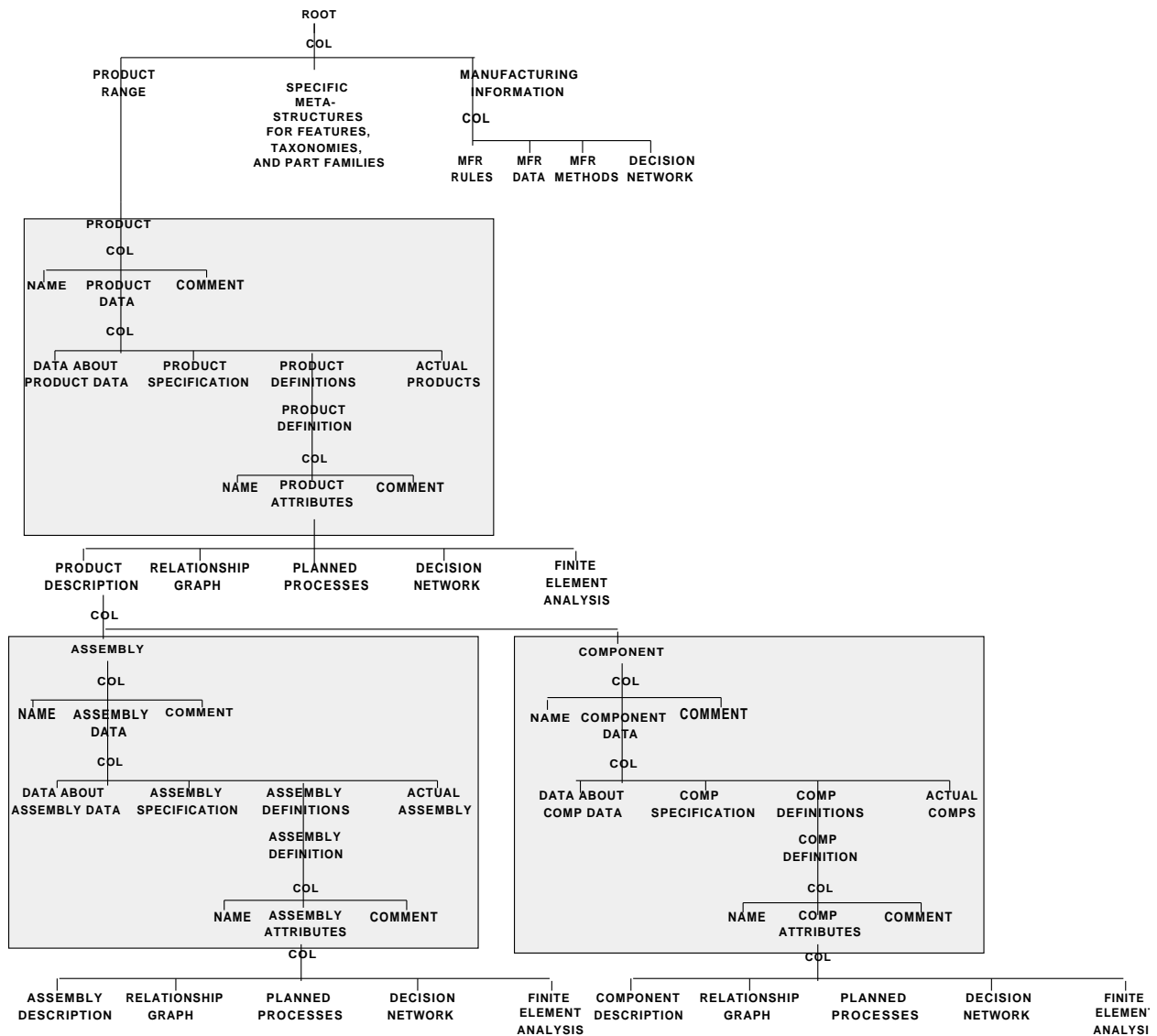


Figure 1. Fragment of Product Data Model

The Leeds structures are not typical time-based models of design processes like PERT/CPM diagrams (and of course they need not be). Instead they are something else, but it is not clear what. They are not just descriptions of the product because they have references to engineering analyses high in the structure. These references correspond to a time relationship in the design process: when an assembly model is available, do an FEA on it. Why are these FEA references there? How did someone decide that they belonged there? What is the relationship, in other words, between this structure and its creator's image of the time-based design process? de Pennington and his colleagues quite openly agreed that this was an issue, that the structure simply evolved from their internal debates and industry input, and that a methodology for constructing such structures is needed.

This discussion also points out, again, the fact that one can include data in a "product" data model that actually support or even describe the design process rather than the product itself. This is an important and perhaps paradoxical point. It may be an admission that there is no

such thing as pure product data. A similar point is made by Prof Voelcker: 50 years ago designers annotated drawings with notes like "drill and ream." That is, the designer put process planning instructions on the drawing. In more recent times, the ideal has been to separate design from process. The designer says what tolerances he needs but a process planner decides whether or not reaming is needed to achieve the tolerances. The choice may hinge on what machines are available or how many of the part are needed. This is a nice ideal but it plays a big part in separating design from design for manufacture. The disadvantages of this separation are now clear, but there is still no agreement on whether designers should resume saying "drill and ream." Similarly, product data designers are investigating whether, when, or on what part sets FEA analyses should be done.

Many people familiar with electronic product design and manufacture (VLSI for example) point out that one of the main reasons why VLSI has advanced so rapidly is that designers need not concern themselves with process issues. The process limitations are represented by design rules that can be expressed purely in geometric terms (minimum radii, minimum line width and separation, etc.). These rules can easily be checked and enforced by the computer. Furthermore, most elementary functions in VLSI are represented by standard cells of basic devices and interconnects which the designer can lift from a library. This leaves the designer free to think almost completely in terms of functions.

If the Leeds work is a harbinger, then it adds evidence that mechanical product design will never be accomplished as pure data manipulation at the function level the way VLSI design is.

A final point: this research clearly shows the influence of sophisticated computer science, provided not only by collaborators Prof Peter Dew and David Holdsworth from the CS department but also by staff members Susan Bloor and Alison McKay who combine engineering and CS backgrounds. Dew spent several years working on VLSI data architectures and automated design methods. None of the German CAD research observed during my visits in Europe contains anything like this level of CS participation or sophistication.

Product Function Modeling

Professor Neal Juster and his student Jim Baxter are starting a project to add function modeling capability to the product data model. They began with some interesting "false starts" that were too geometric in their opinion. The first of these was assembly fit modeling similar to what assembly planning researchers do. That is, relations between parts were modeled with the "fits" and "against" relations pioneered by the AI group at Edinburgh in the 1970s. Then they tried the 4x4 matrix relations first published by Gossard and Lee. Neither of these can capture function. To fill that gap, they tried naming the relations more specifically, such as gear mate and screw mate, hoping to mimic the thought process of a designer who wants to mate gears or fasten parts together with screws. They are not satisfied with this approach either, although they presently have another student at a company trying to represent a design process for a product in terms of information that ultimately impacts its assembly.

In the meantime, theoretical thinking is proceeding along the lines of graph representations of functional relations between parts. Baxter has analyzed a gearbox and tried to characterize each of the joints in terms of some function or functions it performs. Examples are

- support
- seal against fluid leaks
- transfer torque
- attach
- locate geometrically
- permit motion
- prevent motion

and so on.

Graphs are then made by linking all the nodes that perform the same function.

Some obvious logical checks can be made by inspecting the resulting graphs. For example, if the graph made by connecting the "support" nodes is disconnected, then parts of the product are floating free and unsupported. As another example, if the definitions of the functions are made carefully enough so that, for example, "attach" is never confused with "fasten," then if an attach graph and a fasten graph ever share a node, a classic design error might be detected: using a screw to provide geometric location. This is inadvisable since screw threads do not provide high quality surfaces for providing location.

This work is still in the early stages and no definitive results are available. It looks interesting, however.

Conclusions

This article deals with two related topics: future strategies and patterns of UK research funding for manufacturing and design, and one university's response to it. The government strategies are becoming decidedly short term - 3 to 5 years to obtain results -but the researchers are able to carry out fairly generic research anyway. It is quite strongly focussed in industry because real case studies are continuously being carried out.

Cross-disciplinary research is proving to be not only intellectually important but institutionally important, too. Collaborators may have higher survival rates. In US universities, tenure usually goes to people who prove they can survive alone. It's an interesting contrast.

Finally, the particular collaboration illustrated by this lab appears especially promising, giving a professional level to the computing aspect of engineering design research that is not often seen.

References

anon., "Manufacturing Research Strategy for the Nineties," ACME Directorate, SERC, November, 1991.

McKay, Alison, "A Framework for the Project Meta-Structure," iss-pds-report-8, an internal working paper of the Information Support Systems for Design and Manufacture Project at Leeds University, July 1989. (Figure 1 above is Figure 4 from this report.)

Point of Contact

Prof Alan de Pennington
Department of Mechanical Engineering
University of Leeds
Leeds LS2 9JT
phone 0532 332112
fax 0532 424611

¹ NOTE TO EDITOR AND SCIENTIFIC DIRECTOR: AT YOUR OPTION, YOU MAY INCLUDE THIS TEXT IN-LINE WITH THE ARTICLE UNDER THE HEADING "CONCURRENT ENGINEERING" OR YOU MAY PUT IT HERE AS A FOOTNOTE.

Concurrent Engineering (CE) is a recent and evolving technique for designing products. Its best practitioners are probably the leading Japanese companies, although companies world-wide recognize its advantages. Its goals are to include more of the manufacturing and field use issues early in the design process than has typically been done. The "non-concurrent" approach resembles an assembly line, in which each department (design, engineering, manufacturing, sales, etc.) does its work on the design and passes the work on to the next department, along with a host of problems that could have been mitigated by mutual consultation. CE presents a wide range of intellectual problems because it requires explicit and rational resolution of highly complex and interacting conflicts between the various departments. Data and algorithms for resolving these conflicts are scarce or non-existent. Most of the companies and some of research laboratories I visited in Europe are addressing one aspect or another of CE. A good example of European industry's efforts in CE is discussed in the ESNIB article "Dramatic Reductions in Lead Time at Volvo Based on Restructuring the Design Process and Introducing Computers."

² This acronym has become the name. It has more than one translation. The most recent is: Product Data Exchange Using STEP/Standard for Technical Exchange of Product Data.

³ "Objects" are data structures that exist independently of each other. Objects are organized as a set of "slots," each of which may contain data, algorithms, or other objects. Data are sometimes called "attributes," because they provide information about the object. Algorithms are sometimes called "methods." They describe how the object is to behave when executed. In "object-oriented programming," software may consist entirely of sets of objects.