As 3D design evolves, so pressure rises correspondingly to use that 3D data in downstream processes. However, 3D geometry alone is not sufficient to express information that production and manufacturing shop floor staff need to do their jobs. Along with the 3D geometry, other information including configuration data, colors, annotations, dimensions, animations, etc. are increasingly required.
The Current Situation of High-End 3D CAD

This chapter discusses how lightweight 3D data technologies which apply 3D CAD and data in downstream processes can support production processes and the manufacturing floor, starting with the 3D CAD software used by design departments.

3D CAD was developed for use in design in the manufacturing industry, which typically deals with countless parts for example in the aviation and automobile sectors where production also involves numerous companies. Mainstream 3D CAD software applications include Dassault Systemes’ CATIA software and Siemens PLM’s NX application. These CAD software programs are able to express the 3D geometry of parts using precise free-form surface representations. CAD programs often come with various modeling functions which deliver complicated surfacing tools such as fillets, in addition to those for designing basic shapes. As more and more products are being designed using CAD, so CAD products are providing even more technical modeling tools such as special modules for designing molds, pipes, or wire harnesses.

The Pro/ENGINEER CAD software from PTC, the first CAD manufacturer to commercialize parametric design functions, is widely used by electronics manufacturers. Parametric design allows the automatic generation of appropriate 3D parts just by changing parameters in a given design. This is very handy for designing diverse parts with similar shapes. High-end CAD applications are used by design departments that are upstream of manufacturing. They are indispensable tools for design of large products for which high quality and accurate design has to be ensured. These applications provide tools which assemble multiple parts appropriately in a virtual environment and define product structures. Product design work is complete when all parts have been created or selected and are correctly laid out. When designing and manufacturing products such as airplanes and automobiles, the number of parts used can range from tens of thousands to several million. In such cases, the management of part data is important. For this reason, various CAD manufacturers are now also providing product databases (PDM - Product Data Management). Recently, in addition to straightforward 3D design, users are also starting to seek collaborative design tools which allow them to carry out design work while sharing data.

PDM is gradually becoming a mainstream business to many CAD vendors. Now that products can be designed with CAD, and the data managed by PDM, CAD vendors have developed overarching systems which cover the whole product lifecycle: from design at the upstream to downstream processes in production and plants. They call these systems PLM - Product Lifecycle Management - and position PLM systems as an infrastructure tool for manufacturing.
The spread of Microsoft Windows and the development of PC hardware led to the introduction of relatively inexpensive mid-range 3D CAD products in the latter half of the 1990s. SolidWorks (bought by Dassault Systemes in 1997) enables 3D parametric design on a Windows user interface and is one of the first examples of such a product. Today, it is still favored for design of home appliance manufacturers and by small-to-medium manufacturers. PTC also delivers a mid-range CAD application called CoCreate. Interestingly, PTC’s CoCreate software does not have parametric design functions, but uses ‘explicit design’ as its major feature so that direct editing on each part is possible without having to use parametric rules. CoCreate is mostly used in the precision machine industry which has little need for parametric functions.

An example of 2D CAD software applications, and one which is now regarded as a worldwide standard, is AutoCAD developed by Autodesk. For 3D mechanical CAD, Autodesk provides its Autodesk Inventor product. AutoCAD users, who are familiar with 2D-based design, are now gradually using Autodesk Inventor as a 3D design tool. When 3D CAD is used, 2D drawings are typically created directly from the 3D after design is complete. Autodesk has expanded the amount of its 3D CAD users by selling upgrades to its existing 2D users. As a result, many small-to-medium sized companies are now using 3D.

These mid-range CAD products deliver tools for low cost and easy 3D modeling. Recently, with the ever-increasing offerings of 3D modeling functions and CAM/CAE applications, and the release of simple and affordable PDM systems, the difference between mid-range and high-end CAD is becoming increasingly undefined.

To differentiate themselves, CAD vendors are now starting to provide integrated systems (PLM/PDM) to manage 3D data used in design and manufacturing processes. Figure 3.1 shows 3D CAD manufacturers and their products.
3. The Evolution of Manufacturing Using Digital Information Technology

Figure 3.1. 3D CAD vendors and products

**From 2D to 3D**

So how do users choose between all these CAD products? Generally, the design department of large manufacturers design products use high-end 3D CAD, while Tier I suppliers use high-end or mid-range CAD, and secondary and third party suppliers would use 2D CAD to distribute information on the drawings created. Even at large companies, mid-range 3D CAD and 2D CAD are still used for facility or tool design. As the performance and tools available for mid-range 3D CAD improve, so more and more leading manufacturers are turning to it. In whatever scenario, however, 3D CAD products are becoming more and more popular, replacing 2D CAD, even among small and medium sized companies. The reasons for these trends are shown in Figure 3.2, and are described below.

1) The popularity of 3D CAD is growing due to improvements in ease of use, and reduced barriers for companies introducing it into their business process.

2) With 3D CAD having been established among large manufacturers, CAD vendors are now targeting small and medium size companies, and starting to sell inexpensive applications.

3) 3D CAD applications have reasonable compatibility for 2D drawing demands. These applications are able to obtain cross-sectional drawings from 3D CAD models, and use them in 2D drawings. Some 3D CAD software products provide functions which use design via 2D drawing tools and convert the data to 3D geometry.
4) More and more leading manufacturers are distributing data in 3D CAD formats, causing more companies to work in 3D data instead of 2D. Organizations such as the Japan Automobile Manufacturers Association (JAMA) and the Japan Electronics and Information Technology Industries Association (JEITA) are also promoting 3D design processes.

5) 3D CAD education at universities and vocational schools is increasing in availability and quality. Many municipalities are also encouraging the use of 3D CAD. And some organizations such as the Computer Software Association of Japan (CSAJ) can certify a company’s 3D CAD competence (3D CAD Usage Engineer Test in the case of CSAJ) to allow qualitative comparisons among companies.

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**Figure 3.2. Transitions for 2D CAD to 3D CAD**

| 1) Improvement in ease of use and functions of 3D CAD |
| 2) More and more low-priced and packaged 3D CAD products |
| 3) Improvement of drawing functions of 3D CAD |
| 4) Distribution of data in 3D by more and more leading manufacturers |
| 5) Promotion of 3D data use by educational organizations and municipalities |

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**Examples of 3D Education by Municipalities**

A sign that the spread of 3D CAD is accelerating can be seen in the efforts of the Iwate Prefecture in Kitakami City, Japan. Kitakami City is well-known for success in industrial agglomeration by inviting manufacturing companies to the city. In an effort to differentiate itself from other cities, Kitakami City has been committed to supporting the use of 3D CAD/CAM since 1999. In 2006, the City focused on its “Kitakami City 3D Manufacturing Innovation”, introducing CATIA for CAD and XVL for 3D data use to educators as well as to businesses in the area. Students who master both 3D design and the use of 3D data are expected to become leaders for the region in 3D. The city also holds seminars on 3D CAD for those already in the manufacturing industry and those who want to work in manufacturing.

In addition, the city also holds 3D CAD seminars using SolidWorks for elementary school and high school students, teaching them how to use 3D CAD through character
design: - The seminars for elementary school children are said to be especially popular (Figure 3.3). Using the models created, the children experience 3D printing on laser stereo lithography machines and make their own physical models of their designs. These efforts to promote 3D design are expected to boost the resources and underlying strength of the region’s industry. The municipality believes that 3D CAD design data has value beyond a single company’s needs because, in addition to the company which created it, related partner companies then use the 3D data and so on through the manufacturing process - and only people and companies with 3D literacy and skills will be able to exploit this.

Figure 3.3. CAD classes for Elementary and High School students

The Need for Lightweight 3D Data

So what changes are needed as 3D CAD data is used in downstream processes? 3D CAD is essentially a tool for design, and is not something which the layman can easily and quickly use. After a design is approved, the 3D design data should be referenced at the manufacturing floor but should not be able to be changed or corrected. When using 3D on the shop floor, users need to reference the 3D data and extract the information needed to do the job at hand.

But the more 3D CAD is used in design, the more the tendency arises for problems, as shown in Figure 3.4, to occur in downstream processes. The phenomenon seen is as follows:
1) 3D data size becomes massive as product designs become more and more complicated.

2) Emergence of 3D CAD for 64-bit PCs.

3) Increased need for 3D data transfer with globalization of manufacturing bases.

4) Support for multi-CAD environments.

5) Need to add and transfer manufacturing information to 3D data.

Figure 3.4. The need for lightweight 3D data

1) 3D design data becomes more and more complicated as more and more functions and performance are used by the designers. As CAD performance improves, so designers move rapidly towards building complete 3D assemblies of complex products. When those product designers start to precisely express fillets, minute holes, screws, bolts, wire harnesses, and so on in 3D, the data itself becomes massive. Many high-end and mid-range CAD applications are increasingly used for large scale design, which means the resulting data that represents the full assembly model of the product is enormous. Even though each individual part can be designed using CAD, the complete assembly, often made up of thousands of parts, cannot easily be viewed due to hardware restrictions. In other words, although the product was designed using 3D CAD, it cannot be easily or rapidly checked as a whole using 3D CAD.

2) With more and more powerful 64-bit PCs on the market, many 3D CAD programs are becoming compatible with the hardware. With the increased memory and processing power of 64-bit PCs, CAD models of several gigabytes can be created. However, these high end PCs are usually only located within Design and specialist Engineering departments. The low specification PCs, with limited memory, normally used in downstream processes, do not have the ability to display complicated product shapes at all.

3) Manufacturing continues to globalize. With continuous trends to design at headquarters and manufacture at globally distributed production centers, it is crucial to have a mechanism to ensure that the 3D data designed at the headquarters is distributed safely. These distributed production centers usually start by checking the product designs, making preparations for its production, and then manufacturing it according to the assembly instructions received. In terms of facilities at these centers, developing countries lack the facilities that the developed world has. For instance, broadband, which is already part of our everyday life, might be unavailable at the production base in a developing country.
With this in mind, the data size to be sent to these bases should be as small as possible and thus native 3D CAD data is not very appropriate.

4) Support for multi-CAD environments: Given that one product is usually made up of many parts, most companies tend to have different 3D CAD applications to satisfy the wide variety of needs of different departments. Add to that the fact that subcontractors may not be using the same CAD software, and 3D CAD data of several different formats tend to gather at the manufacturing site. And because the manufacturing operation is unable to introduce all the different CAD applications this would demand, it has led to growing demands for data management in a single format.

5) CAD is a design tool. The manufacturing staff require other information such as process information for manufacturing, assembly information, inspection information, etc. which CAD information does not include. A mechanism which adds this information to 3D data and enables its use in the manufacturing is therefore necessary.

In order to meet these needs, lightweight 3D data formats which can describe CAD, production and manufacturing data as accurately as possible and tools which can display it easily are indispensable.

Lightweight 3D formats were first introduced at the beginning of 2000 beginning with Lattice Technology’s XVL. They were also proposed by CAD vendors such as Siemens PLM Software of Germany with a format called JT, and Dassault Systemes of France with a format called 3D XML. Adobe of the U.S. also proposed a mechanism to include 3D data inside its PDF format. As the use of 3D CAD started to accelerate, 3D data started to accumulate at the design departments. In order to use 3D at the manufacturing site, there was now a need for lightweight 3D data which was easy to use.

Birth of Lightweight 3D XVL Data

The following discusses the features of XVL which was developed by the author as a 3D format for manufacturing, and is now widely used at Japanese and global manufacturing companies. The case studies discussed in Chapters 6 and onwards demonstrate work process innovations that use 3D data, from the viewpoint of XVL users in manufacturing. But first let’s take a look at how XVL has been developed and the aims from those who developed XVL - not views from users at this time. Figure 3.5 describes the features of XVL.
1) Realizing lightweight 3D plus precision
When the Internet was born in the 1990s, the need to circulate 3D data became stronger, and for it to include text, images, and visual data. In response to these trends, a format called VRML (Virtual Reality Modeling Language), a 3D expression method, was proposed in 1994. In 1997, this format was certified as an international standard by ISO as VRML97. VRML describes a group of planes called polygons. Polygons are, however, insufficient for expressing accurate product design data. But to describe free form surface data accurately, the data volume increases dramatically, so much so that it could not be realistically used across a network environment. The author of this book and others on his team therefore founded Lattice Technology in 1997, and started research & development of a new way to reduce 3D data volume. By finding an effective way to describe 3D data using surfaces instead of using polygons, we were able to reduce file size while retaining high accuracy. As 3D data size increases when surfaces are used in 3D CAD data, the team at Lattice invented a way to reduce the data size by reconstructing surface information from the data, without using surfaces themselves. By eliminating surface data, which makes up a large part of the CAD data size, 3D data size is dramatically decreased compared to the corresponding 3D data, now to as much as 0.5% of the original data size. This methodology allows 3D data to be sent, displayed and checked, even in the comparatively slower networks in use in 2000. Figure 3.6 shows the comparison between VRML97 and XVL. The 21549 Kbytes of data in VRML97 described using polygons can be described using 520 Kbytes using XVL.
3. The Evolution of Manufacturing Using Digital Information Technology

2) Delivery of a free XVL Player

Next, we thought of how we could distribute the new XVL format: Not every technology spreads just because it is superior in performance. To resolve this issue, we distributed a free application for viewing XVL, called ‘XVL Viewer’ (now called ‘XVL Player’). XVL Viewer was provided as a plug-in application for Internet Explorer at the end of 1999. At the beginning, it was capable of only displaying 3D, but by adding an ‘animation play’ function, it evolved as the XVL Player we have today, answering the call for lighter CAD data in the manufacturing industry, and for communication of assembly processes using animations. It is, of course, provided in English as well.

The latest XVL Player (Version 10) is able to read 3D and provide dynamic 3D cross sections, in addition to product configuration information. Its measurement tools are also provided free of charge. It can be downloaded at no charge from http://www.lattice3d.com/index.html. This application allows display of configuration and attribute information of 3D CAD data, viewing of the 3D parts and full assemblies, viewing of animations that explain assembly processes, and listed work instructions, parts lists and more, all of which can be referenced at the manufacturing floor even on inexpensive low specification PCs. Figure 3.7 shows the XVL Player. Because it also includes functions to display cross sections and measurements, it is able to easily provide the information required by the manufacturing site.

Figure 3.6. Comparison between VRML97 and XVL

VRML97 : 21549K bytes
XVL : 520K bytes
3) Display of linked attributes
As a result of initial efforts in 2000, XVL became a technology that was well regarded, winning prestigious awards at home and abroad. Demonstrations were well received by audiences of every type. But early in 2000, however, there were very few customers who would actually purchase it as a product, probably because the market was not yet mature, and since it simply showed 3D, did not seem to add much value to the manufacturing process. Although XVL was able to send and display CAD data in 1/100 of the time it would take to send 3D CAD data, at first it merely remained as an “interesting technology”.

Needless to say, there is so much other information required in manufacturing processes besides 3D; design information that needs to be communicated to downstream processes; production information that needs to be defined by production engineering and communicated to manufacturing floor; product quality information that should be delivered by the quality inspection division, and so on. Some of the information created also has to be communicated back to a previous phase. And some information cannot simply be expressed using 3D data. To meet these needs, XVL was evolved and developed as a format which can express not just 3D but also configuration information, color, annotations, dimensions, and animations, etc. It also allows attributes to be added to each part. Because XVL uses XML - eXtensible Markup Language - structured information can be easily added, allowing attribute information and 3D information to be linked and interrelated. By achieving this link between lightweight 3D and manufacturing information, and by sharing this information for collaboration, people started buying applica-
3. The Evolution of Manufacturing Using Digital Information Technology

Figure 3.8 summarizes the different types of information which can be handled by XVL. Broadly speaking, attributes handled in XVL can be categorized into three types; attributes which are defined by CAD and inherited in XVL, those added and edited using XVL-based software, and those within an external system such as PDM or BOMs. Information inherited from CAD includes shapes, configuration information, and materials. Information which can be added by XVL-based software includes annotations, dimensions, and snapshots for saving display states such as viewpoints. Definitions of animations, results of interference calculations and parts and process lists can also be saved in XVL. Information which can be exchanged with an external system includes part attributes and process information. This innovation established a way to effectively use all available information by exporting data from existing systems, embedding information in table calculation software such as Microsoft Excel, and so on.

4) Support for massive data size

At the beginning of 2000, Lattice’s corporate mission was focused on finding a means to distribute and share 3D data even in narrowband networks. Shortly thereafter, networks started to become more and more broadband. On the other hand, as 3D CAD design became more and more widely used, data started to become bloated. This trend was further accelerated by the emergence of CAD applications that support 64-bit PCs. This led to the real-world problem of having to display a 10 Gbyte 3D car assembly, at high speed, but on a normal PC.

<table>
<thead>
<tr>
<th>Information inherited from CAD</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Sharing of shape information (Accuracy: Max. 0.001)</em></td>
</tr>
<tr>
<td><em>Attribute information from CAD</em></td>
</tr>
<tr>
<td>- Configuration and materials information</td>
</tr>
<tr>
<td>- Attribute data such as property information</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Information which can be added to XVL</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Annotations, dimensions, cameras, snapshots</em></td>
</tr>
<tr>
<td><em>Animations, processes, interferences, disassemblies</em></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Information between XVL and external sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Parts information, process information, disassembly information</em></td>
</tr>
<tr>
<td><em>Annotations, dimensional information (Export only)</em></td>
</tr>
</tbody>
</table>

Figure 3.8. Example of attribute information which can be handled by XVL

In 2003, we succeeded in delivering high speed 3D geometry display by minimizing memory use, and saving the geometric data in a form that best suits the graphics library structure of PCs. One competitor’s technique was to use a method which reads
and displays only the visible parts without needing to read the whole data. However, in most design and manufacturing, there is a critical need to cut cross sections of a part or an assembly to check various shapes. As a result, this method for purely reading visible parts became unviable as the user needed to read and see the whole data set during cross section calculations, resulting in slow response times. XVL was improved so that not much PC memory is used even when the whole assembly is being displayed, resulting in the ability to read highly accurate data, which was originally gigabytes in size, on a regular PC. Figure 3.9 shows an example of a complex 3D shape.

![Example of a complex shape designed using Autodesk Inventor, and displayed using the XVL Player (Data provided by Autodesk.)](image)

With XVL even facility designs using more than 8600 parts, designed using Autodesk Inventor, could be easily displayed on a PC, in any office. When zoomed to high levels, even bolts can be displayed clearly.

5) Rich applications
At the beginning of 2000, neither users nor the author were clear on what 3D software would contribute to the manufacturing industry other than CAD/CAM/CAE. Because 3D CAD was not used widely in design at the time, the idea of improving manufacturing processes by using 3D data downstream was pretty much ignored. Lattice spent more than five years visiting manufacturers to demonstrate its applications, and evangelizing lightweight 3D data. Now we have software products for verifying design for design departments, and for sharing information between production technology departments and plants. Collective interference calculations using mass data volumes are able to identify even the smallest design problems. Large scale processes can also be studied, and conveyed as animations to plants. By adding 3D information to reports in Excel, a rich variety of information can be conveyed to downstream processes using standard documents. Generating illustrations directly from 3D data is now also fast, accurate and
easy. Because of this development and focus, software applications tuned to the needs of downstream manufacturing are now available. Details are described in Chapter 5.

XVL progressed while being rigorously tested in Japanese, US and European-based manufacturing companies. The fundamental performance of XVL is determined by the amount of compression it can deliver, its memory saving ability, and high speed display. As of 2009, XVL has all of these traits with industry-leading performance. In addition, the network infrastructure of developing countries is not expected to grow overnight and it will probably take many more years for normal PCs to have gigabyte-class memory and be able to display massive data in normal 3D CAD applications.

To resolve these issues, Lattice has been committed to the development of XVL technology. The more that 3D design is carried out at upstream design departments, the more demands for efficient use of that data downstream will grow, because 100 times more people than the number of original designers want to reference the information it contains. The efficient use of 3D data across manufacturing will increasingly require lightweight 3D data such as XVL even more as we push into the future.

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About ‘Improving Lean Manufacturing Through 3D Data’ by Dr Hiroshi Toriya.

This book, one of several published by author, Dr. Hiroshi Toriya, discusses how Japanese manufacturers are addressing the critical need to continually improve manufacturing processes across the entire enterprise. In the cases highlighted in this book, manufacturers are turning to 3D data practices and processes to enable greater leanness of manufacturing. This book discusses why this is a necessity in the current economic conditions and discusses real world examples through in-depth interviews with manufacturers of all kinds.

Originally published in Japan in 2008 by JIPM Solutions, this book is available in English via e-book from Lattice Technology, and is available at www.lattice3d.com