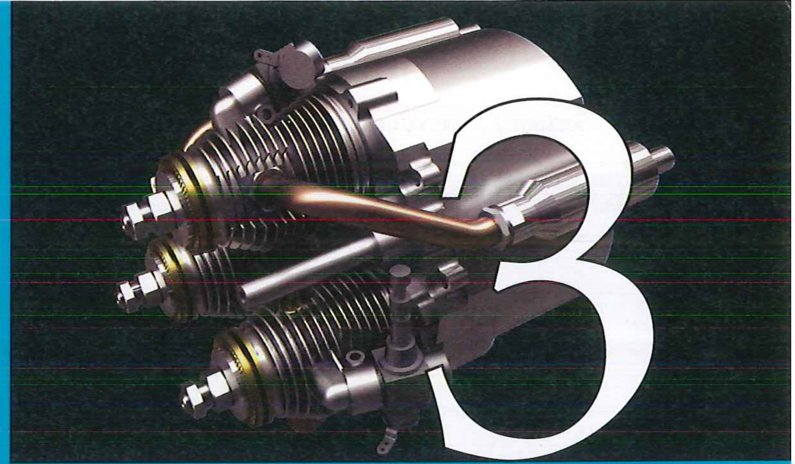
Introduction to CAD



Learning Objectives

After studying this chapter, you will be able to:

- Explain computer-aided drafting and design.
- Identify common applications for CAD in different areas of drafting.
- List the components of a typical CAD workstation.
- Identify features of CAD software and how they should be evaluated when selecting a program.
- Explain the advantages of specific CAD applications.

Technical Terms

Advanced mechanical drafting and modeling CAD packages
AEC CAD packages
Building information modeling (BIM)
CAD
CAD workstation
Central processing unit (CPU)
Commands
Computer-aided manufacturing (CAM)
Computer numerical control (CNC)
Constraints
Digitizer puck
Display controls
Drawing aids
General purpose CAD packages
Inkjet plotters
Inkjet printers
Input device
Laser printer
Layers
Light pens
Loft
Mainframe
Monitor
Network
Objects
Output device
Parameters
Parametric modeling
Pen plotter
Primitives
Rendering
Software
Solid model
Storage devices
Surface model
Sweep
Symbol library
Video card
Virtual building

What Is CAD?

CAD is an acronym for computer-aided drafting. Simply put, CAD is a tool that replaces pencil and paper for the drafter and designer. While CAD makes the process of designing a product or structure much easier, the fundamentals of design remain unchanged. This is very important to remember. *CAD is just a tool.* A drafter/designer using a computer system and the appropriate software can:

- Plan a part, structure, or other needed product.
- Modify the design without having to redraw the entire plan.
- Call up symbols or base drawings from computer storage.
- Automatically duplicate forms and shapes commonly used.
- Produce schedules or analyses.
- Produce hard copies of complete drawings or drawing elements in a matter of minutes.

The results produced using CAD can be simple or quite complex, **Figure 3-1**. All types of mechanical, engineering, and construction drawings can be produced with CAD.

The computer used in CAD can be as simple as a home PC or as complex as a networked mainframe. The ***software*** consists of the instructions that make the hardware perform the intended tasks. CAD software ranges from very basic programs that can be purchased for under $100 to programs that cost several thousands of dollars.

The hardware and software of a CAD system are tools for creating drawings, just like pencils and triangles are for manual drafting. Using a CAD system to design parts and generate

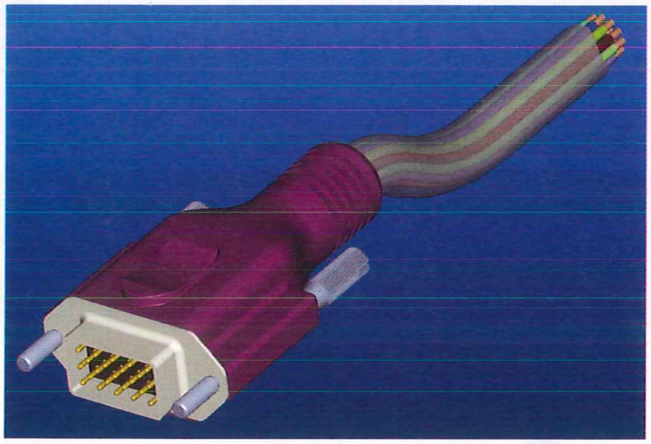


Figure 3-1. CAD has greatly improved the process of designing and creating products. (EdgeCAM/Pathtrace)

drawings still requires a sound understanding of drafting principles. You must know the fundamentals of orthographic projection and the construction methods of different types of views, the proper usage of drafting conventions, and dimensioning standards. Drafters using a CAD system are still responsible for communicating ideas in a way that is recognized by people in a given field.

Initially, the term *CAD* referred to computer-aided (or assisted) drafting, but now it is used to designate computer-aided drafting, computer-aided drafting and design, or both. Computer-aided drafting and design has also been referred to as *CADD*. This term is technically larger in scope than CAD, integrating design, analysis, and often "premanufacturing" as well as drafting. However, this text uses the term CAD for all applications of computer-aided drafting, computer-aided design, and computer-aided drafting and design.

Why Use CAD?

There are many reasons to use CAD, but almost all of these reasons can be boiled down to one simple statement: *CAD saves time and money*. Once a design has been completed and stored in the computer, it can be called up whenever needed for copies or revisions. Revising CAD drawings is one of the greatest time- and money-saving benefits. Frequently, a revision that requires several hours to complete using traditional (manual) drafting methods can be done in a few minutes on a CAD system. In addition, some CAD packages automatically produce updated schedules after you revise the original plan, thus eliminating the need to manually update the schedule.

Productivity

Modern CAD programs let the drafter/designer quickly develop and communicate ideas in a precise and professional manner. Once an operator learns how to use a given system, productivity is generally increased and work is typically of a higher quality. In addition, the drafter does not make an endless number of revised drawings for each small change. Instead, the change is made in the CAD system and a drawing (hard copy) is only generated as needed. In fact, editing drawings is often where CAD repays its cost to the company. Changes are easy to make and some software makes the corrections in every affected drawing or schedule. Even the most basic CAD packages speed the change process.

Another productivity benefit of CAD is the use of symbol libraries. A ***symbol library*** is a collection of standard shapes and symbols typically grouped by application, **Figure 3-2**. These symbols can be inserted into drawings, thus eliminating the need to draw the symbols over and over. Inserting standard symbols and shapes is quick, easy, and accurate. Once a standard symbol has been drawn and stored in the library, it can be called up and placed as many times and in as many drawings as required. For example, symbols for structural materials, welding symbols, and surface quality symbols are usually included in a mechanical symbol library. Most companies also develop unique symbols for their own applications and store them in their symbol library.

The time saved by CAD in making drawings with many repetitive features is impressive. For example, the time required to draw the welding symbols on a structural drawing by hand is significant. Using a CAD software package, a symbol can be applied to the area in a few seconds. Other examples of repetitive features include fasteners, threads, standard notes, and so on, **Figure 3-3**. It is easy to see that inserting

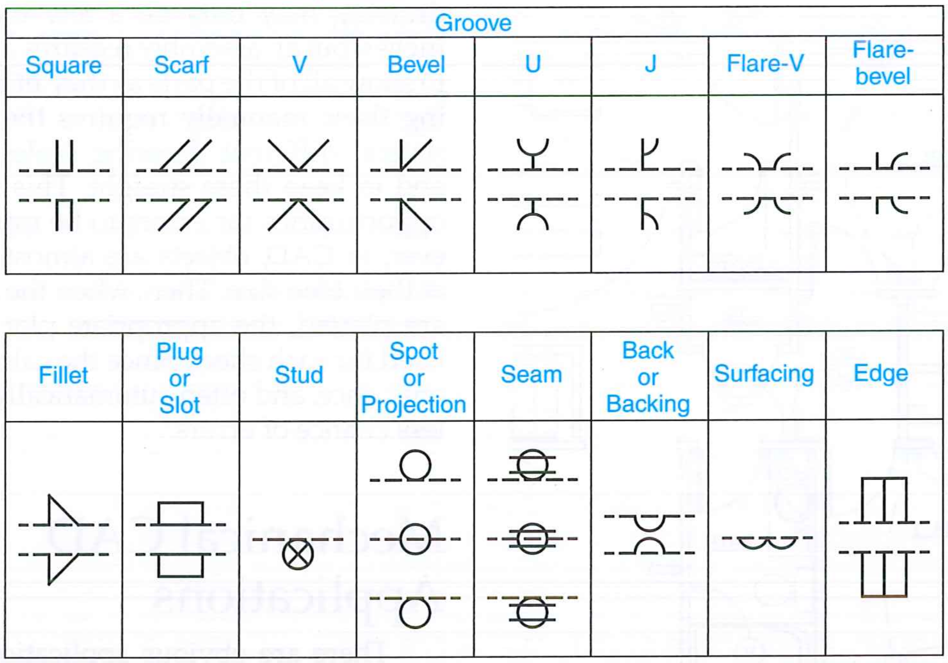


Figure 3-2. These welding symbols are stored in a symbol library. Any one of these symbols can be quickly inserted into a CAD plan drawing, repeatedly if needed.

standard details and making minor changes can save many hours in a single set of drawings.

Flexibility

Flexibility is a significant advantage of using a CAD system to generate drawings. Once a design is complete, printouts of the entire design or portions of the design can be made in minutes. Depending on the equipment being used, a drawing may be:

- Plotted at any scale that will fit on the drafting medium.
- Plotted in several colors.
- Developed in sequential steps.

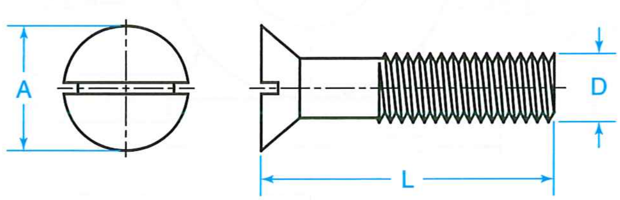


Figure 3-3. This machine screw detail can be inserted into any drawing as required. It is obvious how much time can be saved by simply inserting the existing detail rather than redrawing the detail.

- Presented on different media depending on the intended use.

In addition, CAD offers the added flexibility of sharing drawing data with other CAD users. Generally, the other users do not even have to be using the same CAD software. Most CAD software programs have various options for sharing data, including import/export functions, e-mail options, and web posting capabilities.

Uniformity

Drawings produced on a CAD system will possess a high degree of uniformity regardless of who makes the drawings. Multiple skilled CAD drafters with strong drafting fundamentals can work on a single project and produce a result that is very uniform in appearance and adheres to standards. Each drafter must possess the technical knowledge to select the proper symbol, size, linetype, and so on. For example, every time an electrical symbol is placed in a floor plan drawing, it is reproduced exactly the same as before. Every symbol drawn will be identical, **Figure 3-4**. Typically, the only variables are scale and rotation. Such uniformity greatly improves communication among those who use the final

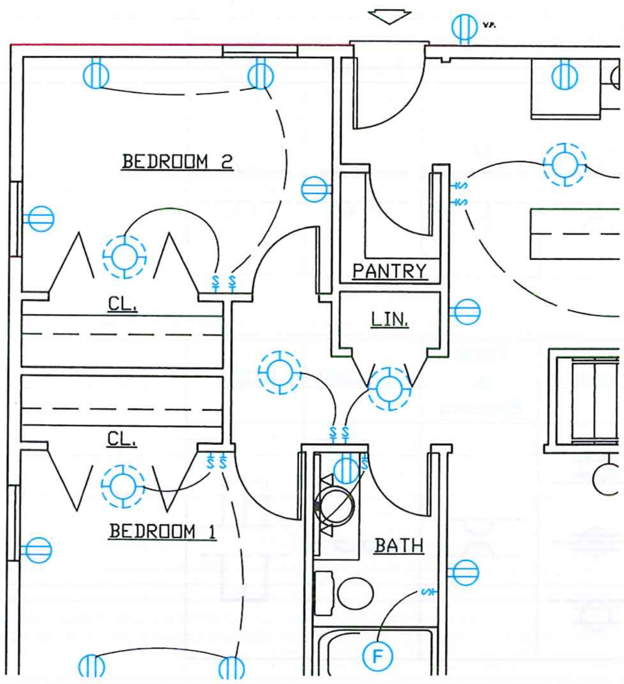


Figure 3-4. All symbols in this drawing are uniform. The only variable is the rotation of the symbols. In this case, all symbols use the same scale. Some of the symbols, but not all, are shown here in color to help identify them.

drawings. However, the CAD system cannot decide which symbols to place and where to place them, or determine good design practices. The drafter and designer must possess basic design fundamentals to avoid creating beautiful, but meaningless, drawings.

Poor line quality is not an issue with a properly used CAD system. It is easy to ensure consistency in line thickness, **Figure 3-5**. Smudged lines or sloppy lettering, both of which often lead to errors in the manufacturing process, are not problems with CAD-generated drawings. In addition, since CAD drawings are typically duplicated by creating another printout, there is no degradation in quality from repeated duplication. Degradation can occur when a hand-created drawing is repeatedly duplicated on a diazo or blueprint machine.

Scale

One additional advantage of CAD for technical drawings is in scale. A set of technical or machine drawings will include many drawings, many with different scales. For example, a part drawing may only be a few inches by a few inches, but an assembly requires a very large area to show all of the parts as they fit together. Drawing these manually requires the drafter to use several different drawing scales (instruments) and to keep them straight. This presents many opportunities for errors to be introduced. However, in CAD, objects are almost always drawn at their true size. Then, when the final drawings are plotted, the appropriate plot scale is calculated for each sheet. Since the calculation is done only once, and often automatically, there is much less chance of errors.

Mechanical CAD Applications

There are obvious applications for CAD in producing mechanical drawings. All drawings that would traditionally be done by hand are drawn on the computer. These include all of the individual part drawings. In addition to these obvious applications, there are several other applications for CAD in technical drawing, depending on the software you are using.

Schedule Automation

Some CAD packages have the ability to automatically generate part schedules, machining operations schedules, and various reports,

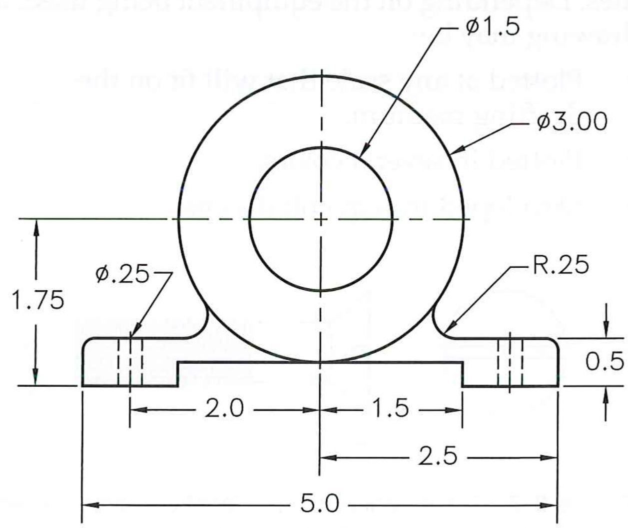


Figure 3-5. Line thicknesses are consistent in this CAD drawing.

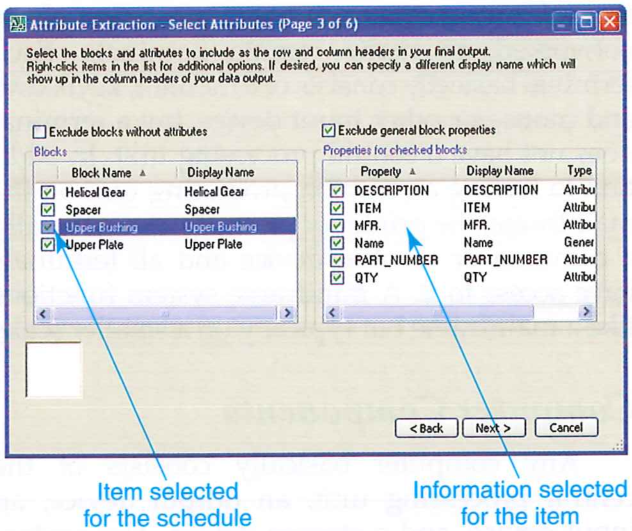


Figure 3-6. Some CAD programs have the ability to automatically generate part schedules for assemblies when the drawing is properly set up. Here, information for a bushing is being added to a schedule. A description, item number, manufacturer, part name, part number, and quantity will be included in the schedule.

Figure 3-6. This may sound like a great time-saving feature, and it is when the drawing is properly created. If the drawing is not created with appropriate attributes, this feature is useless. Therefore, planning and proper drawing setup is very important.

In addition to automatically creating the schedules, some CAD programs have the ability to automatically update or correct the schedule when an item from the drawing is changed. The time required to redraw or update a schedule because of a simple change is significant using traditional drafting methods. Using CAD, such a change requires only a few seconds to complete.

Renderings

An important part of mechanical design is the presentation drawings used to communicate a design idea. In mechanical drafting, presentation drawings usually consist of isometric or oblique views. Presentation drawings are covered in Chapter 11. A properly made CAD drawing can be used to generate a computer ***rendering***, or presentation drawing. This ability is typically found on mid-range and high-end CAD systems. However, this application is exceptionally suited for the right CAD program.

Animations

Related to presentation drawings are animations and rendered animations. They are used to represent one or more parts of a model in motion. Animations can show features such as gears or cams operating other parts as a person would see them functioning. See **Figure 3-7**. With the right CAD software and a skilled drafter, a client or review board can be shown a very accurate representation of what the final assembly will

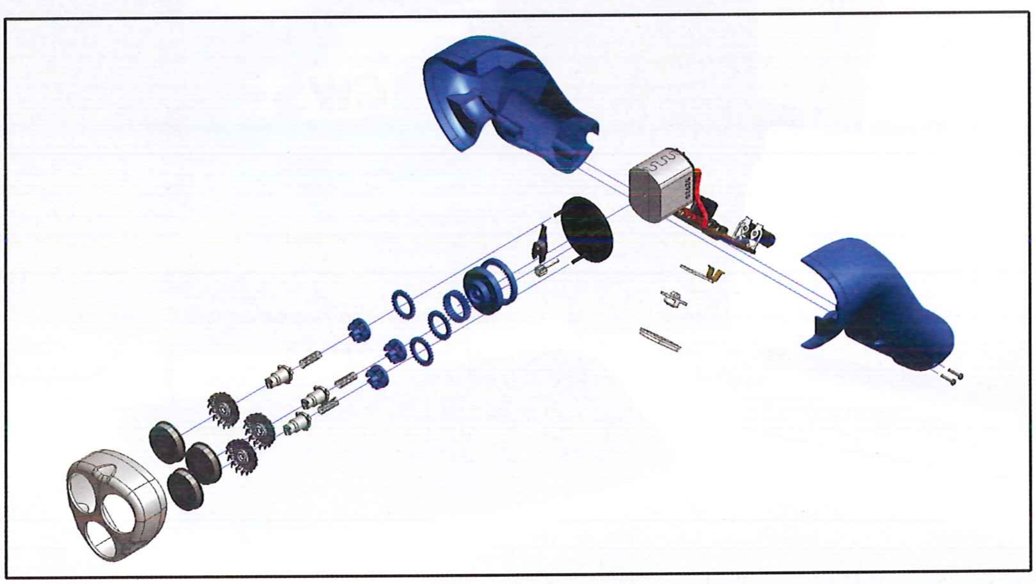


Figure 3-7. Animation can be used by the CAD designer to simulate the assembly of parts for this model of a shaving device (currently shown in an exploded view for presentation). (Autodesk, Inc.)

look like. As with the ability to render, animation capabilities are typically found on mid-range and high-end CAD systems.

CAD Workstation

A ***CAD workstation*** generally consists of a computer or processor, monitor, graphics adapter, input and pointing device, and hard copy device, **Figure 3-8**. Most CAD programs, even high-end software, can be run on "up-to-date" home computer systems. These stand-alone systems are inexpensive, powerful, and can be purchased at most appliance and electronics stores.

Often, several stand-alone systems are connected in a ***network***. This allows each computer to share information through the network wiring. However, the "computing power" is contained in each individual machine. A network typically allows devices such as printers and plotters to be shared among the computers. Networks are generally found in larger offices and companies.

Some CAD programs are designed to run on a type of computer called a ***mainframe***. This type of computer system consists of a common, centrally located processing unit that is connected, or networked, to many remote terminals. Each terminal basically consists of a monitor, keyboard, and mouse or other input device, but a terminal does not have a central processing unit. In addition to having a common processing unit on the mainframe, the printer or plotter is also generally a common or central device and all terminals have access to it. A miniframe system functions like a mainframe but typically on a smaller scale.

Computer Components

Any computer basically consists of the central processing unit, an output device, an input device, and a storage device. The ***central processing unit (CPU)*** contains the processor, RAM, and input/output interfaces. This is the "box" found on most PCs.

The output device that all CAD systems have is the display or monitor. This "computer screen" provides visual feedback on what the computer is doing, and what you are doing with the computer. CAD systems also have a hard copy output device, such as a printer or plotter. However, this device may not be connected directly to the workstation.

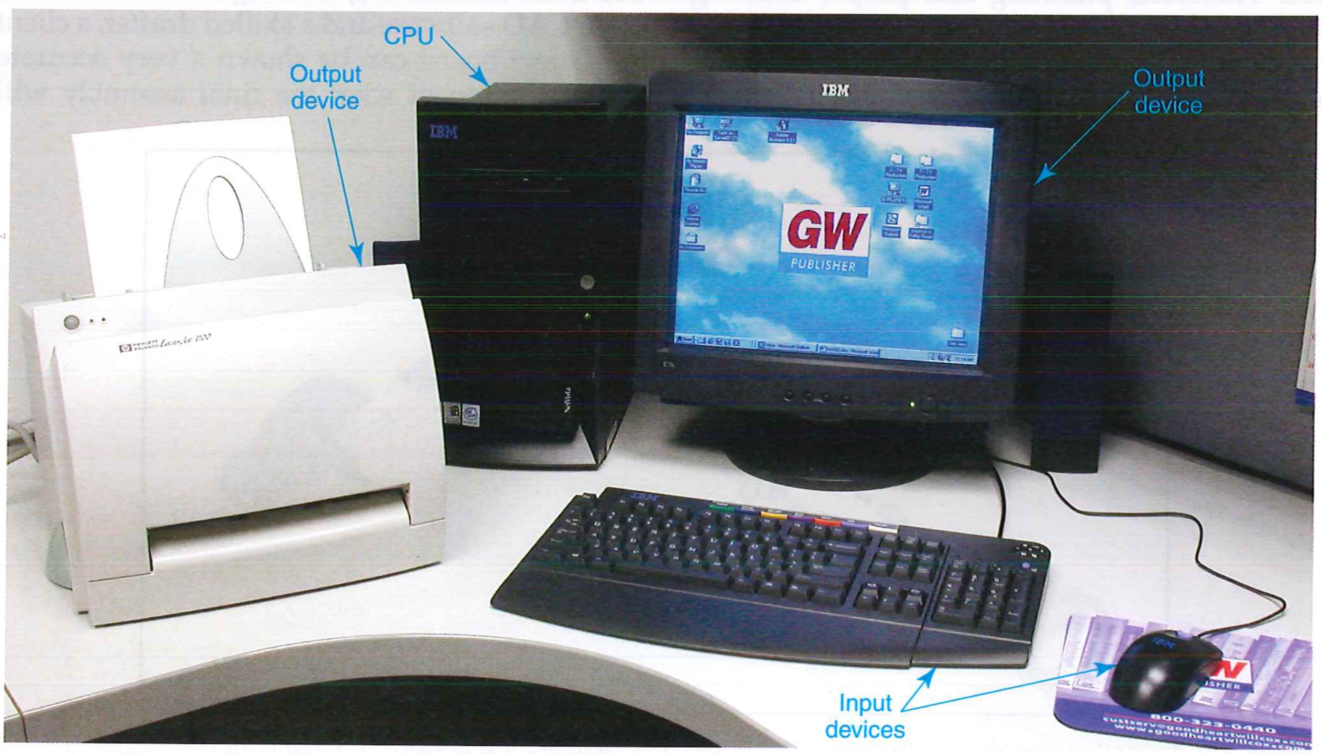


Figure 3-8. The components of a typical CAD workstation.

All CAD systems also have a keyboard. This is an input device. CAD systems also have another input device generally in the form of a mouse or digitizer puck. These input devices allow the user to communicate with the CAD system.

Storage Devices

Storage devices are used to save data, such as drawings, for later use. The storage device places the data on storage media. The computer hard drive in your home PC is a storage device with self-contained media. A CD-R drive, or CD-ROM recordable drive, is also a storage device. CD-R drives store data on recordable compact discs (CD-Rs). There are also CD-RW drives, DVD drives, floppy drives, tape drives, and Zip drives. Each type of drive uses a different type of media on which data is stored.

Display Devices

The display device of a computer is typically referred to as the ***monitor*** or "screen." These are general terms that cover a wide range of display devices. There used to be several different types of display devices varying in display color, mechanical function, and size. Now, display devices are generally described in terms of size and screen properties.

Most monitors are cathode ray tubes (CRTs). These are just like a standard television set. Another common type of monitor is a liquid crystal display (LCD). LCDs are found on laptop computers. The newer "flat" monitors are also generally LCDs.

When selecting a monitor for a CAD system, size is important. The size of a monitor is measured diagonally, just like a television. Generally, a 17″ monitor is the smallest that can be effectively used with CAD. Many CAD systems have a 21″ or larger monitor. The larger the monitor, the more actual drawing area that can be displayed. With small monitors, most of the computer screen can be taken up by toolbars and menus.

Another important aspect of a CAD system's display device is the graphics adapter or video card. The ***video card*** is the device that transmits data from the CPU to the monitor. Most video cards have their own RAM (memory). The more RAM on the card, the less of the CPU's RAM consumed processing video information. There are also video cards specifically designed for CAD and high-end 3D graphics. Generally, one of these video cards is best suited for a CAD system. However, each card has advantages and disadvantages. When selecting a card, locate a hardware review in a computer or CAD magazine. There are several magazines aimed at the CAD market. These frequently conduct hardware reviews. Use this information to determine which card is best suited for your application.

Input Devices

An ***input device*** provides a means to enter information into the computer. The most common input device is the keyboard. The second most common input device is the mouse. Both of these input devices can be found on nearly all computers.

A variation of the mouse is the trackball. This is like an upside-down mouse. Instead of moving the entire device to move the screen cursor, only the ball is moved. This can be more efficient than a mouse. However, many computer users find it difficult to switch from using a mouse to using a trackball.

A ***digitizer puck*** is another variation of a mouse. It is moved around like a mouse, but it can have several buttons to activate a variety of functions. See **Figure 3-9**. However, digitizer

Figure 3-9. Digitizer pucks are available in a variety of configurations. The light pens shown here are another type of input device. (Kurta)

pucks are specifically designed for use with CAD systems. The puck is moved on top of a tablet menu that displays tiles for commands. When placed over a command, it can be activated by pressing the appropriate button on the puck. The puck is also used to digitize a drawing that is placed on the digitizing pad.

Light pens are sometimes found on CAD systems. These devices work with a tablet menu, like a puck. When used with the proper display device, an appropriate light pen can also be used to select menu items directly on the monitor.

Output Devices

The monitor is the most common ***output device***. However, as a drafter, you also need to create printouts of your drawings. There are several ways to produce hard copy.

The traditional device for creating hard copies of CAD drawings is the ***pen plotter***. This device uses one or more pens to trace the object lines in the drawing. A plotter pen is typically a felt tip or ballpoint pen. However, the best pens have a ceramic or steel point similar to a technical pen. Pen plotters produce the hard copy as the drawing was drawn. This can be a disadvantage, especially if there are many colors in your drawing. The multiple pen changes can take a lot of time. Also, since some pen plotters move the paper around under the pen, it can take more time to complete a plot. This is because a plotter plots vectors, or "complete" lines.

A common hard copy device is the ***laser printer*** or plotter. This device operates in much the same way as an office copy machine. Laser printers are fast, quiet, and easy to use. The drawing is produced as a raster image, which is a series of dots. The biggest disadvantage of laser printers is the lack of color in the hard copy. There are color laser printers and plotters, but these are generally expensive to purchase and operate. They also typically do not produce very good color. Another disadvantage for certain drafting applications (such as architectural drafting) is that few inexpensive laser printers can produce D- and E-size prints.

Inkjet printers and ***inkjet plotters*** are becoming very popular. See **Figure 3-10**. These are raster devices that are fast, quiet, and easy to use like a laser printer. They also produce very good color and are inexpensive to purchase. In the past, the ink has been a disadvantage of inkjet devices. It was not stable and could smudge or smear very easily. However, advances in this area have virtually eliminated this problem, *once the ink is dry*. An advantage of inkjet devices is that you can produce hard copies of renderings in full color. When printed on special "photo paper," it is often hard to tell a good rendering from a photograph. In the architectural field, this can be a great asset. Inkjet printers typically produce small-size prints, such as A- and B-size. Inkjet plotters can produce up to E-size prints.

All of these output devices have advantages and disadvantages. For example, pen plotters produce very high-quality line reproductions in color. However, they are slow and cannot be used to reproduce renderings. Laser printers are fast and inexpensive to operate, but most cannot produce color or large-size prints. Inkjet devices beautifully reproduce color renderings, but they can be slow and very expensive to operate. Be sure to determine exactly what your needs are before purchasing an output device.

Selecting a CAD Package

There is a wide variety of CAD programs on the market. These range from very basic

Figure 3-10. Inkjet plotters are commonly used to produce hard copies of CAD drawings. This plotter is being used to output a rendering.
(DesignJet Division, Hewlett-Packard)

programs that can only draw simple 2D objects to high-end programs that are fully 3D capable and have advanced features such as parametric modeling and premanufacturing tools. In order to get the best CAD system for your needs, you must first know *what* you want to accomplish with the software. If all you plan to do is produce 2D drawings, then you do not need all of the "bells and whistles" of a high-end system. But, if you are going to be producing 3D models and renderings, then you will probably need a high-end system. The answers to these basic questions may help you select the best package for you:

- How easy is the program to use? Does it provide help screens and clear instructions?
- What kind of support does the company provide after you purchase it? Does the company provide updates either free or for a reasonable cost? Will it answer your questions over the phone? Is there training available at a local college or trade school? Remember, some CAD programs can be quite complex and you may need some help in using them.
- What are the hardware requirements of the package? If you need to upgrade your computer to run the software, perhaps another package with less requirements is better suited to your situation.
- Does the program require special hardware not common to other packages? If so, you might want to think twice before purchasing the package.
- How well does the package meet your needs? Is it useful to you?
- Check the warranty. What does it provide? What is the length of time covered?
- What are specific features of the software? Is it broad or narrow in application? Is it 2D or 3D? Is it compatible with other popular packages?
- How much does it cost? How does the cost compare with other similar packages? Consider a price-to-performance ratio.

You may be able to think of other questions to add to this list. These should be helpful in weeding out packages that do not fit your needs. If possible, use the program before you purchase it, or at least talk to someone who has used it.

For the purpose of this discussion, CAD programs are separated into three broad groups. These are general purpose, advanced mechanical drafting and modeling, and architectural, engineering, and construction (AEC). ***General purpose CAD packages*** are usually designed for making typical mechanical drawings and other general drafting applications. Advanced mechanical drafting and modeling programs and AEC specific programs typically have most, if not all, of the same functions as a general purpose program, but they also have specialized functions. ***Advanced mechanical drafting and modeling CAD packages*** are designed for more advanced applications, such as special solid modeling functions, animation capabilities, or CAD/CAM. ***AEC CAD packages*** have functions that would typically only be useful to an architect, construction technologist, or engineer. While structural drawings, electrical drawings, plumbing drawings, and welding drawings can easily be created using general purpose CAD packages, an AEC specific program may be better suited to a particular application.

General Purpose CAD Packages

General purpose CAD packages are available to meet a wide range of needs. Some are high-end programs and offer many advanced capabilities. Others provide only basic functions and are typically used for CAD education, home use, and basic applications. The next sections provide a brief description of the main features of popular general purpose CAD packages. This is not intended to be a comprehensive list. Remember, when selecting a software package, be sure to review your answers to the questions provided earlier.

Objects

Objects are the basic elements used to create drawings. They include items such as lines, points, circles, arcs, and boxes. In most programs, objects can also be drawn by using a freehand sketching function. Other types of objects, such as polylines, fillets, and chamfers, add function to the program. These may not be available with basic CAD programs. The number and type of objects included in the program are very important for speed and ease of drawing.

Dimensions

Properly dimensioning a drawing is one of the fundamentals of drafting. Yet, dimensioning has always been time-consuming and a source of errors or omissions when done by hand. Most CAD packages provide the ability to automate dimensions. In fact, if the program does not provide this feature, you may want to think twice before purchasing it. An exception is software designed for rendering and animation, as its main function is not typical drafting tasks.

Hatch Patterns

Hatching is an important feature of any drawing requiring a section view. Hatching is also used in mechanical drafting to represent a variety of different materials, such as steel, brass, glass, and many other features. Common CAD packages may include several standard hatch patterns, **Figure 3-11**. Some higher-end CAD programs also allow you to design your own patterns. This can be very time-consuming. The more patterns that the software includes, the greater the savings in time.

If you are going to be modeling in 3D, hatching is not necessarily as important to you. Instead of hatch patterns, materials are defined and applied to objects. Then, the drawing is rendered to produce the final result.

Text

The ability to place text on a drawing is very important in most drafting situations. Therefore, it is important for the CAD software to have good text support. The number of typefaces, or fonts, available is not as important as how easy it is to place and edit text. However, you should also try to find a program that can use several different typefaces. Most Windows-based CAD software can use any font installed in Windows for text on a drawing.

Lettering style is important in mechanical drafting. A drafter will select a lettering style that is clear and appropriate for the type of

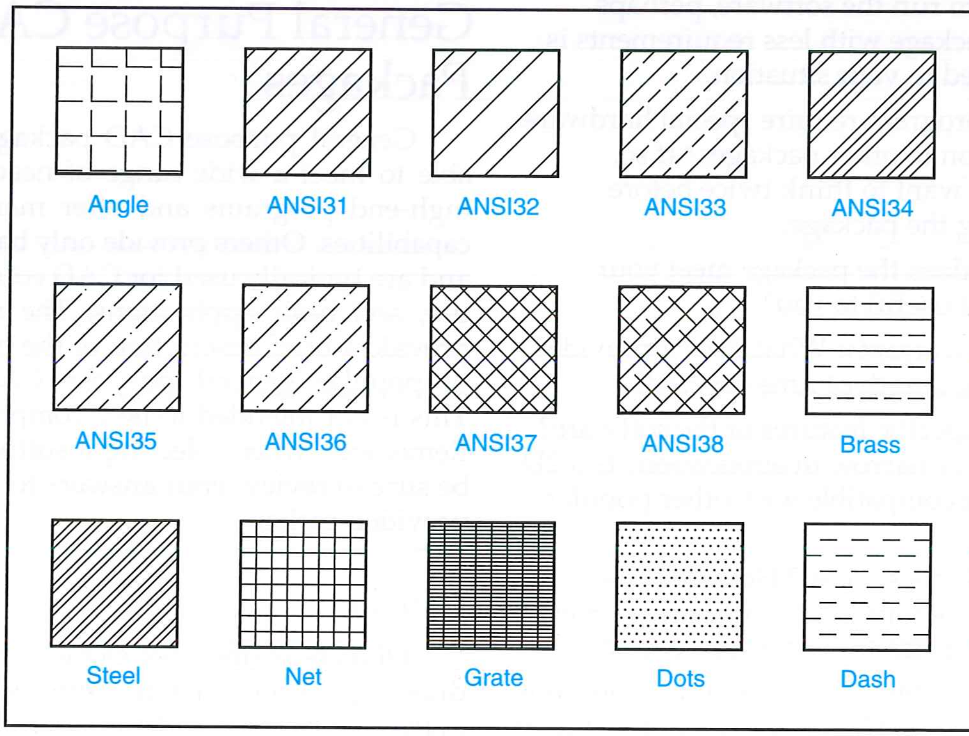


Figure 3-11. A CAD program typically allows you to choose from a variety of hatch patterns.

drawing being created. Therefore, it is important to select a CAD package that contains appropriate lettering fonts. Some CAD packages also have the ability for the drafter to design and use his or her own font. This is an important feature for drafters in some drafting fields, such as architectural drafting.

Editing

The ability to edit a drawing is one of the most important aspects of CAD. Editing functions include copying, erasing, moving, scaling, rotating, trimming, breaking, exploding, arraying, dividing, mirroring, extending, stretching, and a variety of other functions. A CAD program with several editing tools from which to choose is an advantage. Some of the basic CAD programs offer limited editing capabilities. You should stay clear of CAD software that does not offer an appropriate number of editing functions.

Layers, Colors, and Linetypes

Layers are similar to transparent drawing sheets on which you can draw. They allow various parts of a drawing to be placed on different "sheets" or layers. This feature is especially useful in creating several drawings that must relate to each other in some way. Layers also help when plotting a variety of outputs from a single complex drawing. Not all CAD programs support layers. However, the advantages of layers makes it worthwhile to invest in software that supports layers.

Object display color can be very useful when designing objects on a CAD system. For example, certain features can be assigned a certain color for easy viewing. In addition, color aids communication. Most CAD packages provide a selection of colors and some permit the creation of user-defined colors, **Figure 3-12.**

The Alphabet of Lines is an important part of drafting, whether the drawing is created by hand or on a CAD system. In order to correctly follow the Alphabet of Lines, a CAD system should have the ability to use different linetypes. In addition, the program should have the ability to set line thickness or width. Most general purpose CAD systems support several different linetypes. These linetypes may include continuous (solid), dashed, hidden, center, and phantom.

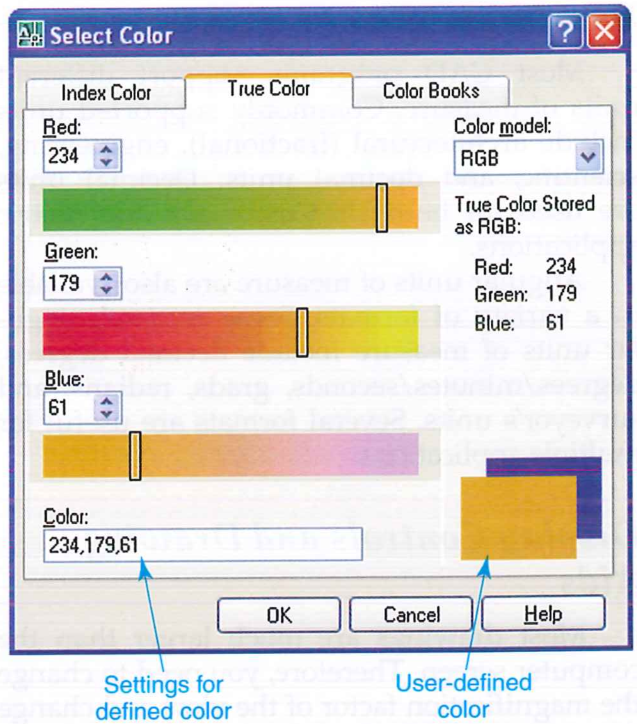


Figure 3-12. The ability to create or choose from an unlimited number of display colors is a big advantage of high-end CAD programs.

Coordinate Entry and Command Entry

A basic requirement to make drawings is the ability to tell the software where to place objects. There are generally several ways to do this in any given CAD program. For example, when drawing a line, you can generally type coordinates or pick points with the mouse or puck.

Just as there are different ways of providing locations, there are generally a variety of ways to give instructions to the software. These instructions are called ***commands.*** Generally, a command can be entered from a pull-down menu, screen menu, toolbar button, command line (keyboard), or digitizer tablet menu. The manner in which the command is entered does not change the function of the command. However, entering a command by different methods may change the steps needed to complete the command.

Drawing Units

Most CAD programs support different units of measure. Commonly supported units include architectural (fractional), engineering, scientific, and decimal units. Decimal units are used for both US Customary and metric applications.

Angular units of measure are also available in a variety of formats. Some common angular units of measure include decimal degrees, degrees/minutes/seconds, grads, radians, and surveyor's units. Several formats are useful for multiple applications.

Display Controls and Drawing Aids

Most drawings are much larger than the computer screen. Therefore, you need to change the magnification factor of the view and change the view itself. The functions that allow you to do this are called ***display controls***. They include zooming and panning commands, as well as other related commands. All CAD programs should have a variety of display controls. Higher-end CAD programs generally also provide a means to save views to be restored later. The ability to manipulate views is a very important part of CAD.

Drawing aids help you locate position on screen and on existing objects. They make the task of drawing easier, faster, and more accurate. All mid-range and high-end CAD programs offer a wide variety of drawing aids. Common drawing aids include display grid, grid snap, object snap, orthogonal mode, isometric mode, dynamic location, and construction planes. Without good drawing aids, CAD can be hard to manage.

Printing or Plotting

Nearly all CAD programs provide a printing or plotting function. This is how the drawing is transferred from the computer to a hard copy. Some rendering and animation programs do not provide printing functions. This is because the output is saved to a file that is then used in other software, which generally can print.

Program Customization

Program customization includes displaying and hiding toolbars, modifying menus or toolbars, creating new menus or toolbars, and writing macros, commands, or "programs" to help streamline the drawing process. The degree to which you can customize the software is especially important to an experienced CAD user. By customizing the program to suit specific needs, the drafter can become highly efficient. In addition, program customization can help a CAD manager better standardize a department's drafting procedures.

3D Capability

Three-dimensional modeling is an advanced capability of some CAD programs. Much of the drafting done in CAD is in two dimensions, just like a manual drawing on paper. However, 3D modeling creates a "virtual" object in the computer that has width, length, and depth. The 3D object can be shaded or colored, rotated, and sometimes animated, **Figure 3-13**.

There are two basic types of 3D models. A ***surface model*** is created by drawing a wireframe, much like a 2D drawing, and placing a skin over the wireframe. A ***solid model***, on the other hand, has volume and mass. It is not empty on the inside like a surface model. Both types are used in technical drafting. Unless there are specific requirements for one type or the other, the one that is drawn depends on the software capabilities and drafter's preference. There is a general trend toward creating solid models because, in general, the final result can be used for analysis.

Mass property analysis provides important information about a product. The information can be used for engineering calculations or for "premanufacturing" on a computer. Surface models are not generally suitable for mass property analysis. Solid models are almost exclusively used for mass property analysis.

Data Exchange

The ability for a CAD program to share data with other software is important for most applications. Even the most basic CAD programs

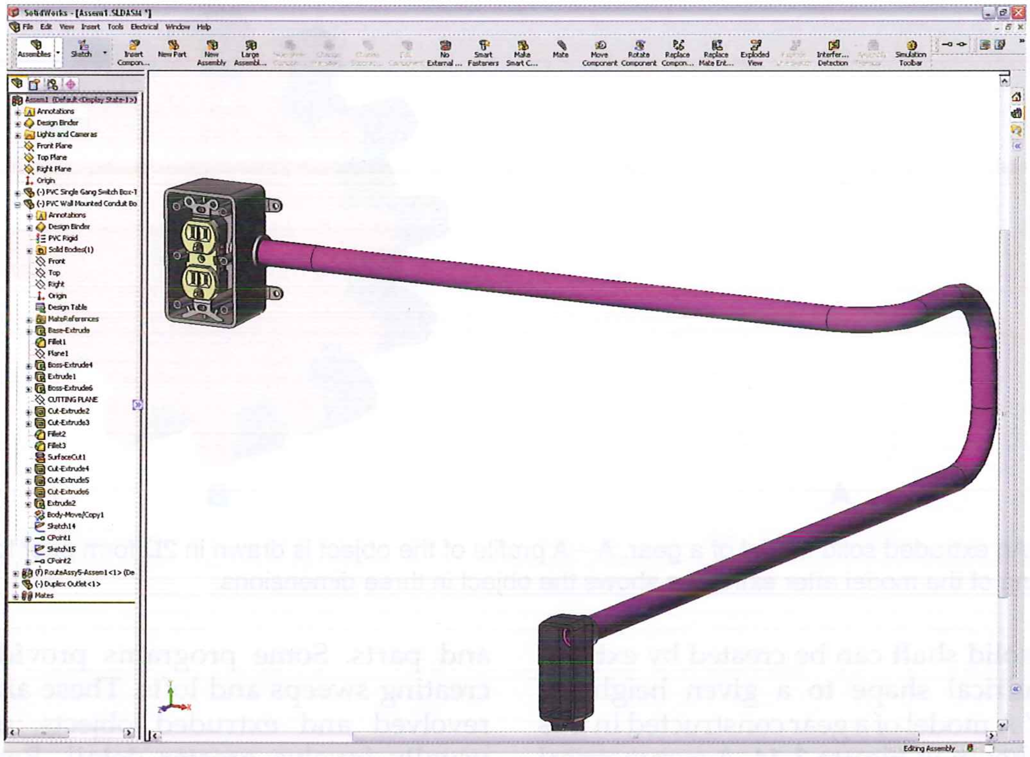


Figure 3-13. Three-dimensional models provide realistic representations of objects such as this conduit run. (Image Courtesy of SolidWorks Corporation)

support importing and exporting of a variety of file types. Before purchasing a CAD program that is not one of the more common programs, be sure to determine if it can import and export common file types. One of the most common file types used to share data is the Drawing Interchange Format (DXF) format. This file format supports 2D and most 3D features. In addition, many CAD programs can also exchange data with database software, such as Microsoft Excel or Lotus 1-2-3.

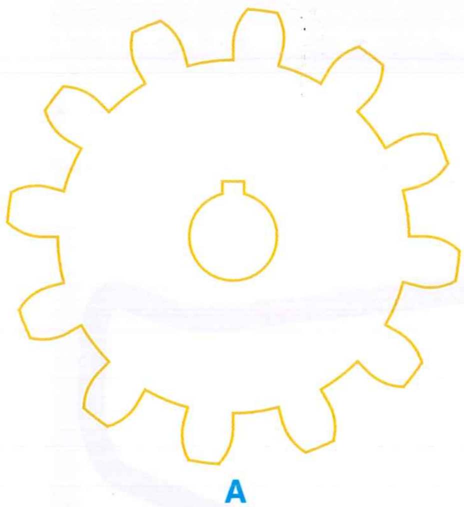
Advanced Mechanical Drafting and Modeling CAD Packages

Advanced mechanical drafting and modeling CAD packages are designed for higher-end applications in mechanical engineering. These packages generally include all of the functionality of general purpose CAD programs. However, they include additional tools and features for use in three-dimensional modeling. These functions are very useful for designs in manufacturing applications. These functions are discussed in the following sections.

Solid Modeling Tools

Solid modeling tools are widely used in CAD-based mechanical drawing applications. As previously discussed, solid models are very useful in engineering and design because mechanical parts can be analyzed, tested, and/or prototyped before manufacturing. Mechanical drafting CAD programs with modeling capability provide a number of ways to create solid models. Different methods are available, depending on the type of software. In more simple programs, solid models can be created from building elements called ***primitives***. These are solid shapes, such as boxes, cylinders, spheres, and cones, that form the building blocks of a model.

Solid models can also be created from 2D geometry in most programs. Profiles of objects can typically be converted into 3D form by extruding or revolving the 2D geometry. For



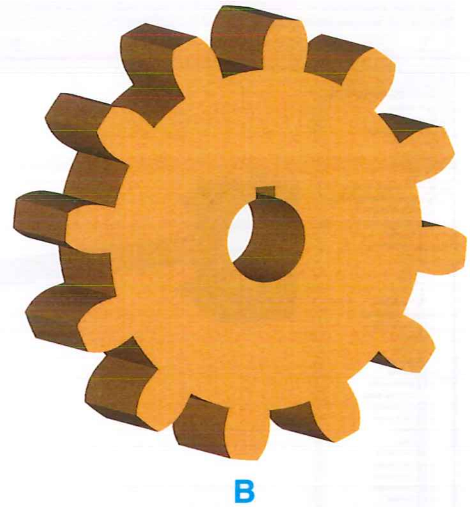
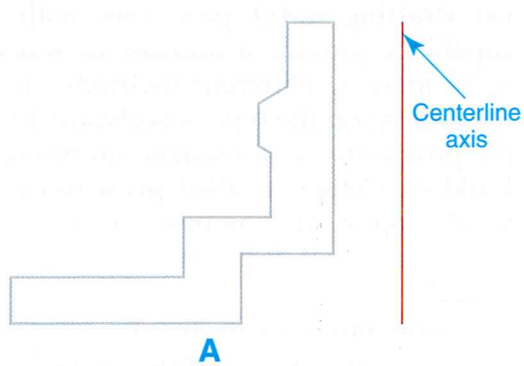


Figure 3-14. An extruded solid model of a gear. A—A profile of the object is drawn in 2D form prior to extruding. B—A rendering of the model after extruding shows the object in three dimensions.

example, a solid shaft can be created by extruding a cylindrical shape to a given height or "thickness." A model of a gear constructed in this manner is shown in **Figure 3-14**. A symmetrical object, such as a hub or flange, can be created by revolving a profile shape about a centerline axis. See **Figure 3-15**.

More advanced modeling programs provide additional tools. When creating hole features, for example, some programs allow you to "cut out" material from solids by automatically generating drilled, counterbored, or countersunk holes. Threads can be added after drilling by specifying the thread type and depth. In some cases, external threads can be "cut" on cylindrical solids.

In certain programs, other modeling methods can be used to create complex solids and parts. Some programs provide tools for creating sweeps and lofts. These are similar to revolved and extruded objects, except they usually involve greater detail. Both types of objects are generated from sketched profiles. A ***sweep*** is created by extruding a profile along a path, **Figure 3-16**. A ***loft*** is created by extruding one or more cross-sectional shapes (profiles) along a special type of path called a *rail*. Lofts are used for more complex shapes, such as objects that have many bends or curved surfaces. See **Figure 3-17**. The pry bar shown was created by lofting a series of rectangular cross sections along a rail curve. The notches at the ends were modeled by extruding ellipses into solids and using them to "subtract" material from the body.



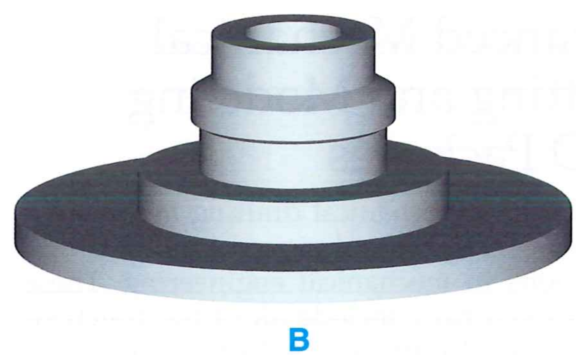


Figure 3-15. A revolved solid model of a hub. A—A profile of the object and centerline axis are drawn using 2D geometry. B—A rendering of the model after revolving the profile about the axis.

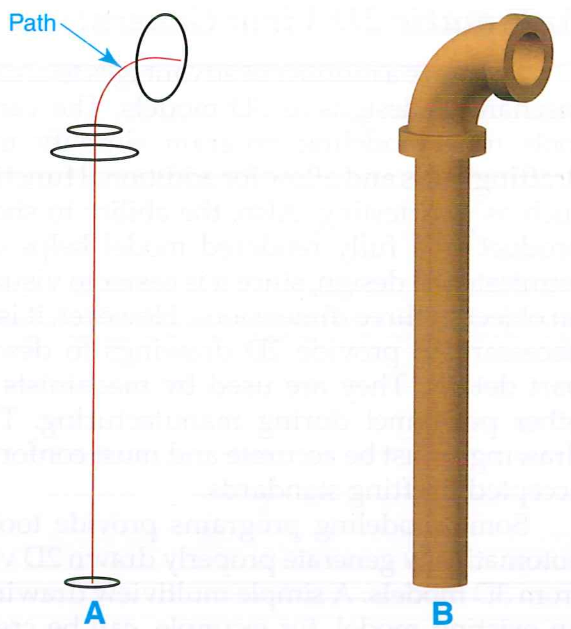


Figure 3-16. Using a sweep tool with 2D geometry to create a solid model of a standpipe. A—Circular profiles are drawn to define the pipe sections. The path axis consists of a single line that curves to define the elbow. After the profiles are drawn, they are selected with the path to create the sweep. B—A rendering of the swept model. (Anthony J. Panozzo)

Parametric Modeling

Parametric modeling is a form of 3D modeling that allows greater control over the creation and modification of models. Advanced mechanical drafting CAD programs are typically based on parametric modeling. In this type of modeling, dimensions and geometric features called ***parameters*** are specified when creating an object. For example, to create a cylindrical section for a part, you may be prompted during a command to specify several parameters, such as a center point for the base, a height, and a radius or diameter for the cylinder. Parameters may also be used for creating more complex objects, such as a screw. For example, you may only need to provide the diameter, length, and threads per inch. Using these values, the system draws the necessary geometry to describe the screw. A parametric model is shown in **Figure 3-18**.

Once a parametric model is created, its parameters may be changed to alter the object's dimensions. If changes are made to a parametric model, or if new components are added, the system stores the new parameters in the existing model. The parameters define dimensional

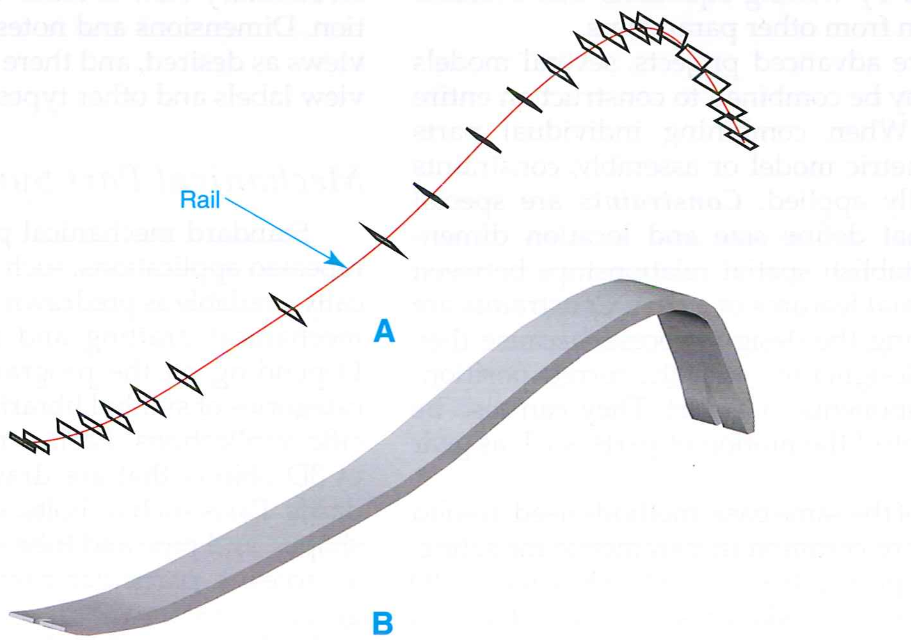


Figure 3-17. Lofting operations are used to model objects with curved surfaces and/or irregular cross-sectional shapes. A—A series of rectangular cross sections is drawn to define the sections of the pry bar. The cross sections are spaced along the rail prior to lofting. B—A rendering of the lofted model. The notches at the ends of the bar are created by extruding elliptical shapes and using them to remove material. (Anthony J. Panozzo)

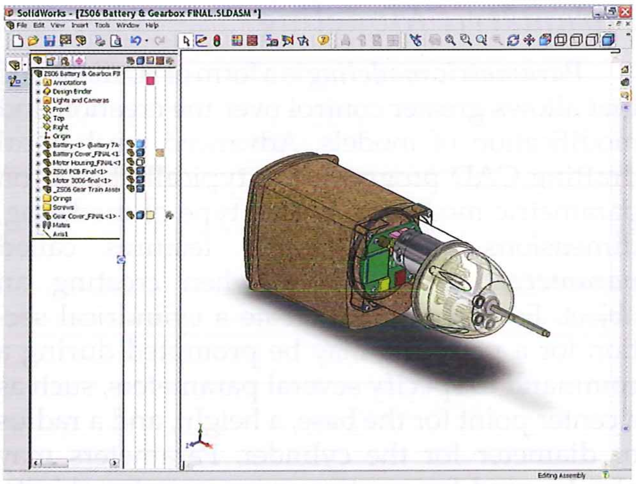


Figure 3-18. Parametric modeling programs provide advanced tools for creating mechanical parts such as this motor assembly. (Image Courtesy of SolidWorks Corporation)

and spatial relationships between features. As parts are added, the object parameters are evaluated by the system to establish whether the model is a valid design. To properly build a parametric model, design data added during the modeling process must conform to previously defined parameters. In some cases, parameters are defined by writing equations that evaluate information from other parameters.

In more advanced projects, several models of parts may be combined to construct an entire assembly. When combining individual parts in a parametric model or assembly, constraints are typically applied. ***Constraints*** are special controls that define size and location dimensions to establish spatial relationships between the individual features of a part. Constraints are useful during the design process, because they allow the designer to verify the correct positioning of components in a part. They can also be used to control the motion of parts, such as gear rotation.

Some of the same basic methods used in solid modeling are common in parametric modeling. Designs typically begin as sketches using 2D geometry, and the sketches are converted into solid models. However, the software provides additional controls to help the drafter evaluate the model and visualize the final product as the design develops.

Automatic 2D View Generation

There are a number of advantages to creating mechanical designs as 3D models. The various tools in a modeling program simplify many drafting tasks and allow for additional functions, such as part testing. Also, the ability to show a product as a fully rendered model helps communicate the design, since it is easier to visualize an object in three dimensions. However, it is still necessary to provide 2D drawings to describe part details. They are used by machinists and other personnel during manufacturing. These drawings must be accurate and must conform to accepted drafting standards.

Some modeling programs provide tools to automatically generate properly drawn 2D views from 3D models. A simple multiview drawing of an existing model, for example, can be created by first developing a base view of the model. The base view might be designated as a front view or top view. Then, the base view is used by the program to generate the other views. In addition to orthographic views, you can automatically create section views, auxiliary views, isometric views, and details. The 2D views can also be edited to change characteristics such as colors or line visibility. For example, you may want to alter an auxiliary view to remove unneeded information. Dimensions and notes can be added to the views as desired, and there are tools for creating view labels and other types of annotations.

Mechanical Part Symbols

Standard mechanical parts that are used in repeated applications, such as fasteners, are typically available as predrawn symbols in advanced mechanical drafting and modeling programs. Depending on the program, there are various categories of symbol libraries with parts for specific applications. Each symbol library consists of 3D objects that are drawn to industry standards. Parts such as bolts, screws, common steel shapes, and pipe and tube sections are available. To access a particular part, the user locates the general category (library), navigates to the part, and selects a standard size, material type, or description, such as a thread specification. The part is automatically generated by the program and can be used as a component in a model.

CAD/CAM

Computer-aided manufacturing (CAM) is a manufacturing process that uses CAD design data to automate machine operations. In this type of manufacturing, drawing data from a CAD system is used to control the operation of ***computer numerical control (CNC)*** machines. The drawing data is used by a machining program to control tool direction and speed. The processed data is sent to a milling machine, lathe, or other type of machining center. CAD/CAM speeds up the manufacturing process since the same information used to create the design is used by machinery to machine the part. See **Figure 3-19**.

There are many advantages to CAD/CAM programs. Before being sent to a machine, the design data can be used for machine tool simulation. The computer displays the tool path, and errors in movement can be detected before a part is machined. If the tool moves too fast or too deep, the designer can edit the tool path. Without this type of testing, most errors are caught when a tool breaks because of a wrong move. CAD/CAM programs are discussed in more detail in Chapter 21.

AEC CAD Packages

Architectural, engineering, and construction (AEC) CAD packages are programs designed for a specific field. These packages generally include all of the functionality of general purpose CAD programs. However, they include tools and features for use in the AEC fields. The extra functions improve the workflow for AEC drafters. The following sections cover some of the features found in AEC CAD packages.

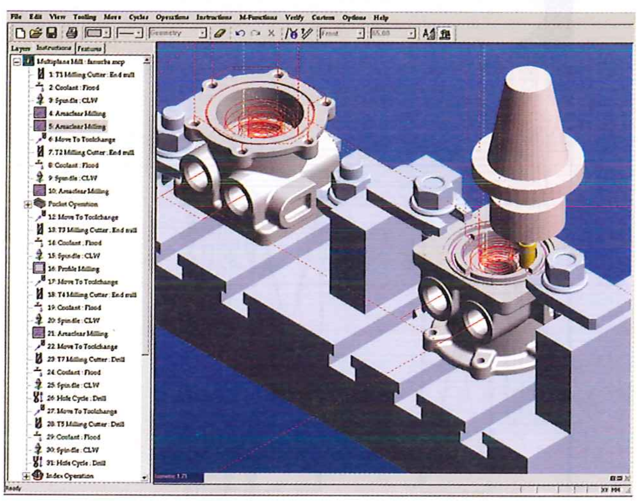


Figure 3-19. An assembly modeled for manufacturing using a CAD/CAM software program. The information for machining, including operations sheets and tool lists, is automatically generated by the software. (EdgeCAM/Pathtrace)

Schedule Generation

Most AEC CAD packages provide automatic schedule generation. The information is taken from the attributes of objects or symbols in the drawing. Also, once the original object or symbol is edited, the schedule is automatically updated. The ability to automatically generate schedules is a great time-saving function, especially on large projects.

Space Diagram Generation

Space diagrams are useful planning tools. They are simplified representations of floor plans and typically provide square footage or dimensions of the space. Some AEC programs will automatically convert a space diagram into a floor plan complete with wall thickness, **Figure 3-20**.

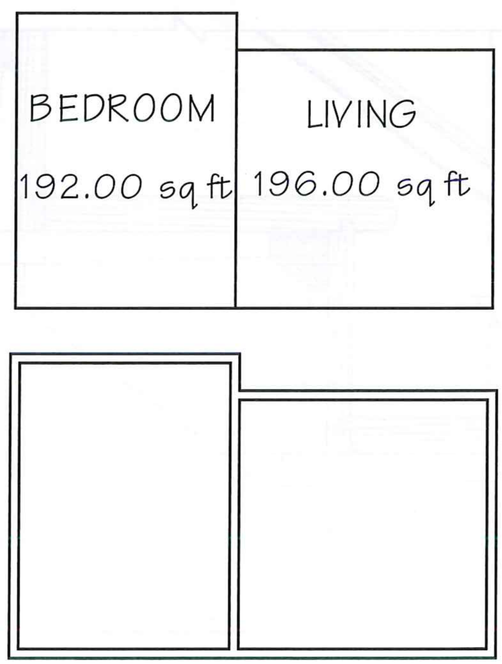


Figure 3-20. Some AEC CAD programs can take a space diagram (top) and create a floor plan from it (bottom).

Stair Generation

Stair design requires a considerable effort, both to calculate and draw. Some AEC CAD programs include automated stair design features. The drafter enters basic data from the architect's sketches and the software automatically draws the stairs, **Figure 3-21**. Data that is typically entered may include the finished-floor-to-finished-floor

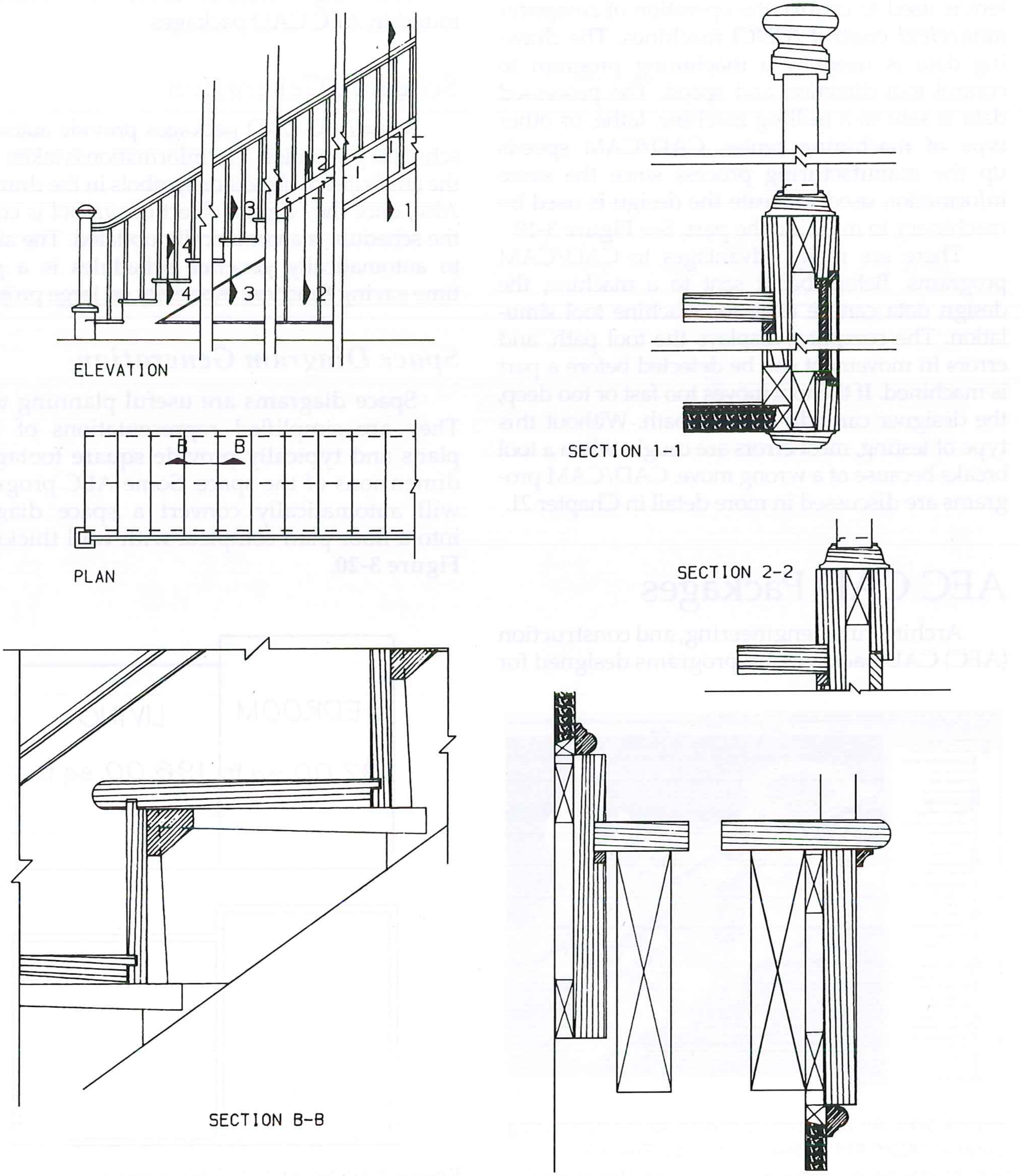


Figure 3-21. These standard wood stair construction details are generated from data supplied by the drafter. (Prime Computer, Inc.)

height, stair width, and the run of the stairs. Some AEC CAD programs also offer the ability to extract details from the drawn stairs. Generally, options are provided for wood, metal, and concrete/steel stairs. High-end AEC CAD programs also include elevators and escalators.

Hatch Patterns

AEC CAD programs offer hatch patterns that are specifically designed for the AEC field. A general purpose CAD program may not offer the patterns needed in the AEC field, such as shakes or shingles, various brick patterns, earth, sand, concrete, and foliage. These patterns can be difficult to create if they are not included in the program.

Walls

Architectural packages generally provide more than one method of generating walls, **Figure 3-22**. Often, walls can be drawn directly from space diagrams, as continuous walls, and from dimensions. Features such as intersection cleanup, wall thickness specification, and alignment are important time savers that can be found in most AEC CAD programs. If not available in the "standard" features, many CAD programs can be customized to add these features.

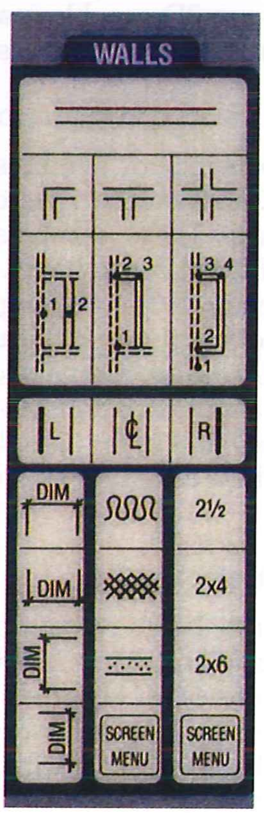


Figure 3-22. This digitizing tablet provides several options for drawing, manipulating, and hatching walls.

Symbols

AEC drawings typically contain many symbols. Symbols are used to represent various features, such as an electrical connection, tree, or plumbing fixture. Some types of symbols that may be found on an AEC drawing include:

- Standard door types
- Standard window types
- Plumbing symbols
- Electrical and lighting symbols
- HVAC symbols
- Furniture symbols
- Tree and plant symbols
- Appliance symbols
- Vehicle symbols
- Title symbols
- Structural symbols

Standard door and window types

Doors and windows require a considerable amount of time to draw from scratch. Therefore, it is important to have the appropriate symbols in a symbol library. A good AEC CAD package will include all of the standard door and window symbols, **Figure 3-23**. The symbols may be in a "general" library or may be in their own library. In addition, many window and door manufacturers provide symbol libraries of their products free of charge. Therefore, the ability to "add" these libraries to the CAD program is important for many architects and designers.

Structural symbols

Structural symbols are a necessity for commercial work but also needed for residential design. Many AEC CAD programs include structural symbols in a library. Structural

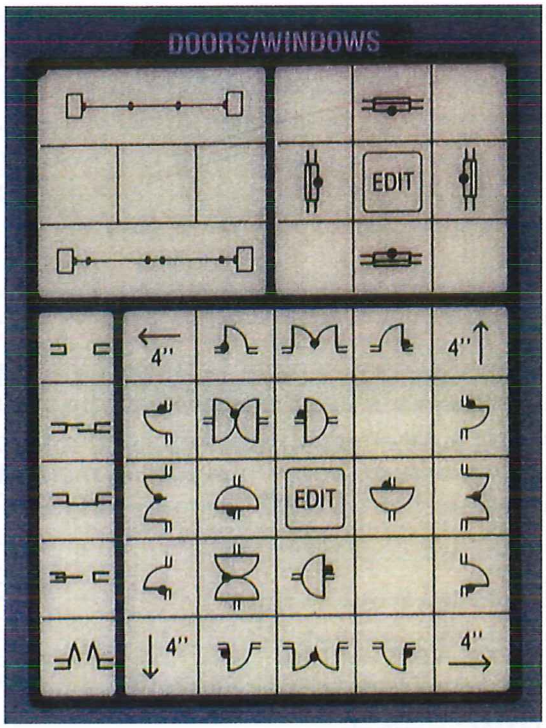


Figure 3-23. Standard window and door symbols should be included in a quality AEC CAD program.

symbols can include I-beams, U-channels, and cast concrete members.

Plumbing symbols

Most structures, whether residential or commercial, have some sort of piping or plumbing plan. AEC CAD programs include standard plumbing symbols in a library. Typical plumbing symbol libraries include symbols for tubs, lavatories, shower stalls, toilets, bidets, plumbing lines, and valves. Some high-end AEC CAD programs that have 3D capabilities also provide 3D pipe symbols, or have the ability to add these symbols to the library.

Electrical and lighting symbols

Most residential and commercial structures require an electrical plan. Electrical symbols are simple to draw, but a single electrical plan may contain hundreds of symbols. Therefore, it is very important to have a good electrical symbol library that includes standard symbols. Most AEC CAD packages include several electrical and lighting symbols.

HVAC symbols

Commercial structures include a heating, ventilating, and air conditioning (HVAC) plan. Residential structures may also include an HVAC plan. HVAC symbols are often not included in lower-end AEC CAD packages or those designed just for residential applications.

Tree and plant symbols

Tree and plant symbols are used to show site details, landscaping details, or to "dress up" a drawing. Plant symbols are used on all plot plans and on many presentation drawings. Generally, these symbols are shown in a plan or elevation view. In addition, AEC CAD programs that have 3D capabilities often provide 3D views of plants and trees.

Furniture and appliance symbols

Symbols of typical furniture pieces are part of most AEC CAD packages. Some basic office furniture is typically offered with all AEC CAD programs. However, extended libraries are usually an additional purchase. AEC CAD programs that are 3D capable may provide 3D symbols of furniture or appliances.

Title symbols and construction details

Title symbols include symbols for meridian (north) arrows, revision triangles, drawing titles, scales, and tags. These symbols are usually included in AEC CAD programs. Construction details are generally much larger and more complex than other symbols, **Figure 3-24**. Construction details are so specialized that most of these symbols are created by individual users or companies. They can save many hours of work in situations where a common detail is used over and over.

Vehicle symbols

Vehicle symbols can range from basic block representations to fairly detailed plan and elevation views. Most AEC CAD programs only offer a few of these symbols, if any. However, they can generally be purchased separately. Perhaps the most commonly used vehicle symbols are 3D symbols. There are many different libraries available that contain 3D vehicle symbols.

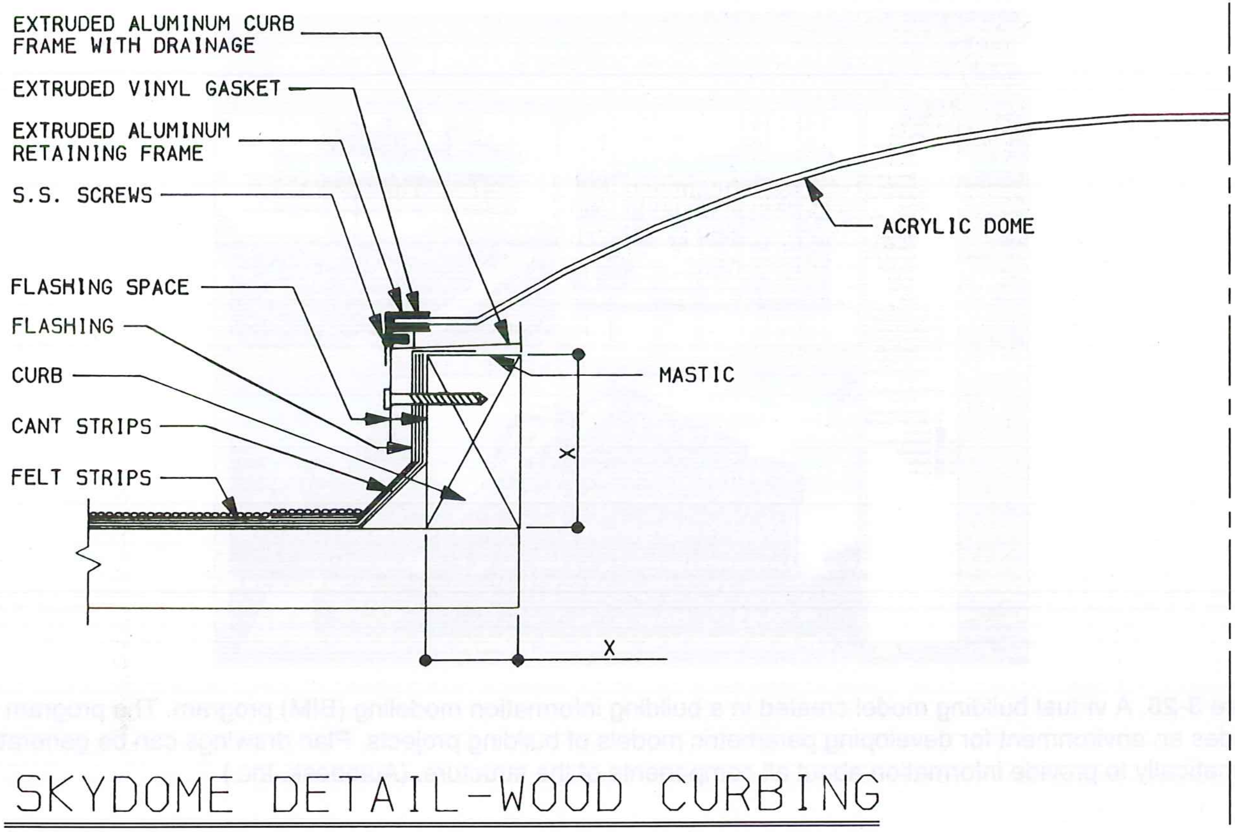


Figure 3-24. Construction details can be stored as symbols in a library. They are often created by individual users or companies. (Prime Computer, Inc.)

Building Information Modeling

Traditionally, construction drawings have been generated as sets of drawings for use in building projects. Plan drawings such as site plans, floor plans, elevations, and sections are added to the set of documents as a specific project develops. In many cases, these drawings are generated in 2D form and referred to by different personnel. Some of the most common AEC CAD programs provide tools for creating drawings in this manner. However, more advanced programs incorporate different tools and methods for designing building projects as comprehensive models.

Building information modeling (BIM) is an application of CAD-based design that combines drawing data from different building systems into a single model. See **Figure 3-25**. The components making up each system, such as framing members, roof members, and structural supports, are intelligent objects that, when created, are evaluated in relation to other objects in the model. As each component is drawn, the model is updated to reflect the addition. This type of modeling creates a parametric model that contains all of the information needed for construction (including dimensional data and materials). In some programs, the parametric model is referred to as a ***virtual building***.

Programs with building information modeling capability provide most of the AEC CAD program functions previously discussed. Objects such as windows and doors are typically provided as predrawn geometry that can be added to the model as needed. Objects can be drawn in 2D or 3D views. As changes are made to the design, geometric relationships between objects are maintained. For example, if a wall is changed in length, the wall openings for doors and windows are updated to maintain the defined distances from the wall ends. In addition, wall framing members are added or removed depending on spacing requirements. This provides many advantages to the designer. Different designs can be compared quickly to assess their potential appeal as well as building requirements, including material costs.

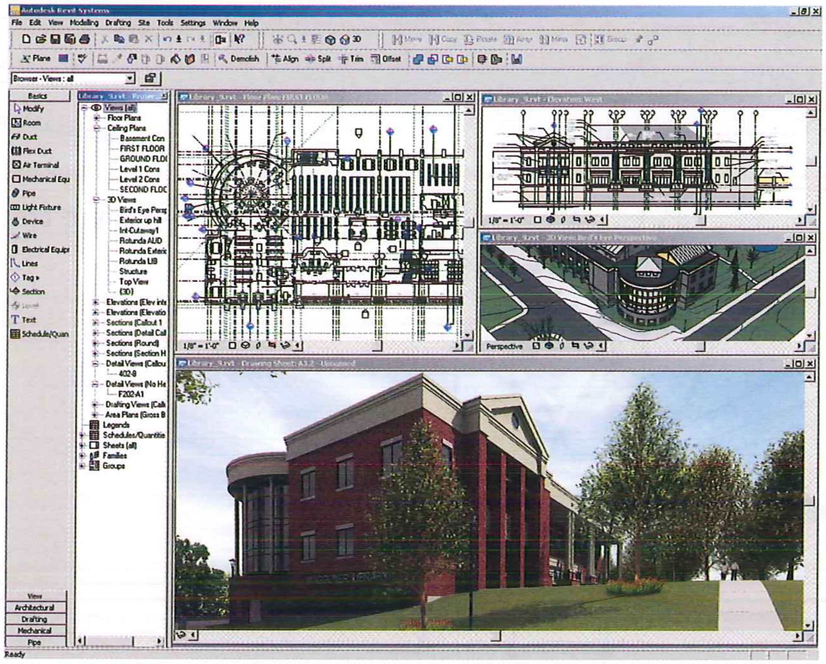


Figure 3-25. A virtual building model created in a building information modeling (BIM) program. The program provides an environment for developing parametric models of building projects. Plan drawings can be generated automatically to provide information about all components of the structure. (Autodesk, Inc.)

One of the most powerful applications of building information modeling is the ability to automatically generate different types of plan drawings from the model as needed. Drawings such as elevations and sections can be generated from 3D views at any time for visual evaluation or structural analysis. This also presents the potential of saving the drafter from creating each type of plan drawing required. Programs with building information modeling capability also provide automatic schedule generation functions and advanced functions, such as tools for making renderings, animations, and prototypes.

Chapter Summary

CAD is an acronym for computer-aided drafting. CAD is a tool that replaces pencil and paper for the drafter and designer. All types of drawings can be produced with CAD.

There are many reasons to use CAD, but most important, CAD saves time and money. Once it is stored electronically, a drawing can be called up whenever copies or revisions are needed. CAD programs let the drafter/designer quickly develop and communicate ideas in a precise and professional manner. Flexibility is another advantage of CAD. For example, drawings may be plotted to any scale, plotted in color, presented on different media, or shared with others by various means.

Drawings produced on a CAD system will have a high degree of uniformity regardless of who makes the drawings. Poor line quality and sloppy lettering are not issues with a properly used CAD system. In CAD, objects are almost always drawn in their true size, but plotted to any scale desired. This reduces errors.

Some CAD packages have the ability to automatically generate part schedules, machining operations schedules, and various reports. Computer renderings are commonly produced using CAD.

A CAD workstation generally consists of a computer or processor, monitor, graphics adapter, input and pointing device, and hard copy device. The computer consists of the central processing unit, an output device, and a storage device. Most monitors are cathode ray tubes or LCDs. The most common input device is the keyboard; the second most common device is the mouse. The monitor is the most common output device. Plotters are used to make hard copies of drawings.

There is a wide variety of CAD programs on the market. Be sure you know what you want to do with the package before you make a selection. CAD programs may be grouped into three broad types. These are general purpose CAD packages, advanced mechanical drafting and modeling CAD packages, and AEC CAD packages. General purpose CAD packages meet a wide range of needs, but generally lack advanced applications for specific fields. Advanced mechanical drafting and modeling CAD packages are designed for applications requiring special solid modeling and parametric modeling tools, automatic view generation, and CAD/CAM. These packages usually include the functionality of general purpose CAD programs, but also have extra tools for use in mechanical drafting. AEC CAD packages contain tools that are useful for architects, engineers, and other drafting personnel in the AEC industry.

Additional Resources

Computers and CAD Software

Autodesk, Inc.
Developer of AutoCAD, Inventor, Revit Systems, 3ds max
www.autodesk.com

Auto-des-sys, Inc.
Developer of Form•Z
www.formz.com

Bentley Systems, Inc.
Developer of MicroStation
www.bentley.com

Cadalyst
www.cadalyst.com

Compaq Computers
www.compaq.com

Dell Computers
www.dell.com

Hewlett-Packard
www.hp.com

Mastercam
Developer of CAD/CAM software
www.mastercam.com

Parametric Technology Corp.
Developer of Pro/ENGINEER, Pro/MECHANICAL, Pro/DESKTOP
www.ptc.com

Pathtrace Systems, Inc.
Developer of CAD/CAM software
www.pathtrace.com

SolidWorks Corporation
Developer of SolidWorks
www.solidworks.com

Surfware, Inc.
Developer of CAD/CAM software
www.surfware.com

UGS Corp.
Developer of Solid Edge
www.solidedge.com

Review Questions

1. The acronym *CAD* stands for _____.
2. CAD _____ consists of the instructions that make the hardware perform the intended tasks.
3. What is the main reason for using CAD?
4. A(n) _____ is a collection of standard shapes and symbols typically grouped by application.
5. In CAD, objects are almost always drawn at _____.
   A. half size
   B. any scale
   C. true size
   D. quarter scale
6. In mechanical drafting, presentation drawings usually consist of _____ or _____ views.

7. A CAD _____ generally consists of a computer or processor, monitor, graphics adapter, input and pointing device, and hard copy device.
8. An input device that all CAD systems have is the _____.
   A. puck
   B. keyboard
   C. light pen
   D. None of the above.
9. The size of a _____ is measured diagonally, just like a television screen.
10. The _____ is the device that transmits data from the CPU to the monitor.
11. The monitor is the most common _____ device of a computer workstation.
12. Which of the following is an advantage of a pen plotter?
   A. It can produce renderings.
   B. Its operation is very fast.
   C. It produces very high-quality line reproductions in color.
   D. None of the above.
13. What are the three broad groups of CAD programs?
14. _____ are the basic elements used in creating CAD drawings.
15. Materials such as brass, steel, and glass are shown as _____ patterns in a section view.
16. Which of the following is *not* an editing function?
   A. Erasing.
   B. Rotating.
   C. Dividing.
   D. Drawing.
17. _____ are similar to transparent drawing sheets on which you can draw.
18. What are the two basic types of 3D models?
19. In 3D modeling, a _____ is created by extruding a profile along a path.
20. Most AEC CAD packages provide automatic schedule generation where the information is taken from the _____ of objects or symbols in the drawing.
21. One of the most powerful applications of building information modeling is the ability to automatically generate different types of _____ drawings from the model as needed.

Problems and Activities

1. Using the Internet, search for various types of CAD software. Make a list with the software grouped by general purpose, advanced mechanical drafting, or AEC.
2. Identify the components of your CAD workstation.
3. Contact a local AEC firm that uses CAD. Identify the criteria they used to justify switching from manual drafting to CAD.
4. Obtain a plan for a manufactured product. Determine where CAD can be used in the project. Identify areas of the project in which CAD would provide a large benefit over traditional manual drafting.