A Survey on Personal Computer Applications in Industrial Design Process

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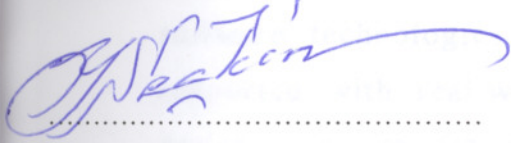
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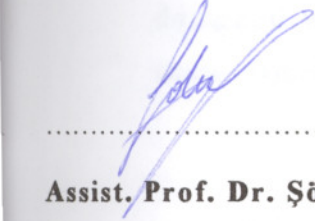
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ABSTRACT

In this thesis, computer aided design systems are studied from the industrial designer's point of view. The study includes industrial design processes, computer aided design systems and the integration aspects. The technical issues are priorly studied , including current hardware and software technologies. The pure technical concepts are tried to be supported with real-world examples and graphics. Several important design software are examined, whether by personal practice or by literature research, depending on the availability of the software. Finally, the thesis include a case study, a 17" LCD computer monitor designed with a set of graphic programs including two-dimensional and three-dimensional packages.

Keywords: Computers, industrial design methods, design software, computer aided design.

ACKNOWLEDGEMENTS

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

INTRODUCTION

The computers are getting densely into the daily life of people. It redefines the way we communicate, the way we store our personal information, even the way we enjoy and educate ourselves. This is especially true in many different areas; computers have a big impact on the nature of the related business itself.

Industrial design is one of the fields which are mostly affected by the computers, including its related fields such as manufacturing businesses. For the first time, a single machine is able to help the designer, from the initial sketches to the final product. Our era is the first one in which we produce images with a machine. Computers have changed even the way we design, visualize and manufacture a product.

There are some thoughts about computers assuming that they seriously restrict the creativeness of designers. This can be true in some points, because despite of the close integration of computers and design processes, this new tool is not used effectively by many designers. In the thesis, the possible contributions of computers to the design processes are generally accepted and the suspicious opinions about computers are overlooked.

This survey considers computer systems in two different categories: the first is based on the concept of computers as a design tool closely related with the requirements of the design processes. The second examines the computer systems in a strictly technical context. Industrial design processes is a part of this study, however the technical aspects of computer aided design systems are predominantly taken into consideration.

It is obvious that computers are not still a strictly necessary tool for a designer to create a successful product. But, with the growing demands of the industry, the designer can define his role in the business in a much more flexible manner. He can have greater control over the final product with the help of automated production processes that computers supplies to both designers and engineers.

1

The developing technology aims to fully automat᷾   ic
systems to reduce the need of human assistance as mᴜ
This is especially true for manufacturing purposes, but ᴜ
processes can be automated to some level. Chances are that future
software will include a sort of "styling filters" such as "streamlining"
"Blade Runner-look". Computers then will generate many different
iterations of a design and allow the designer to select the one that fits
best.

But in fact, computer technology can be considered still in its
infancy. Design and manufacturing system have complex user interfaces
and the user is still forced to handle manually the highly technical
subjects required by the computer. If computer systems are to be used by
a designer, he or she must have a good technical knowledge about this
tool. This technology is getting more and more complicated for the
designer, and the importance of technical knowledge is more apparent
than ever. To achieve little enhancements over the object generated with
a computer aided design system, a greater deal of expertise and technical
background is required.

This can be considered as the main reason of the priority of the
technical aspects of computer aided design systems in this thesis.
Different design processes are taken into consideration such as
conception, refinement, visualization, documentation and manufacturing
and they are all covered with the appropriate technical aspects which are
important to the designer.

Chapter 1 involves the use of computers in design. A general
overview on computer systems including the hardware and software is
covered within the first chapter, as well as design processes and
computer aided design systems. The design processes are studied in
parallel to its relevant computer practice. In the last section of the
chapter 1, computer aided design systems are considered as a more
general title consisting of computer aided manufacturing, drafting, and
computer integrated manufacturing.

The second chapter is about the integration of industrial design
and computers, including general concepts of computer aided design and

visualization, supporting applications, current three-dimensional graphic programs and new fields concerning the design profession. This chapter includes detailed technical information, especially about three-dimensional modeling and visualization, however a more abstract context, new fields in design profession, is studied within this chapter.

The conclusion basically involves the case study, a LCD computer monitor design. Three-dimensional modeling and visualization is generated with a PC, with various software. The case study aims to form a "computerized model" for the designer.

Literature research, practice on computer aided design and visualization systems and a case study which is based on both technical and integration aspects are used as the main methods of research. The current technologies are studied by using the updated design software available. Many programs were unobtainable, though, they are tried to inspect with the help of periodicals and the internet.

CHAPTER 1

USE OF COMPUTERS IN DESIGN

1.1 AN OVERVIEW OF COMPUTERIZED INDUSTRIAL DESIGN CONCEPT

Computers are gradually increasing their importance in all design-related fields. Since computers are the unique medium covering all the industrial design processes including manufacturing, they have been broadly accepted by many design organizations world-wide. The use of computers in industrial design is also closely related to the developing technology: once the computer systems had user-friendly interfaces, designers felt comfortable to use these machines, as an integrated tool with their profession. Although this was not a rapid process, computer systems proved a very worthwhile use in design field.

1.1.1 History of Computer Applications

The first applications of computers in industrial and manufacturing related fields were primarily in the administrative and finance areas. Manufacturing area had no clearly developed and documented procedures relatively. The available hardware and software of the time were capable to handle the operations needed in the administrative applications. Manufacturing processes needed much more power and reliability. The adaptation of computers to this area required the advance of technology to a stage at which hardware specifications could handle large volumes of data. The problem was not only the technology, also a better organized manufacturing discipline lacked.

The earliest part modeling facilities for CAD applications dates back to late 1950s and early 1960s. Before 1960, hardly any computer

application for design or manufacturing existed. In 1960, first examples of CAD systems began to appear which also reflects the development of other underlying applications.

Automotive and aerospace industries led CAD systems to develop. Most engineering software were limited to calculation programs for batch processing only, thus were no interaction between the user and the program. Many people refer the origins of CAD technology to the beginning of interactive computer graphics. The theoretical basis for computer generated graphics technology is formed by Ivan Sutherland (1963) in his Ph.D. thesis. He aimed a system called "sketchpad" which rendered possible the first interactive computer graphic. This system was developed under the Semi-Automatic Ground Environment (SAGE) project in MIT. Sketchpad helped radar information to change into computer integrated pictures. The system used a vector type display, a light pen and a keyboard. The light pen allowed moving a tracking mark and describing a graphical information on the screen, changing the shape of those graphics and controlling the image processing. This was revolutionary because direct operation on the data (graphics in this case) was possible. The conventional thinking was that a monitor serves only to display the result of computations. But sketchpad brought a new working concept: working through the display to directly affect the graphics, the very first example of interactivity through computers, as we know today.

figure 1.1: Ivan Sutherland with sketchpad (Baker R., 1993 p.15)

In 1964, General Motors developed the first practical application of interactive diagram processing, DAC-1. A light pen and function keys were used to formulate the designs interactively with the computer. DAC-1 set the example of the introduction of CAD for major aircraft manufacturers.

Lockheed started to design aircraft with it's own CAD/CAM system in 1965. This system became commercially available in 1967 but the CAD systems of the time were developed by large companies for in-house use and caused this technology not to become mass popularized.

The first CAD system designed for general market was AGS. It was developed by Applicon Company in 1968, as a CAD dedicated drafting system. The other systems developed up to that date were large systems for use in big computers, as we know as "mainframe" computers today. In contrary, AGS were a much more simple system; a turn of a key and a switch of a button were enough to start the system. Many other CAD systems followed that "turnkey system" after that time.

With the developments in the areas of hardware and software, three-dimensional solid modeling became possible in 1970s. It was for the first time that computers could be used for both engineering drawings and analysis. Systems got higher processing speeds, larger memories, and smaller size with available prices. This helped CAD/CAM systems to gain acceptance in corporate production and design divisions who were pressured by the urgent need of combining computers with their task. But this wave of computerization started with the demands of design planning divisions, not the designers themselves. The effect of computers was mostly on greater production efficiency, which caused the production divisions to attract the most of the attention. There were few examples of design divisions and designers who benefit from the use of computers.

Kaplinsky argues that the origins of CAD lie in an extensive interaction between the military, aerospace, automobile and electronic sectors, spin-offs from academic institutions and venture capital

enterprises. He believes that the military and aerospace industry has played an important part over the years, particularly in the U.S.

"... the first technological breakthrough for CAD - that is, the refresh graphics screen plus lightpen, which allowed for an interactive relationship between the screen and the operator – was developed for the SAGE early warnings radar system in the 1950s. Later, in the 1960s, the US Department of Defense played an important role in disseminating the virtues of CAD, culminating in a major conference between defense and industry in 1968 when the concept of CAD/CAM ... began to receive prominence. This concern with automation (i.e. CAD/CAM rather than CAD alone) remained a preoccupation of the military in the 1970s, leading, via the work of the Air Force Integrated Computer-Aided Manufacturing (ICAM) Program (funded jointly by the US Airforce, the Army, the Navy and NASA), to the establishment in 1979 of a committee attempting to implement common software standards which will allow different CAD/CAM systems to intercommunicate with each other. The military played a significant role in the origins of particular firms, especially Intergraph, which has been he most rapidly growing CAD vendor since 1976 and is now the fourth largest firm in the industry. Intergraph had its origins in wiring Large Scale Integration (LSI) software for the US army; but most importantly it was able to recruit software specialists from the neighboring NASA center in Huntsville, Alabama, after the winding down of the Apollo Moon Program. Not only did this occur during a period of ... acute shortage of experienced software writers than any of Intergraph's competitors." (Kaplinsky R. 1982)

Applications in the non-military aerospace, automobile and electronic sectors provided a second stimulus to the growth and development of CAD.

"General Motors instigated the first industrial application of CAD with its Design Augmented by Computers program, beginning in 1959. This was followed shortly afterwards by similar programs in Lockheed and McDonnell aircraft firms in the U.S. the U.K. CAD industry's historic pre-eminence amongst European countries (especially in relation

to software) is attributable to the relatively advanced state of its aircraft industry in the 1960s. ...Over the years pioneering American firms provided a cadre of trained software writers who were instrumental in the formation of many of the major turnkey CAD vendors in the 1970s, as well as in the development of the basic graphics software which these firms used." (Kaplinsky R. 1982)

1.1.2 Industrial Design Process

Computers are increasingly being used in the design practice. The main aim of computers for a designer is to provide a unique medium of design offering the best possible conditions in simulating, questioning and becoming informed as well as creating. The software and hardware are new and varied tools for the designer helping to approach, develop and test a design in a way that was never seen before. These tools combine multiple tasks in only one medium facilitating data transfer between them.

There are different phases of design process which are basically *research, conception, refinement, visualization, production and design documentation*. All of these require quite different skills, but for the very first time, computer yields as the only answer to the "workflow", "real-time" working environment and integration problems.

The research phase is the first step of the design process. Computers serve as an information tracking tool which helps assessing design strategies. Via local area networks (LAN) or internet (ISDN), the information required is as close as a touch of a button. Computers are the only tools (except some others like internet TV), enabling to reach internet, the fastest growing database to date.

Internet includes a huge amount of data in a variety of forms. These include texts, pictures, sounds, animations and even three dimensional models prepared with Virtual Reality Modeling Language (VRML). The information needed can be reached with the help of the "search engines" offering many different and detailed searching

possibilities. Newsgroups are another useful concept of the internet enabling to reach colleagues and treading information world wide. Computers are one of the best tools helping to reach the information, building databases and presentations for all phases of research.

The conception stage is where new ideas and concepts begin. This process requires a high level of drawing ability as well as creativity. The new born concepts should be presented in the best way within the least time possible . Computers are important tools helping the designer in a number of ways. In the case of a "package" design, consisting enclosures wrapped around components, a simple three dimensional (3D) software enables the designer to create many different component configurations virtually. These simple models can be further manipulated and enhanced for additional operations.

Especially in the conception phase, computers should be taken as a tool, like many others that the designer relies on such as refinement or visualization. Depending of the task required, computing can become a very time consuming process. Sketching a three dimensional complex form, such as a car body or a dashboard, is a difficult task. Although some software packages includes two dimensional sketching abilities with a good integration in a three dimensional environment, traditional hand-drawn sketches on a paper can be necessary.

Simple objects are much more suitable for beginning to work with computers. For example, a radially symmetrical object (like a lathed object, a pen or a glass for instance) can be generated quickly with many different variations, via computer. This is a much faster and accurate method compared to hand drawing methods. Some tasks are much easier while many others are more difficult for computing. Computer Aided Design (CAD) interfaces have still need to become sophisticated enough to allow the designer the ease of use of traditional tools such as felt-tip markers, pastels or airbrushes.

Refinement, is a very important phase of the whole design process, enabling the concepts to take their final shapes. This is probably one of the most beneficial uses of computers to designers. The core of today's computing technology, both software and hardware, fits seamlessly to

the refinement procedures: interactivity, undo operations possibility, parametric modeling capabilities to name a few.

3D modeling is the essential of the refinement process. Today, despite all the difficulties and inadequacies of the past technologies, computer based "soft" modeling is integrated into industrial design practice as a tool. An accurate computer generated model serves the designer for visualization, communication, simulation and also production. The designer is able to compose many refinement decisions "real-time" with the computer. According to the model and the processing power of the hardware and software, even complex forms can be generated and manipulated in real-time, that is to say the user can get immediate feedback to his or her requests transmitted through the user interface of the software. Different variations can be saved to different files, and virtually all operations can be "undone", which decreases the time required for a project and the risk of facing big catastrophes.

Another important feature, creating different surface texture and color alternatives, is a very simple task for a computer. However, rendering by hand all the different texture and surface color possibilities a client may wish to see, is practically impossible for the designer. Once the 3D model is complete, it can be used an edited over and over, for visualization, simulation and production purposes. The future of modeling techniques lies in the ability of generating the product's working simulation, even before the prototyping stage. It may involve studying the user's reactions to the virtual model and also examining the design from production point of view.

Visualization, is the most spectacular function of computing in industrial design. In visually based professions, computer generated images are becoming increasingly widespread. Fully detailed 3D virtual models can simulate the real object with it's surface properties such as texture, color, shininess, reflectivity, transparency and so on. These inputs, with the help of the real-world physical facts such as shadows, fog, or some special effects like lens flares, distance blurs, will make possible to take a "photorealistic render" of the object. Moreover, these

renders can be saved as a "raster" file, enabling further two dimensional editing.

These photorealistic images, help the designer to communicate his ideas with clients or colleagues. The images can be really impressive because of their very nature; a virtual object formed by some mathematical functions creating a lifelike picture. Still images are not the only tool of visualization. Also includes animations, simulations and multimedia possibilities.

Animations include a scenario in which the object is moving, rotating, changing color or even changing into it's last shape. The whole creation process can be animated, from the very first sketch to the finished model. Usually, animation requires additional software, hardware capabilities and further knowledge. Simulations, on the other hand, can be considered in a more technical context with their sophisticated abilities such as testing the strength of materials or simulating how this material might flow in a mould. But it can also, as mentioned earlier, be an interactive tool simulating the user-product relation. Multimedia is probably much more popular than simulations, because of it's truly interactive nature. It includes pictures, animations, sounds, texts and even simulations within a specially designed user interface. The viewer can navigate in the program interactively, exploring the object with it's audio-visual facts.

Computers are not only able to generate the "virtual" or the "immaterial". With the help of some additional devices, computer generated 3D models can be transformed into a rigid, three dimensional object. Computer Numerical Control (CNC) machines and Rapid Prototyping (RP) systems are the keys to achieve such objects.

Numerical Control refers to the control of a machine tool motion with a set of instructions. This set of instructions are digital data which creates the basic difference from the manual or mechanical tool control methods. Thus, NC is much more reliable, precise, accurate and flexible, because of the new generation automated tools decreasing the need of human interaction.

In the earlier systems, NC systems were originally programmed at the NC machine itself. This programming concerned the direct entries of coordinates for the machine tool, such as a drill or milling tool, to create the shape required. The programmer had to calculate the proper position of the tool for the desired shape, and "key" these coordinates to the machine, which is a slow process. Today, all these coordinate values and other necessary instructions are automatically generated by the CAD/CAM software, based on the virtual 3D model. The digital data is then analyzed and sent to the NC machine in any of a number of special formats.

Machining processes are based on a cutting tool and the possible geometry are therefore limited with the motion and shape of the cutter. Generally, fine details are very difficult and internal details are impossible to define, except perhaps by mould making and assembling multiple pieces, which is however a very expensive and time consuming method.

Rapid Prototyping systems, unlike CNC machines, are additive in nature. They are also based on the input of 3D surface data from surface or solid modeling CAD systems. The basis of the RP systems (also named Solid-Object Modeling, Tool-less Manufacturing and Desktop Manufacturing) is the use of successive layers of material to form the shape. A solid object is generated as a series of layers, either of liquid polymer, plastic powders or partially cured polymer. A number of different technologies are involved in RP, including Stereolithography (STL), Selective Laser Sintering (SLS) and Laminated Object Manufacturing. The stereolithography process, the most widely applied, has also been used to provide patterns for investment casting. By thermal spraying of metal onto the polymer, it makes possible tooling for injection molding and electric discharge machining.

Rapid modeling is used all around the world for conceptual modeling, design review, fit and function testing. This can save great time and money, since the process takes several hours producing a model which usually eliminates the need of a prototype.

Design documentation is an area in which computer excels in performance. The huge capability in data storage and retrieval renders the computer to be the most useful documentation machine ever. Many different data in various formats can be stored, edited or transmitted including texts, images, sounds, animations, videos and so on. Spreadsheets for example are useful concepts in documenting technical or financial aspects. Any required database can be formed via computer, covering all the information, pure digital data (such as 3D soft models) or digitized data (such as scanned sketches or three dimensional solids, captured video sequences). All this information can be stored into the computer itself, or backed-up in a tape device, a CD-ROM or even a DVD-ROM which lowers the storage costs dramatically.

1.2 COMPUTERS

Computers are very complex systems, which consists of a huge number of different components. Hardware and software are the main elements of a computer system, both embodying many other units. A computer system is usually designed for some special task. For example, a graphic workstation has a powerful CPU, lots of memory and a special graphic accelerator. A common PC for home and office applications does not generally include such high-end peripherals, because the software used in these computers does not require high computational resources.

Considering all available hardware and software, there are nearly infinite number of possible computer system configurations. Thus it is a very important aspect for a designer to choose the right hardware and software configuration for the appropriate tasks.

1.2.1 A Brief Historical Overview of Computers

Numerical operations can be classified in 3 general levels:

a- to count

13
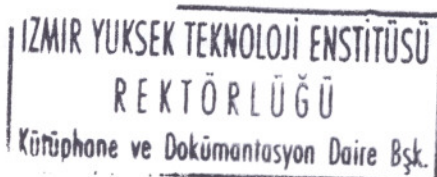
b- to calculate

c- to compute

Counting is the first and the most basic level of three. It's a simple arrangement of numbers. Calculating is the second step, a more complex procedure requiring the ability of solving a numerical problem with mathematical methods. Computing is the most complicated degree of consciousness between the ones mentioned above. It's an action, which requires many complex calculations.

For these numerical operations, three different devices had been developed. These are:

a- counter

b- calculator

c- computer

Numerical counter serve as devices which are capable to count some specified units of liquids, gas, electricity etc. (ex: water meter, electricity meter, gas meter...). Calculators are generally based on four basic mathematical operations: addition, subtraction, multiplication and division. These devices were first based on mechanical structure, but with the technology, they now operate with electronic components.

Computer is the most advanced device for numerical operations. It's able to perform complex and repetitive mathematical operations with a great speed. It also can collect and threat data according to a program, or software.

Electronic computers do not have a long history, some 50 years, but has a much more profound background. Abacus, a manual counter, is probably the first device ever served to humans for some numerical operations. Although the first examples are seen at 1000 BC in Mediterranean countries, it's still in use today in many Asian countries.

A French mathematician designed the first mechanic calculator in 1642. It was based on a mechanism formed by some gears. It was able only able to calculate additions and subtractions. In 1671, a German

mathematician Leibniz redesigned this machine and added the capability of multiplication of numbers. Although this was not a simple process, he demonstrated that this device could be used for divisions also.

In 1830s, an English mathematician Charles Babbage formed the plans of an automated calculating machine. This was the closest machine to today's computers by definition. This device used the differences between the numbers for performing numerical operations. For that reason Babbage named this machine as "Difference Engine". He worked also for a much more improved model called "Analytic Engine". This project was completed after his death, and performed well.

An amateur mathematician, Countess Ada Lovelace, helped Babbage in the design stages of the Analytic Engine. In her personal notes written in 1842, she envisaged that this machine could be used for the solving of any problem whose solutions are common to humans. This task could be achieved via "programming". These notes were written when Analytic Engine was only in it's design stage, just drawings. Long years after, Countess Lovelace was honored as the first programmer ever lived.

After some 20 years of the death of Babbage, an American statistician Herman Hollerith designed a device to use in the population census of 1890. His machine was able to process the data in the form of punched cards. It rendered possible to get statistical data according to varying parameters.

The punched card stayed in use for long years, until 1980s. It offered for the first time, a reusable form of data, which also could be analyzed and manipulated with unit record equipment like counting machines, collators, sorters and key punches. It became widely accepted in administrative and financial applications during the 1950s and 60s. These machines bear little resemblance to today's computers, but they represent their origins.

Hollerith united his own firm (established in 1896) with Computing Tabulating Recording Company. The owner of the firm, Thomas J. Watson, changed the company's name to International Business Machines (IBM) later on.

Babbage's project was born in Massachusetts after 67 years of its initial design stage. In 1937, Howard H. Aiken visited IBM with his own projects. IBM was the manufacturer of some punched card machines and automatic price calculating scales. This cooperation made possible the production of ASSC, Automatic Sequence Controlled Calculator. Later on, MARK I was developed. This was not the first electronic calculator to date and it was only able to multiply numbers in 3 to 5 seconds, a very poor performance even in that time. But it had a unique feature; once it got programmed, it could handle all the calculations necessary automatically.

The first electronic computer was built just after 2 years of MARK I. It was called ENIAC (Electronic Numerical Integrator and Calculator) and built by J.P. Eckert and J.W. Mauchy in Pennsylvania. The first uses of this machine were in the military applications. These were the complex calculations required for targeting bombs and cannons.

ENIAC was a 167-m2 device, weighed 30 tons and operated with 18.000 electronic tubes consuming 150 kwatt, equal to 150 electric heaters. Because of the huge amount of heat produced by the lamps, many failures occurred frequently. But 1 hour of continuous operation completed many complex calculations, which are only possible to handle in more than one week manually. ENIAC was capable to compute 5000 additions per second.

After the success of their machine, Eckert and Mauchy began to search for a financial aid to develop a computer for civil purposes, in large quantities. An organization refused their application after examining the capabilities of ENIAC. Their reason was ironic: 6 such computers in U.S.A. and 3 in Europe would be sufficient to handle all the calculations needed all around the world. For them, such a machine couldn't be feasible at all in terms of economy. Remington-Rand company gets interested with their offer and they produced the two milestones of computer history: EDVAC and UNIVAC series.

World War, despite all of its destructive results, helped computer technology to develop with an incredible momentum. Lowering the costs, increasing the speed and decreasing the machine's physical volume, were

the main objectives. The improvements in electronic technology, especially the invention of transistor and the use of electronic chipsets caused computers to become much more small and faster.

The first commercial computer named Altair 8800 was produced in 1975. A detailed study was published in Popular Science magazine and 2000 amateurs ordered this machine immediately. This computer lacked keyboard, monitor or any software. It had to be programmed by the user with the help of some keys set on the front panel. Although it was not an effective device, it was an important step in spreading the computer concept apart of the universities and big companies.

In 1977, two friends, Steve Jobs and Steve Wozniak produced a personal computer in a garage. They named this computer Apple: it had a keyboard and used a standard TV set as a display. This marked the beginning of personal computer era.

At the beginning, the idea of small personal microcomputers attracted not the big companies like IBM and Digital. But soon they realized that this could be a good marker. IBM introduced its first PC in 1981 who reached a million sales rates within 4 years. It's followed by many other companies, especially in far east countries, producing their own PC's fully compatible with the IBM's standard PC's.

Today, personal computing is not just a business in it's own right. Computers created an incredible market for hardware vendors, software developers, entertainers and many others. PC's and other mainframe machines are indispensable tools for production, education, entertainment and communication.

1.2.2 Computer Systems

Computer systems are composed of hardware and software, and the possible configurations of every different component form a wide range of systems. It is very important to define the proper peripherals to form the right computer system. Although this can be considered as a highly technical subject, general knowledge about hardware and software is vital in many cases.

17

1.2.2.1 Hardware

Hardware is the body of the computer. It consists of many parts, each having a different task. Actually all these devices are completely different in nature, however they are designed to communicate and work with each other. Although there are many different standards for each component –even for the sub-components forming the device itself-, with the help of the software supplied by the hardware producers, they are designed to operate well together.

There are many variables affecting the total performance of the computer. With regard to the main task performed with the computer, proper components should be installed. For example, an improved sound card will not affect the storage capacity at all. But many different facts like central processing unit, random access memory or storage devices can impact the overall three dimensional graphics performance.

Devices forming the computer can be classified in five categories:

a- Basic peripherals

b- Storage devices

c- Graphic and audio systems

d- Communication devices

e- Input and output devices

All these devices have different tasks in the system, but sometimes a unit can be considered in more than one category. A monitor, for instance, is an output device by nature, but it can be considered as a component of the graphic system.

1.2.2.1.1 Basic Peripherals

Motherboard: The motherboard is the foundation of any PC. All the critical subsystems, including the CPU, system chipset, memory, system I/O, expansion bus, and other critical components run directly off the motherboard. Likewise, the interconnections among these components are laid into the motherboard itself (Pabst T., 1998 p.152)

The motherboard is a printed circuit board (PCB) made up of several layers. These layers contain their own network of traces to enable thousands of connections among the different components on the surface of the board. In the market, there is a huge variety of motherboard designs for many specific purposes, targeting low-cost home PC's, powerful graphic workstations or multiprocessor network servers.

The motherboard includes a number of subsystems, all of which are critical for the total performance of the PC. These are:

CPU socket

System chipset

Memory sockets

Expansion bus slots

Bios

IDE connectors

Floppy disk drive connector

Serial and parallel ports

Keyboard and mouse ports

USB ports

System clock

Battery

Power cable connectors

Connectors for front panel LED's and buttons

Jumpers for adjusting system settings

CPU: CPU stands for "Central Processing Unit" and it is the core of the computer. It has mainly two functions which are computer control and data manipulation.

Computer control is the interpretation of the instructions in a program "telling" the computer how to behave. CPU controls the execution of the instructions in the prescribed sequence by the program. These instructions are in "machine code", that is to say that they are composed only of electrical ON/OFF signals. These signals can directly be interpreted by the CPU. By combining a large number of these very

simple instructions, the computer performs extremely complex operations.

The other role of the CPU is data manipulation, or computation, which is performed on data stored in memory. This data is also represented by ON/OFF signals and simple operations (such as additions and subtractions) to perform much more complex operations. As well as from performing computations on the given data, the CPU counts also the number of processing steps necessary to execute an instruction.

The CPU is made up of millions of transistors (up to 8 million individual transistors for a common CPU) and according to Moore's Law, they continue to double in performance approximately every 18 months. They are based on a 0.25 micron technology, 1/400th the width of a human hair. Their performance is based on the clock speed and the internal architecture of the core. The Pentium III CPU runs up to 550MHz, or 550 million ticks per second. That's 70 times faster than the 8MHz CPU of the original IBM PC, and approximately three times more than the precedent generation CPU – the Pentium Pro.

RAM: Ram is Random Access Memory, being the short-term memory of the system. It is a contrast to the ROM (Read Only Memory) which will never erase it's contents even with the power cut down. Ram is used to quickly serve up data to the CPU. The data stored on Ram can be erased or manipulated to hold instructions for execution by the CPU.

In order to run the application programs like a word processor or a drawing software, it is necessary to add this to the memory. The base software executing the application, which is called operating system (OS), and the picture or text data edited by the application are all stored in memory as well. This can begin to require a large amount of memory; the more complex and more multifunctional the application, the more memory it tends to require. (Computer Designics p.26)

1.2.2.1.2 Storage Devices

Disk Controllers: One of the most critical issues in PC storage, is the interface used to connect the device to the PC. With a slow

connection, the whole system cannot benefit from a fast harddisk. There are two main choices for the disk storage interface on PC: the Small Computer System Interface (SCSI) and the Integrated Drive Electronics (IDE).

These two technologies are very different in both scope and implementation. Both have advanced features and high performance for the growing demands of PC hardware and software. They also provide the flexibility to serve as much more than just a connection for harddisks.

IDE is created as an alternative to unreliable and slow interfaces based on old technologies such as ESDI, MFM and RLL drive technologies. Since then, it has been widely accepted, virtually every PC motherboard includes one or more IDE style controllers and ports. This ensures compatibility with a large number of disk drives and other devices.

SCSI has first appeared in the graphics workstation market and proved itself versatile, high performance technology, which is able to fulfill a variety of missions. Unlike IDE interfaces, SCSI is a feature-rich data bus designed for various uses such as scanners, recordable optical drives, video capture modules and networking devices.

Despite their relatively high price, SCSI systems are the first choices of 3D graphic designers, animators or video editors. They offer an excellent throughput, flexible layouts and strong multitasking capabilities with high speed connections.

Hard disk: Hard disk is the unit which stores the programs and the personal data. The way it works can be compared to a record player. A reading and writing head detects or changes the patterns recorded on a magnetic media. This magnetic media is a series of platters mounted on a atop the other on a spindle. A motor on the spindle turns the platters to position them exactly for the head to reach the data.

There are often two, three or more platters in a disk drive, each with a pair of read/write head positioned above and below them. The operating system and applications perceive these platters as a single logical drive, but in fact, the data is spread across multiple physical

disks. In order to enable quick access to data, hard disk drives are laid out into four types of segments: platters, cylinders, tracks and sectors. Each cylinder is divided into tracks, and each track on the disk is broken into a number of sectors.

There are different types of hard disks available. IDE (Integrated Drive Electronics) drives can transfer up to 33MB Per second. These drives are plugged into the enhanced IDE connector found on most motherboards. Installation and support becomes an easy process with the use of these drives.

SCSI disks can handle 80MB per second data transfer rates. They perform well in multitasking and they are suitable for users accessing multiple media types. However they are much more expensive than IDE drives and only a few mainboards include a built-in SCSI port, which makes the installation process difficult for the end user.

A/V hard disks are widely used by video editors to capture analog video to disk. This is an extremely performance demanding task, which requires an uncompromised stream of data through the bus to the disk. A/V disks are SCSI based systems but they differ in the internal housekeeping mechanism. They lack the thermal calibration process, measuring the media area in order to compensate for disk expansion that occurs due to heating; therefore, they are not suitable for use of normal data operations.

RAID disks (Redundant Array of Inexpensive Disks) consist of five RAID specifications addressing issues of data integrity and performance. They come as a unit, but they are simply standard SCSI disks partnered using dedicated RAID electronics. A RAID array is very expensive but it is vital for network servers, Web servers or workstations to defend them against data loss.

Tape Backup Drives: Tape devices are the slowest, most restrictive and least applicable form of mass storage for PC. Finding the data is a very slow process, and the transfer rates are inferior compared to hard disks or CD-ROM devices.

The main reason for using the tape backup drives is it's cost. It is the best choice regarding to cost per megabyte.

Tape backup drives are not suitable for every need, in fact, they are only appropriate for a very small portion of common storage need. The tapes are linear in nature, thus preventing the reading head to jump to the exact spot in which the data needed is stored. They are slow in access time and also in reading/writing time, but they serve perfectly well for restoring large amounts of data.

Near-disk Storage: Near-disk storage devices work like hard disk drive. The main difference is that the spinning magnetic media is contained in a removable cartridge housing. In that aspect, they look like floppy drives, but they differ mechanically in the reading and writing process.

Near-disk storage units consists of three different categories: floppy disk successor, large capacity magnetic and large capacity magneto-optical (MO) devices. Products in different categories can often serve the same tasks. Both a large capacity magnetic and a large capacity magneto-optic drive are suitable for backing up and archiving data, but their cost (both the drive and it's media)varies a lot. Even floppy disk successors which are the least expensive can serve as backup devices via their 100 to 200 MB storage capacities.

Optical Storage: The need of storing large amounts of data arise especially with the emergence of multimedia features and enormous programs such as MS Office, CorelDraw, AutoCAD or Windows. The solution developed as an optical drive and media format called CD-ROM (Compact Disk-Read Only Memory). CD-ROM disks use the same technology of common audio CD's.

CD-ROM disks can hold up to 650 MB data and they are preferred for mass distribution of software and data, including digital audio and video files that are simply too large to store otherwise.

DVD-ROM (Digital Versatile Disc-Read Only Memory) is a high density, high data rated optical media, that was designed initially for the use of video playback tasks. It is superior to CD-ROMs in performance and has replaced them in many high-end PCs. DVD-ROM uses the same 5.25 inch form factor disc, same as the CD-ROM drives. The difference is the recorded media, which is a tighter pattern of tracks and pits to

increase the density of data. A single DVD-ROM disc can have 2 layers of data in both sides resulting in a total of 17 GB maximum capacity.

There are two major streams of optical storage devices which are read-only and recordable/rewritable media. Both CD-ROM and DVD-ROM have different standards. For fast, less expensive and reliable data access, CD-ROM or DVD-ROM devices are the better choices, since they lack the additional electronics and optics required to write data to disk. But the ability to record is very important for the safety point-of-view, thus these more expensive systems are being preferred by many professionals and amateurs.

1.2.2.1.3 Graphic and Audio Systems

Graphics board: Graphic accelerators takes over the tasks that would decrease the CPU performance resulting in the increase of system performance. The graphics board is a system unto itself. It consists of a graphics chip and memory, bus interfaces and output converters enabling the data transfer and communication with other peripherals. All these variables are involved in the overall performance of the graphics card which affects the system's graphic performance.

Graphics board can have 2D, 3D support capabilities, or both. Virtually all graphics boards accelerate a similar set of 2D operations, although some may provide optimizations for infrequently accessed functions that are common for high-end applications. A basic set of 2D operations is formed by bit block transfers, line drawing, color and pattern fills, clipping and off-screen memory caching.

The most important area of graphics hardware development has been in 3D. Many applications ranging from high-end modeling and animation packages to popular games such as Flight Simulator or Quake makes use of true 3D graphics to produce more speed, reliability and realism.

3D acceleration is crucial for graphic professionals. There are many functions that the graphics card should handle to increase the

system performance: geometry, texture mapping, bilinear&trilinear filtering, flat&gouraud shading, alpha blending, lighting, Z-buffering, MIP mapping and so on.

Many professional modeling software relies on professional APIs (Advanced Programming Interface) like OpenGL and Heidi. A mid-range or high-end graphic workstation should include a 3D graphics card supporting OpenGL (developed by Silicon Graphics) and Heidi (developed by Autodesk) for a high performance.

Sound cards: Until 1994, most PCs did not ship with built-in sound units. The first sound cards were usually very difficult to set up with the current hardware configurations.

Today, virtually all PCs have a sound card, either as a separate add-on card or built in the motherboard. These systems can handle digital audio files, matching the fidelity of audio CDs. There are several varieties of PC based audio formats and technologies. The major ones are digital audio, midi audio, 3D positional audio and AC-3 audio.

Digital audio works with the representation of the analog waveform audio to produce digital sound. To achieve this, audio files create a digital reproduction of the sound wave by taking snapshots of the wave as it goes by. The more closely the PC can re-create the exact amplitude and frequency of the original analog sound. This process is called *sampling*. (Pabst T., 1998)

Midi (Musical Instrument Digital Interface) is a communication standard developed by the music industry. It enables the synthesizers and other electronic musical instruments to share a common platform. Midi files contain certain commands describing the instrument and notes to be played, including how long each note should be attacked, released and sustained. Technically, midi does not need to be used for music at all. Some 3D animation packages include the capability of midi commands based on controllers for animations. But midi standard is a critical part of sound card operation.

Positional 3D and AC-3 audio represent a growing class of technologies targeted at entertainment software titles. The technologies, which often require new hardware to run smoothly, deliver enhanced

realism and impact to multimedia titles, digital movies, and other rich content. (Pabst T., 1998 p.401)

1.2.2.1.4 Communication Devices

Modem: the modem can be considered as the crucial innovation of the internet age. This device connects individual users to the internet, biggest network to date. Today almost every PC is equipped with a modem to get connected to the internet, sending and receiving emails, getting into newsgroups and so on.

The word modem is derived from *modulate-demodulate*, describing the way these devices convert digital bits into sound and back into bits again. Modem transforms data on the PC into the screeching sounds. These sounds are transferred via phone line, and at the other end, decoded again into digital 1s and 0s.

There are five currently available modem technologies. These are analog modems, ISDN, satellite, xDSL and cable modem. Analog modems are defined by the communications protocol they support, which determines how fast the modem can communicate. ISDN (Integrated Services Digital Network) provides many advantages such as eliminating line noise and quantization noise. It can get high speeds of data transfer and as a result, it acts like a standard network connection, without high costs.

xDSL (Digital Subscriber Line)technology describes a family of all digital, packet based, public data network technologies. Similar to ISDN, xDSL can handle the analog noise problem. But the latter is faster and it is expected to form the backbone for mainstream connectivity.

Cable modems use the advantage of high bandwidth supplied by the thick coaxial cable. In U.S., this cable runs over 60 million houses for cable TV, but they can run internet data as well as the existing television programming. Cable modems offer an extremely attractive technology, since they offer very high speeds at affordable prices.

26

Satellite technology is beneficial to rural users. It's main advantage is that it can operate even in remote locations. The requirements are a phone line, an interfacing hardware including the satellite dish and a comm adapter. But there are some disadvantages such as the expensive hardware, the difficulties of installation, high service costs and relative fragility of satellite-based access.

Networking: Internet enables the connection of PCs all around the world for online publishing, emailing, instant access to data and other online services. Similar benefits can occur also on a smaller scale network. Connecting two or more PCs in a local area network (LAN), is an important issue for private office practices.

Networks, regardless of their technology, have some key characteristics in common. Network system enable PCs to share resources and data among themselves using a standard language, called *protocol*. This determines also the data transfer in order to ensure that bits do not get lost and systems do not get "confused".

A network involves many hardware and software components for connecting PCs. These are server and client computers, network interface cards (NIC), cabling, hubs, switches, routers and network operating systems.

A PC should include a NIC as a separate peripheral in order to connect to a network. This can be a PCI, EISA or ISA based add-in card including a port for plugging into the network wire. Incoming and outgoing data are handled by NICs. These data are transformed into formatted packets of data that servers and other network computers can read. The packets are then turned into electrical signals and transmitted out onto the cable.

NICs are sold generally for the PCI and ISA bus, but PCI cards offers a lot of compelling advantages. PCI cards include plug&play capabilities, guaranteed bandwidth, and bus mastering.

1.2.2.1.5 Input and Output Peripherals

The interaction with the computer can be achieved with both the user interface of the software, and the input and output devices. Operating systems, graphic programs, word processors or even computer games need an input device in order to be operated by the user. For common uses, a set of ordinary input devices can be used for different applications. For example, the keyboard and mouse are used both to write a text and to build a three dimensional model in a graphics program. For more special uses, some additional devices can be more suitable. This is also the case for output devices; a printer can be used both in text based and graphic based applications, but a larger plotter will serve many graphic purposes better.

Input Devices

Digitizer boards: Digitizer boards are electromechanical vector graphic input devices that typically resemble a drafting board with a movable stylus called a *cursor*. They are used to enter drawings into computer by taping the drawing to the flat surface of the digitizing board and placing the cursor over points whose coordinates are to be entered. Three subgroups of digitizer boards exist including free-cursor digitizers, constrained-cursor digitizers and motorized-cursor digitizers. Free-cursor type consists of a light weight cursor allowing an easy use. This is the most common digitizer in the market. In constrained-cursor digitizers, the cursor slides along a gantry that traverses the entire digitizing board. This provides the capability of working in an upright position. Although this is an advantage in comparison to the free-cursor digitizer, it is harder to work with. Motorized-cursor digitizers combine the best features of both free-cursor and constrained-cursor units but usually add some extra expenses.

Tablets: Conventionally, smaller digitizer boards are called tablets. Tablets use a "pen" instead of a cursor as the input device, which resembles a common pen or an airbrush. The main advantage of tablets are that they are pressure sensitive systems, therefore they best serve in raster graphics. They can be used as a brush, an airbrush or an

ink pen, and they react just like a common analog tool. Designers often use this device to sketch preliminary ideas, and later they apply details, colors or textures for further presentations.
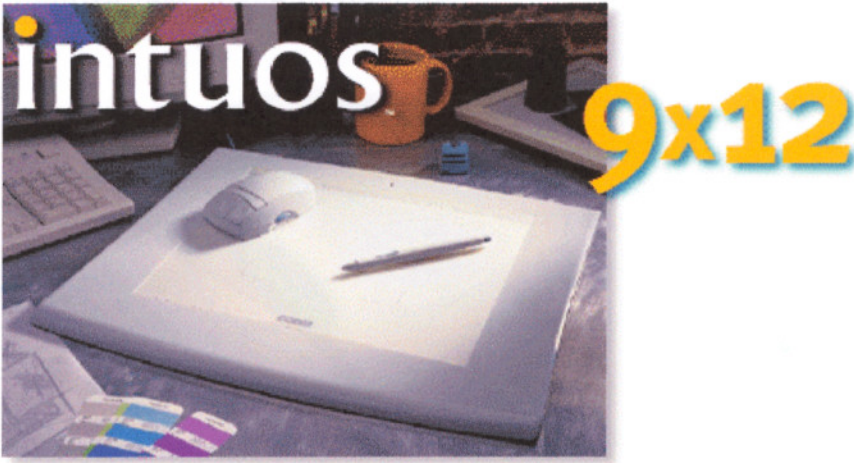
figure 1.2: A tablet and it's digital pens, with "dual tracking" usage.

Mouse: Mouse is the most popular input device along with the keyboard. It is used to move the pointer on a display screen. The movement is relative to the current position, thus limited free space of a tabletop can be used. Making unlimited cursor movements requires lifting the mouse to separate the motion sensory system from the flat surface. Mouse coordinate detection generally uses a mechanical system, but optical versions are also available. One to three trigger buttons exists on a mouse. The number of buttons and their interpretation differs according to the operating system of the compute and the application used.

Trackball: This device moves a screen cursor by sensing the rotations performed by the user through a ball, with the palm or fingers of the hand. The principle is that of an upside-down mechanical mouse. Trackballs are widely used in portable computers instead of a mouse, because they require less space to operate.

figure 1.3: A mouse with an integrated trackball.

Keyboard: The keyboard is used to input the character codes that are assigned to alphabetic characters. The key number of a keyboard can vary in different countries according to their language. Keyboards are unique tools for text-based applications, but they are also used in many other applications such as graphic software or multimedia applications.

Light pen: The light pen is a stylus-shaped pointing device that senses light emanating from a display screen. The end of a light pen is composed of optical fiber and lens. When the cathode ray tube (CRT) screen where the lens pointing is lit, coordinate values can be obtained from the CRT synchronization signal. Light pen is a passive device thus it cannot detect coordinates by itself; it is used to select shapes that are already displayed on the screen. It has the advantage of being similar to the traditional pen because of the directness of the pointing action, however the need to hold the pen up to the screen is a tiresome process.

Touch panel: The display screen is equipped with sensors and coordinates to input directly by pointing with the finger. There are non-contact types which have a line of lights and receptors mounted on the frame. The screen detects an object when it breaks one of the beams.

Contact types are equipped with a transparent pressure-sensitive membrane, and can be used for three dimensional input.

Joystick: Joystick consists of a stick that works by angling it in the X and Y directions acting to move an object on the screen relative to the current coordinates. Joysticks have been built into notebook-type computers for use in place of a mouse or trackball, and there are very small models that can be operated with the tip of the index finger.

Image scanner: An image scanner is a device for inputting diagrams, drawings or images on paper into a computer. They are available in various shapes and sizes such as drum type, flatbed type and handy type. For color drawings, the image is analyzed into RGB components. Depending on the use, an image-sequential type or a line-sequential type is used. The scanned solution is in dpi units and most scanners have a read resolution of 200 to 600 dpi. Although limited, flatbed scanners can also be used to scan three-dimensional object to obtain two- dimensional raster image of the object.

3D Digitizers: Three dimensional digitizer is basically an input device of 3D objects. These are much like scanners, but with the ability of scanning three dimensional objects, as vectoral data. 3D digitizers come in several different sizes and can have different systems to operate, including optical and mechanical systems. A basic mechanical system resembles a robot arm, that requires a manual effort to point out the necessary control points of the scanning object. These devices can help the modeling process if there is a pre-built real model, enabling later enhancements and detailing to the scanned digital model.
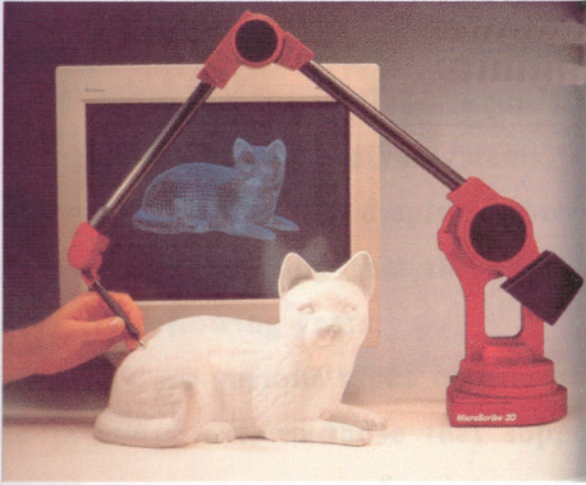
figure 1.4: MicroScribe 3D Digitizing Arm (I.D. Magazine Vol.43, No:4 1996 p.62)

Output devices

Monitors: In computer systems, any visual information, whether graphical or text-based, are in mathematical form and they can be viewed only through the graphic display. Monitors are the main display devices of a computer system. They are in various sizes and they can be based on different functioning principles. The most common are cathod ray tubes (CRT), similar to a television picture tube. It is an evacuated glass bottle, the inside front of which is coated with phosphor, with the property of emitting visible light when struck with a stream of electrons. Plasma displays are based on a thin (approximately 1 inch) glass envelope, which is filled with an inert gas, such as neon. When voltage is applied, the gas enters the plasma state of matter, and in this state it emits visible light. Another system is liquid crystal display (LCD) which is also popular in watches, cellular phones and children's toys. When the liquid crystal material is submitted to an electric field, it reflects light depending on the polarization.

CRTs are the most common type of graphics display. They consume relatively large amounts of power and require high voltages for image generation. There is a potential radiation hazard with every CRT, but because of the mass production of television sets, they are by far the least expansive type of graphics display. Plasma displays are flat, can be

transparent, possess high light output and require low power. These are relatively expensive systems, similar to LCDs. LCDs have low power consumption and they are very flat, requiring minimum space on desktop. They are relatively expensive systems, but with recent efforts, they have become a high quality display systems, even for high-end graphic purposes, and it is likely that they will be a standard graphic display system in the following years.

Printers: There are various types of printers, including those that are mainly for printing text, to those that support high-quality image output. The most common types of printers are dot-impact, ink-jet, thermal-transfer and thermal dye-sublimation printers.

Laser printers and ink-jet printers are suitable for high resolution output, while thermal dye-sublimation printers are best suited for photographic quality output. Laser printers use a printing method similar basically to photocopiers; image signals cause the laser beam to charge a rotating drum coated with selenium, and toner ink adheres to the charged parts of the drum. Ink-jet printers use CMYK ink cartridges; they simply inject the ink to the proper location on the paper. While laser printers are commonly grayscale systems without the ability of dithering the tones, ink-jet printers are able to reproduce high resolution color graphics.

1.2.2.2 Software

The expression "software" is derived from the term "hardware" which is the physical part of the computer. Software, on the contrary, is something abstract that cannot be seen or touched, which is programs written by programmers in a special language for operating the hardware.

Software is essential for the computer system; without the software even the fastest and most advanced computer is not worth much. Thus it is very important that a special system is supported with the appropriate software. In fact, software industry has gained much more importance than the hardware industry. Many times, the programs installed into the computer costs much more than the hardware itself, especially in graphics and database applications. This is the main reason

that many companies have switched from one platform to the other. For example, many people are now using Windows-based PC's instead of Mackintosh based systems, because key business applications are simply not available anywhere other than PCs.

Several types of software exist, all of which are for different purposes. Basically, they can be classified as:

- Operating Systems
- Utility Programs
- Application Packages
- Programming Languages and Compilers
- Communication Software
- Custom Applications

Operating system (OS) is the primary software for a computer. OS is the interface between the hardware and the applications, containing instructions for the basic operations of the computer, such as how to process instructions and how to execute programs. Operating system runs directly on top of the computer hardware; it is the first program executed when the computer is turned on, and continues to run until the power is off. More importantly, the OS determines how applications should be written in order to interact with the OS itself and the underlying hardware. The OS sets the rules of intercommunication for all applications and their developers, specifying exactly how programs must behave to access resources, as well as defining what is allowed and what is not (Pabst T., 1998). For example, one OS may allow the application to directly access graphics RAM, but another might strictly require the user to make such calls through it.

Different hardware platforms generally require different operating systems to run. For example, with Intel or Inter-compatible CPUs, Microsoft Windows (3.x, 95/98, NT), Linux, IBM OS/2, DOS (Microsoft, IBM, Digital) or BeOS operating systems can work. In other systems like Apple Macintosh, MacOS is required to operate the hardware.

Utility programs can be subdivided into different categories including multipurpose utility programs, disk and file compression programs and optical character recognition programs; the most common ones. Multipurpose programs are used to arrange the files and folders in the disk and to recover some structural conflicts. Norton Utilities is a popular package in this field. Disk and file compression programs, as the name implies, are used to compress large files to save disk space. The most common ones are Winzip, Winrar and Arj. Optical character recognition (OCR) software is used to trace scanned texts to convert them into a text-based file. Once a text image is scanned, with an OCR program, it can be easily exported to a word processor software. Although OCR programs can be available within a graphic software package (such as CorelDraw's OCR Trace), they are also designed as stand-alone applications.

Application packages, are the primary software supporting the OS. The main rule for OS is "the OS with the most applications wins". Application packages are the largest group of software, covering a huge area of different uses. The major subgroups are:

- Word Processors / Spreadsheets
- Databases
- Graphic packages
- Integrated packages
- Desktop Publishing
- Application packages for particular areas

Word processors and *spreadsheets* are widely used as office and personal applications. These are used to write texts and place some images within, and export them for some different purposes. They have replaced the typewriters, because many tasks can be generated automatically with a word processor or spreadsheet software. New generation of word processors and spreadsheets include grammar, style and proofing utilities. MS Word, MS Excel, Lotus 1-2-3, Word Perfect

are among the most popular software in this field. *Database applications* serve in the management of large amounts of data. The information entered to the system is maintained, classified, analyzed and presented by the database software. MS Access and dBase are some important database programs.

Graphic packages can also be separated into different subgroups including business graphics, scientific graphics and computer aided design programs. In fact, it is difficult to classify graphic packages, because they include some important features such as raster/vectoral, two-dimensional/three-dimensional, stand-alone/add-on, visualization based/production based and so on.

Integrated packages are a set of software working together interactively. The data edited can also be linked to another program in the package, easing the handling of the information. A common example is MS Office, including a word processor, a spreadsheet, a database and a presentation program. *Desktop publishing* software are a good means of page editing and print arrangement. These include limited word processing capabilities along with simple image editing. PageMaker, is one of the most best-known desktop publishing software to date. *Application packages for particular areas* include a wide range of purposes such as accounting, finance, payroll, project management, medical diagnosis programs and education &entertainment utilities.

The fourth group of application software *is programming languages and compilers*. These are generally considered as high-end applications for very specific purposes, but new generation of programming software have attracted many amateur users to write their own applications. These new compilers are based on a graphical user interface, such as Visual Basic or Visual C++, thus it enables the user to easily create their own programs and multimedia applications without a very advanced programming language knowledge.

Communication software has become very important with the internet. Net browsers, file transfer programs, e-mail programs, fax utilities and even chat software are included in this category. Net browsers are the primary communication tool of computers, enabling the

user to reach the internet. They include text, graphic and sound capabilities and support Virtual Reality Modeling Language (VRML), a vectoral file format making it possible to visualize three-dimensional objects in real-time. The most popular net browsers and e-mail packages are Netscape Communicator and internet Explorer which are both used by several millions of people all around the world.

Custom applications are generally wide scale applications, generated for the special purposes of a firm. These are not available in the market since they are custom made for the end-user. Custom applications can be written for any platform and according to the feedback by the end user, it can take several months to prepare a complex application.

1.3 COMPUTER AIDED DESIGN

When computer systems found its way through design, a new concept, computer aided design (widely known as CAD) began to get pronounced. In fact, CAD is a very broad concept, covering all design and manufacturing processes. But with the specialization of design and manufacturing tasks, several other subdivisions of CAD appeared. The most common of these is computer aided manufacturing, or simply CAM. The acronym "CAD" in a way is redefined as "CAD/CAM", which covers a much more extensive meaning of the computerization of design and manufacturing.

1.3.1 The Evolution of Computer as a Design Tool

The construction of Crystal Palace for the Great Exhibition in 1851 pointed the beginning of a new era. It was the first o fit's kind in terms of construction. In 1908, the term "Mass Production" was brought to life by Henry Ford in United States, which was another milestone in whole design history. These proved the need of an economic and cultural evolution for the foundation of the infrastructure necessary.

Technological problems were not the biggest question for the new production methods.

Before the Industrial Revolution, technical expertise and the manufacturing capabilities were in the hands of the craftsman, regardless of the cultural peculiarities. The craftsman received traditional training and became able to reproduce models and to produce objects according to the specifications provided by the clients. Their abilities were developed by experimentation, cumulative experience and training: their manual skills helped them to become unique.

After the Industrial Revolution, with the replacement of the hand tools by machine tools, the engineer appeared and gained great importance. The impact was quite inevitable: craftsman was left off the production stage gradually and the basics of mass production were set. Some new concepts then began to get pronounced, including standardization, prefabrication, interchangeability, scientific workplace organization, design of the individual components, machine tools and power sources. With the development of this new production system, the question of formal development arose. Technical data were not sufficient to determine the whole form of the product. "If engineers had been able to master such formal questions satisfactorily, if they had received an education equipping them to tackle the complex relations between objects and the cultural system shaping their production, it wouldn't have been necessary to invent the designer."

With the standardization, firstly prefabrication and the interchangeability of parts became possible which led to the mass production itself. New domestic products like Remington typewriter were produced via existing industrial infrastructure of the munitions factories. After 1870, this production system extended to other objects like cameras, as well as to a wealth of domestic hardware.

Since 1800s, many dramatic changes took scene. These are not only some technological breakthroughs; social, cultural, political and economical changes also affected the way people lives, works and thinks. Industrial design is one of these professions, and maybe the one, which is mostly affected by all above. Many definitions have been made

for industrial design profession, but one the most honest belongs to Raymond Loevy: "Industrial design ... is a serious profession which combines good taste, technical knowledge, and common sense. In the case of my own organization, it is taken seriously by over 75 corporations ... Their conception of aesthetics consists of a beautiful sales curve shooting upwards."

Today, industry is asking more and more optimum design solutions from designers. Much more accurate answers to common or special problems are needed to be found in a much shorter time, with less money. The fierce competition of the market forces the designers into new areas of competence. New tools gained great importance into the design practice, especially the computer. In fact, the computer can be seen as a compact tool helping the designer in all the stages necessary of the design process. Computers prove unique means of enabling industrial designers to meet their clients' requirements for finer design optimizations.

During 1980s, most art and design disciplines included computer applications in many different manners. With the dramatically improving computer technology both in hardware and software, certain disciplines provided great examples of computer integration into their works that many others could learn from. The 1980s witnessed the establishment of computer technology in the commercial fields of art and design.

Today, it's probably impossible to find a design office without a computer system installed for creative work. This is also the case for art and design educational institutions, many of which involving some experienced staff about computer implications into their disciplines. Students graduated within the last two decades have had practiced computer tools, many of them gained influential positions in design organizations thanks to their computing abilities.

Computing has been applied to design and the visual arts in two ways. Firstly, it is seen as playing a supporting role for other disciplines. Many diverse areas like industrial design, textile, architecture, interior design, photography, video, graphic design, painting, printmaking and sculpture uses computers to visualize ideas

and to provide instructions for making objects. In this case, computer is seen as a tool, which tends to operate in parallel with traditional techniques.

On the other hand, computing is considered as a topic in its own right. It's taken as a major subject, like painting, graphic design or industrial design. Many educational institutions and progressive design organizations are developing some different aspects of computing as a commercial design discipline.

Currently, use of computers is considered largely within the first category. This relatively new technology had penetrated into a variety of disciplines in one way or another because many aspects of these disciplines are appropriate for computing. At the beginning, computers were not taken as a serious tool for any design discipline, but with the four major conditions which took place in recent times, designers ceased to perceive these machines as "aliens". These conditions rendered computers to become a ubiquitous tool aiding the whole process of design.

First of all, the development of Graphical User Interface (GUI) allowed the designer to communicate with the computer in a much more comfortable way. GUI relies on a visual presentation of information, rather than some purely textual or numerical values. This helps the designer, who comes from a visual culture, to apply some of his original skills without having to learn a new "language". Before the development of GUI, there were some cases where computers had been applied to some design practices. But these great pioneering efforts were not enough to prove the capabilities of computers, and many designers had an attitude of suspicion about these machines. This frame of mind concerning the computer's threat to creativity still exists in the backwaters of design profession.

The second major breakthrough was the introduction of the pen and mouse as interactive input devices. Designers never saw keyboards as the appropriate tool for their discipline, and they did not think of an alternative. Ironically, they did not also felt that designing a relevant tool is their responsibility. The pen and mouse were much more accurate

in use because they assured the designers a truly interactive communication with the machine for the very first time. This way of communicating allowed designers to create a liaison with their own traditional design skills.

Thirdly, cost was an important factor for the use of computers in design, like any other commerce area. Hardware and software were very expensive for the design organizations which are not used to make high capital investments. The traditional tools were much more cheaper and their function and role in design process were much clearer. Only larger and more profitable practices used computers initially, but with the costs dropped, computers became much more widespread and many smaller design companies established their own systems.

The fourth condition is met when the low-cost, user friendly software became available. It's the question of communication again for the designer which is satisfied with the introduction of design software. These programs enabled the designers for the use of their own design language. They began to understand the basis of the new deign communication and production tool.

In the case of other design disciplines, computers were first applied to industrial design. The main goal was to automate existing work practices and skills. The software used enabled two dimensional technical drawings to be generated in a digital medium. The creation of computer aided drafting was an easy process seeming to be more conventional then many other tasks. The use of drawing sheets, overlays, borders, variations in line thickness' are the results of the efforts for the familiarization of the whole drafting process. In that way, the users could feel the new technique as just an extension of manual paper practice.

This approach disregarded many advantages of the new digital tool bringing fresh concepts like "pull-down menu" and shared databases. These rendered possible high level of accuracy and the storage capability of full-sized information. The digital data could be used and manipulated in many different ways, and this challenged the traditional conventions and the role of technical drawings itself.

Three dimensional computer modeling was another breakthrough for design practice. Modeling is a native process in industrial design with a long history unlike digital modeling which very recently dominated design practice. When first introduced, three dimensional (3D) digital modeling was so difficult that many failed to take it or became dissatisfied with it as a design tool.

But with the major changes occurred both in hardware and software technologies, many designers feel much more comfortable using 3D digital modeling techniques. This "soft" models became much easier to create when compared to traditional models made of clay or foam. The virtual model allowed to edit many design iterations including shape, texture and color without incurring a great time penalty. Despite of the still existing communication difficulties with the interface, 3D computer modeling is integrated into the industrial design practice today.

The skills required for soft modeling are relatively new for the designer and they are completely different from those for building a physical model. The main point is not to compromise the design intention because of the computer's inability. The computer is simply a tool, thus it is very important to get the knowledge of numerical models, how they are made and assembled.

3D modeling software have tried to mimic the physical process, like the user-product interaction. But, they are superior in creating photorealistic images rather than working constructs. Even the new generation Computer Aided Industrial Design (CAID) packages requires quite precise and detailed information for the aimed 3D digital model. This generally causes some problems with the initial stages of the design, because ambiguity and imprecision are often the very essentials of the design process. In spite of this, computer modeling skills are becoming more popular than ever, and as a standard tool in the design studio, it challenges traditional working procedures.

"the computer and the human mind have quite different but complementary abilities. The computer excels in analysis and numerical computation, the human mind in pattern recognition, the assessment of complicated situations and the intuitive leap to new solutions. If these

different abilities can be combined, they amount to something much more powerful and effective than anything we had before." (Cooley M., 1988)

1.3.2 Computer Aided Design Systems

As computers are getting more and more specialized in design and production processes, every different task of the computer should be considered in it's own right. A single computer system can help the design process, from the initial sketches to the final model. These can be used both for visualization and production purposes. The same digital model can be used again for process planning and for the preparation of NC programming or rapid prototyping. This digital model will also become the basis of the mould design, for mass production purposes. All these tasks, regardless of the differences in their characteristics, use the same tool, the computer. With the appropriate hardware and software supplied, a single machine is able to handle all these tasks proving it's power and impact on the industry.

The integration of computers with design and production processes has taken almost thirty years and has become very complex. The improvements in this area have led many new branches to appear, which were used to be considered as a single process in the past. Even today, the integration of computers design and production processes is widely known as computer aided design, or simply CAD.

CAD is often a misleading acronym, because for many people, it is just a computer software helping the designers and engineers to "draw" their projects. To some, it is a highly technical concept, a symbol of a new digital era in which the role of humans has decreased whereas the role of computers has increased their prominence dramatically. In fact, CAD is simply a set of digital tools helping the productivity both in design and production processes.

CAD embodies some other less common concepts such as CAM (computer aided manufacturing), CAPP (computer aided process planning), CAD (computer aided drafting), CIM (computer integrated

manufacturing) and CAE (computer aided engineering). CAD itself is widely used as the symbol of the use of computers in the design process, such as two dimensional drafting, three dimensional modeling or two and three dimensional visualization.

CAM is probably the most widely known acronym after CAD; but actually it is a notion on its own. CAM includes very important manufacturing concepts like computer numerical control (CNC) and rapid prototyping (RP). The key to the CAM application is the extraction of data from the design model generated with a CAD system, for use in analysis and in manufacture. The main method to date of translating CAD data into CAM instructions is the generation of data for numerical control (NC) machining. There are some further advances in this field, such as rapid prototyping (RP), also termed as tool-less manufacturing, which is basically the rapid construction of physical models without the use of tooling. It is likely that the future will see continued development of techniques for manufacture with minimum human intervention.

Cooperative working between different engineering functions lends itself naturally to the sharing of data and of computational aids. In particular, the component geometry developed through CAD is reused in numerically controlled production processes, and also in the planning of manufacturing operations through computer aided process planning (CAPP). These activities in turn feed information, together with bill of materials data from CAD, into the computer aided production management (CAPM) activity. This integration of all manufacturing activities through the use of linked computer systems and a shared database is commonly called computer integrated manufacturing (CIM) (Mc Mahon C., Browne J., 1995 p.249).

The major research efforts at the interface between CAD and CAM have been for the development of CAPP systems which attempts to automate the communication process between product designers and manufacturing engineers. However, these systems have tended to concentrate on automating the traditional process planning function, i.e. the generation of the process plans for manufacturing. CAPP is a

technique used in product and process analysis, an activity which allows the manufacturing function to influence the design process and to ensure that designers are aware of the effects of various design features on the ease of the manufacture of a part.

The integration of CAD systems, especially CAD and CAM, allows the designer to work more efficiently with computers. With this new tool, the designer will have the chance to be concerned with the production of the design and observe the final effects of his ideas on the whole production line.

CHAPTER 2

INTEGRATION ASPECTS; INDUSTRIAL DESIGN & COMPUTERS

2.1 General Concepts in CAD/Visualization Packages

CAD and visualization packages are involved in several important concepts such as two-dimensional rendering, drafting, dimensioning and three-dimensional modeling. All these require unique tasks, but they are also including each other in one way or another. For example, two-dimensional drafting can be the starting point of the three-dimensional modeling process, or two-dimensional rendering can be enhanced with the generated three-dimensional models. Rendering, modeling or drafting processes require also different software packages to perform, thus it is very important to get a good knowledge about the general concepts concerning CAD and visualization for using and program purposefully.

2.1.1 Two Dimensional Rendering

Sketching, is the initial visual representation of an idea. Sketches are useful in the refinement or modification of the idea, or in the presentation to the others.

Generally, for sketching the use of paper is considered to be the most appropriate medium. It requires a certain skill to draw a quality sketch in order to clearly represent the idea. The initial sketches help the designer to explore a range of expression and confirm the direction of the design. The final drawings that follow this stage, represent a more detailed simulation of the product. Often, it is thought that the more photorealistic they are, they serve better their purpose.

Computerization of the sketching and rendering process should be taken into account for many of it's advantages. Computers can be used more efficiently for the final visualization stages of the product, but traditional sketching and two dimensional rendering can be integrated perfectly via computer.

Manual rendering skills generally take years to master, but computer rendering skills can take only few weeks. A powerful software with a clear GUI (Graphical User Interface), offering undo capabilities, is an indispensable tool for designers.

Computers are weak tools in ideation and rough sketching. Dimensional accuracy are not important in sketching, but the line quality and quickness of response with the feel of paper and pen are important to designers. Some digital systems introduced pressure sensitive tablets and new sketching software. They tend to mimic the old tools, but there are some great differences between the two: the designer expects immediate feedback from the medium that is drawn upon. In the case of the digital tablet, the line drawn on the tablet can be seen on another medium, which is screen. There have been designers proving success with these tools but it takes training and time. It can be questioned, whether it is worth the effort or not, when traditional pen and tool can be used even for the computerization of a sketch.

A common hand drawn sketch can be transferred into the digital medium by a scanner.. this device works like a photocopy machine, but it's output is not a paper print. The scanned image is encoded as digital data so that it can be edited with a computer.

The scanned image, like 3D render outputs, is a raster image file. In this method, the entire picture area is divided into small homogenous cells like a grid. Each cell has it's own color (if required), such as a tile in a mosaic, with all tiles having the same size and shape. In the simplest form, every cell contains either a color or shade. These cells are called picture elements, or more commonly, pixels.
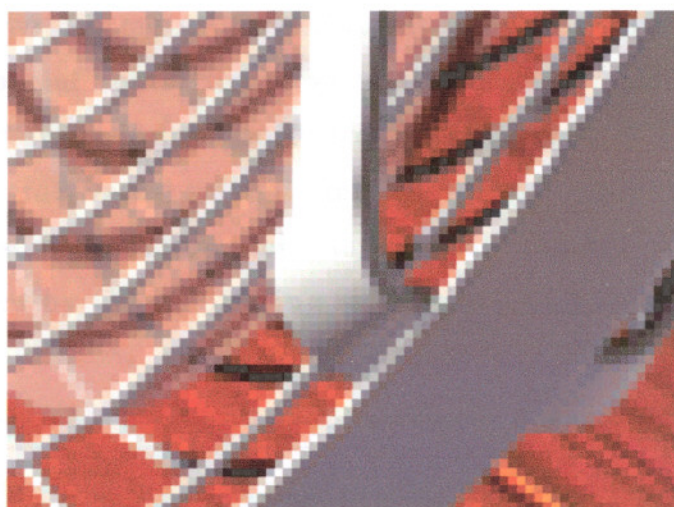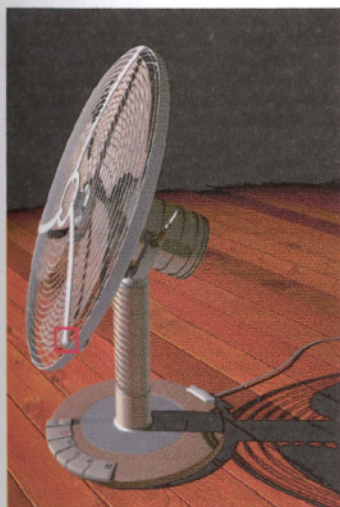
figure 2.1: A raster image consists of "pixels"

The quality of a raster image is based on two parameters: the number of pixels Per unit of area (resolution) and the range of colors and shades permitted each pixel (palette). The higher the resolution and the greater the variety of available colors and shades, the higher quality the picture will be.

Rendering raster images has some important restrictions. First, the resolution and the size of the image must be well adjusted for the purpose of the image. For example, a typical screen resolution is 72 dots Per inch (dpi), but an offset print resolution requires a high 300 dpi resolution. The size of the image should be well defined also, because after the completion of the image, increasing the resolution or the size of the picture will cause a great loss of quality of the image.

Computers have the tendency to mimic the traditional rendering methods. These machines do not suddenly enable a person to draw who could not before. It takes time and practice, but usually less than traditional drawing methods. Additionally, the designer does not have to worry about the quality of paper, or the amount of ink left in the marker. Computers enable the use of any color in any quantity, and an unlimited number of electronic sheets of paper.

Also, the use of a scanner helps the designer in the two dimensional visualization stage. Once the sketch has been digitized via

scanner, it can be enhanced with some vectoral lines at the edges. Then, it can be rendered using special tools, found virtually in every raster package. Generally, PhotoShop by Adobe software is considered to be the most popular raster software among designers and graphic professionals. There are some others such as Fractal Painter by MetaCreations and PhotoPaint by Corel, offering many similar or unique tools.
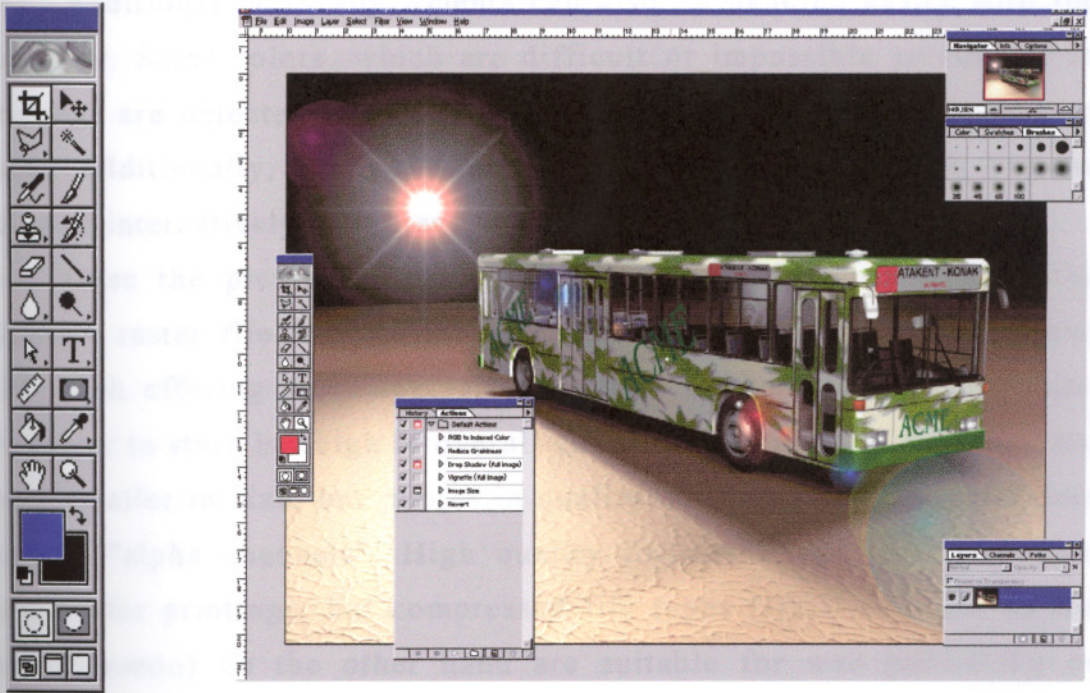
figure 2.2: The tools and GUI of Adobe PhotoShop

Rendering can became much easier by masking tools and layering capabilities of the software. Tools like pen, airbrush, brush or eraser enables the designer to easily adapt himself to the digital medium. As many layers as necessary can be used in a drawing for many different purposes.

Filters can be applied to the whole picture, or to the masked area. These filters include blur effects, flare effects, shadows, highlights, edge enhancements and many more. Also, some special effects such as fire or smoke can be added. Some traditional media techniques like oil paint, gouache, watercolor, pencil, charcoal or pastel can be simulated and

applied to drawings. Different paper textures can be applied to the picture, whether they are custom made or preset textures.

If the image is prepared for digital media, it should be in RGB (Red Green Blue) color mode. For print processes, it should be in CMYK (Cyan Magenta Yellow Black) in order to get the correct results. This is due to the different nature of colors, whether they are based on a light source or on chemical color pigments.

Additional color adjustments can also be handled easily with the computer. Some colors, which are difficult or impossible to achieve in printings are detected by the software, enabling the designer to correct them. Additionally, a color's hue, saturation and brightness can be adjusted interactively to achieve the desired results.

Once the picture is complete, it can be saved in many of the different raster file formats including JPEG, targa, tiff, bmp, GIF and EPS, each offering some special features for different purposes. Some are larger to store but high in overall quality of the picture, but some are much smaller in size, but poorer in quality and lacks some special data such as "alpha channels". High quality formats (targa, tiff, EPS) are suitable for printings, but compressed file types (JPEG and GIF as the most common) on the other hand are suitable for web publishing or screen based presentations.

2.1.2 Two Dimensional Drafting

The two dimensional drafting systems are the first CAD tools that appeared on the market. There was a need for such systems and they offered many advantages like increased productivity, decreased time to market, uniformity on drawings and shortage of good drafting personnel (Tangney J.,1982)

Creating and editing 2D drawings has proved to be technically easier than that of 3D modeling and analysis. Modeling, simulation and visualization generally requires greater processing power than drafting. In the earlier days, the implementation of such skills required mainframe

computers whereas 2D drafting systems were available for minicomputers, making them more available.

Digital drafting systems are replacing the traditional drawing boards. At the beginning, CAD which was the automation of drawing process, provided a primary justification for a company to invest in a CAD system. Even today, computer-aided drafting is synonymous with computer-aided design for many people.

Drafting systems allow the designer to create lines, arcs, points and graphic primitives to be generated, edited and deleted. This can be achieved with a two dimensional coordinate system. The graphic entities in a 2D drafting system are vectoral graphics. With vector encoding, an image is represented in terms of the line it compromises. Each line is defined by the coordinates of its endpoints: curves are described by using very short straight line segments or can be represented by polynomial approximations (Teicholz E., 1985). Unlike raster graphics, they are purely based on mathematical functions, that is to say that they can be freely scaled, rotated, trimmed or extended without any data loss. For a vectoral graphic, there are no restrictions such as "resolution of the image".
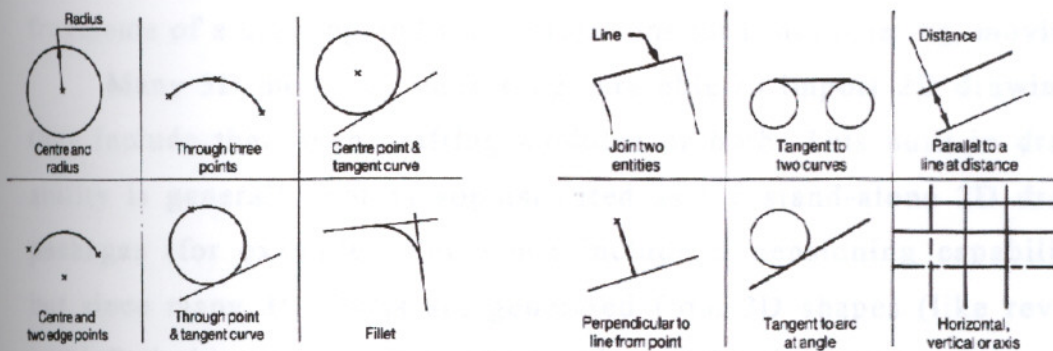
figure 2.3: Methods for line and arc construction (McMahon C., Browne J., 1995, p.27)

The basic elements of 2D drafting process are points, lines and arcs. There are many different methods of construction for these elements. Figure 2.3 illustrates a small number of many available

methods in a typical system for the definition of lines and arcs. The facilities for point generation are of particular note: in drafting systems, the model is often developed from a group of points upon which other geometric entities are constructed. These may be separate point entities, or implied points related to other entities or intersections (such as the center point of a circle). They may be created by the designer by entering a coordinate value or pointing an input device to a position on a computer screen. Many computer screens offer the facility to generate a grid pattern in the virtual construction plane such that user-indicated positions are constrained to lie at grid points. Some other important facilities are those allowing the construction of new geometric entities relative to the existing ones (snapping), or creating new elements from existing curves (like blending routines for generating fillet arcs or chamfer lines).

The primitives, or it's elements, can be generated in a variety of styles like dashed or dotted lines in different color schemes. Some other functions include dimensioning, cross-hatching regions bounded by lines or arcs, structuring drawings (like using graphic components and overlays), drawing using construction lines, evaluating the properties of 2D figures (like area, perimeter, length or center of gravity), windowing fragments of a drawing and transformations (scaling, rotating, moving).

Many 3D modeling packaging are able to import 2D drawings or they include their own drafting modules or both. This built-in drafting ability is generally not as sophisticated as the stand-alone 2D drafting packages (for example, they don't include dimensioning capabilities), but since many 3D forms are generated from 2D shapes (like revolved and lofted objects), this is an invaluable tool for designers.

2D drafting is generally used instead of traditional drawing methods. Because of the component geometry may be defined precisely and constructed at full size, the risk of error in the creation and interrogation of a digital drawing is lower than the manual equivalent. This benefit can be greatly enhanced with important functions such as creating dimensions and some other annotation directly from the stored model. This, combined with the facility to reuse stored models, and to

manipulate the database, is a powerful aid to the engineer (McMahon C., Browne J. 1995, p.27).

2.1.3 Dimensioning

When working in a production environment, one of the most time-consuming and critical challenges is the need to dimension a drawing as quickly and accurately as possible. Dimensioning is made after a drawing has been produced. Dimensions are one of the most important parts of a drawing because they define the size and locate details exactly, moreover they are used to manufacture or assemble what is drawn.

The placing of dimensions in CAD systems is a relatively easy task when compared to traditional hand drawing dimensions. The reason for this is because the computer automates much of the dimensioning process. When drawing by hand, it is necessary to draw each extension and dimension line, all arrowheads and text. But the CAD system generates much of this tasks automatically: the designer just inputs the two points to be dimensioned, the position for the dimension line and the computer automatically places the dimension and extension lines, arrowheads and dimension figure.

There are several basic types of dimension in a typical CAD system, which includes *linear dimensions, radius* and *diameter dimensions, angular dimensions, ordinate dimensions and tolerance dimensions. Linear dimensions* are the most common defining a specific length, whether it is horizontal, vertical or aligned to the dimensioned object. *Radius* and *diameter dimensions* are used to dimension the size of an arc or circle, regardless of the type of the object. Angular dimensions are used to dimension the angle between two non-parallel lines. *Ordinate dimensions* are used to clarify a specific coordinate such as a point from a civil survey. These coordinates are labeled using an ordinate dimension type, which labels the point's exact X and Y coordinates. Finally, tolerance dimensions are used to provide constraints within which the

drawn object can be constructed. For example, a mechanical part can be generated and specified that its length may be 2mm + or − 0.001mm.
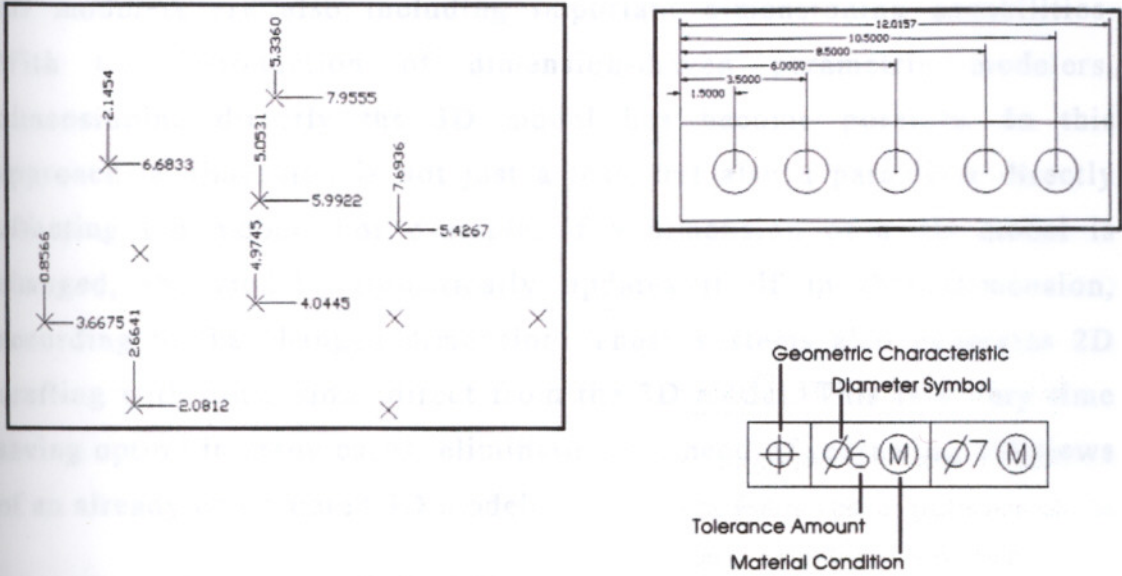
figure 2.4: Ordinate, linear and tolerance dimensions.

One of the main advantages of dimensioning with CAD systems is that certain preset characteristics are associated with dimensioning. These systems allow the user to set the dimensioning style to be used such as architectural, engineering unidirectional and engineering aligned, and English or metric units. The dimension lines, arrowheads or texts can also be formatted, whether based on preset formats or custom formats.

CAD systems usually enables to define the style options in three different categories including *geometry options, format options* and *annotation options*. The *geometry options* are used to control all the dimension system variables related to the geometry of the dimension, such as dimension line, arrowheads, extension line, center point and scale. The *format options* enables to control the location of the dimension text, whereas *annotation options* enables to control how the text looks in the dimensioning. For example a dimension text can represent the linear dimension in decimal units and the angles in decimal

degrees. The font, height and color of the text can also be edited with annotation options.

Although dimensioning is usually related with 2D drafting, many 3D modelers are also including important dimensioning capabilities. With the introduction of dimension-driven parametric modelers, dimensioning directly the 3D model has become possible. In this approach, a dimension is not just a text, but also a parameter directly affecting the model. For example, if a dimension of a 3D model is changed, the model automatically updates itself in three-dimension, according to the changed dimension. These systems also generates 2D drafting with dimensions direct from the 3D model. This is a very time saving option in many cases, eliminating the need of redrawing 2D views of an already constructed 3D model.

2.1.4 Three Dimensional Modeling

Designers have always conceived their ideas in three dimensions. Perspective drawings were the primary means to communicate an idea for the designer. However, a new perspective had to be drawn each time a designer wished to show a different view. Today, with the introduction of three dimensional software, the virtual model of the project has to be "built" only once. Then, unlimited number of perspectives can be achieved, which means that the design can be analyzed from vantage points unavailable through traditional means.

Early 3D computer systems were only able to display simple shapes by tracing outlines of all edges; these are called "wireframe" images. However, displaying complex objects, becomes an ambiguous means since the viewer has great difficulty understanding these images. Software was therefore written, enabling the removal of a line if it was hidden behind another line. The convincing representation of solid surfaces was the next breakthrough and so 3D modeling systems slowly developed into the true photorealistic visualization that is seen today.

When viewers look at a real physical object, they are not fully aware of the complexity of the relationships within this object. They

stand at a certain distance with a certain angle, so that only certain aspects of the object are realized. As they move, other views are seen, and if more detail is needed, they move closer. These are all parts of every day experience occurring as a series of unconscious acts.

However, with the computers, all these factors have to be calculated to establish the same kind of three dimensional effects. But when using computers, the necessary calculations must be driven by a conscious set of choices. The user has to decide exactly what the spatial relationship is between him or herself and the object. This makes 3D computer modeling not only the modeling process requiring different tasks from its physical counterpart, but also the nature of information that is normally assumed to be conscious ones. In addition, with the other characteristics of the model, such as surface texture and the light effects, the situation is further complicated.

In spite of its complexity, 3D computer modeling has become an impressive tool; it can provide a new relationship between the designer and his ideas. There are many different modeling techniques and strategies which are usually very different by nature. One technique can be applied to a specific model successfully, but may fail with some another one. Also, the purpose of modeling should be well defined (visualization, CNC machining or rapid prototyping) so that the appropriate modeling methods are used for the optimum result.

2.1.4.1 Wireframe Geometry

The first of the main 3D schemes is the wireframe geometry. It is the simplest way for displaying a model whether on a computer screen or hard copy. The wireframe geometry can be considered as an abstraction of the model, in which the geometry is defined as a series of lines and curves representing the edges and the sections of the object. Curved surfaces, if there are any, are represented by additional lines (isolines) running along the surfaces.

56

Wireframe geometry can be regarded as an extension into a third dimension of the common drafting techniques. The basic entities used are mainly the same as those of drafting, although the data necessary must be extended for storing the 3D entities. For points and lines this simply means adding a z value to the coordinate data, but for arcs and other planar curves, the plane in which the curve lies has to be defined.
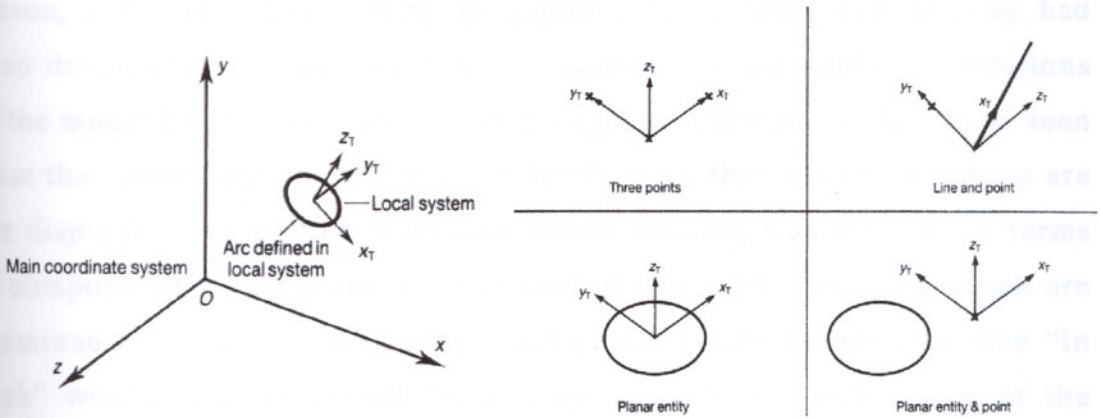
figure 2.5: Use of Local Coordinate Systems (LCS) and methods for defining LCSs. (McMahon C., Browne J., 1995, p.30)

The construction techniques used for wireframe geometry are also quite similar to those for drafting, but to certain extent. The difference lies in the 3rd dimension of the wireframe geometry: in 3D modeling packages, the use of movable work coordinate systems and a number ways of defining World Coordinate Systems (WCS) are provided. Associated with the WCS, are the concepts of the work plane and the working depth. Usually, planar entities such as lines, arcs and conic sections are constructed by default in a two dimensional plane, which is parallel to the x-y plane of the WCS at a z axis value equal to the working depth (height).

The wireframe scheme is relatively straightforward to use, and is the most economical of the 3D schemes in terms of computational resources. The wireframe scheme is very useful in the representation of simple geometries such as an extruded shape along it's normal or a rotated planar profile about an axis (lathing). It can also be useful for the visualization of the motion of simple objects, like an animation of a

moving mechanism. However wireframe geometry does exhibit a number of serious deficiencies. In the case of complex models, wireframes can be visually confusing. The viewer may not be able to perceive which part of the model is in front of the others. Nonetheless, there are some cases in which wireframe models can be useful for the ability of showing the front, back, top and bottom of the object simultaneously. In many cases, this is perceived as a deficiency rather than as an advantage. For this reason, some techniques such as hidden-line removal and haloing had been developed. Hidden-line removal consists of the surface definitions of the model used to determine which edges would and would not be seen from the viewer's point of view, while the ones that would be hidden are not displayed. An earlier technique called haloing was simpler in terms of computational resources. It consisted of every line crossing which are examined to determine which ones are closer to the viewer; the line "in back" would then be erased for a short distance on either side of the crossing point, as if the one "in front" had a halo around it that obscured a portion of the line "in back". Although it was visually effective, it never caught on commercially.

Ambiguity in representation resulting a possible nonsense object, is another important defect of wireframe geometry. The classic example in this respect is the block with beveled faces and a central hole shown in figure 2.6. Is the hole from front to back, from top to bottom or left to right?
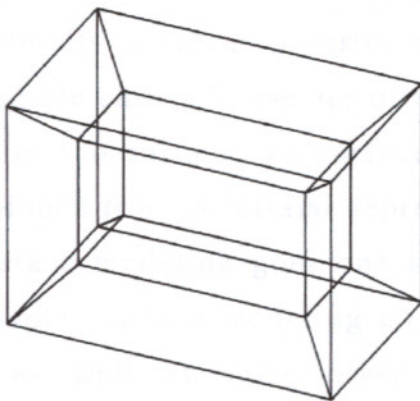
figure 2.6: Ambiguity in wireframe models (McMahon C., Browne J., 1995, p.32)

The ability to calculate mechanical properties, or geometric intersections, is limited in wireframe geometry. It also has little value as a basis for manufacture or analysis applications. But it is very useful in the representation of simple geometry such as extrusions, revolved objects or primitives. Although such shapes are not two dimensional, they do not require sophisticated three dimensional schemes. As a consequence, an intermediate representation, often called "two-and-a-half-dimensional" (2.5D) has been developed, which may be considered a sub-set of the wireframe scheme.
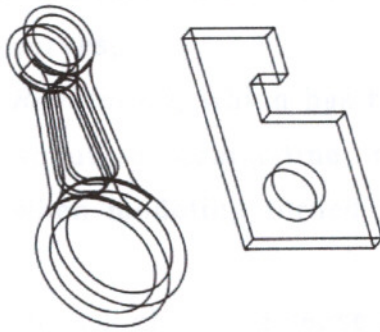
figure 2.7: Shapes constructed with 2.5D representation (McMahon C., Browne J., 1995, p.33)

2.1.4.2 Surface Modeling

Surface modeling is a widely used technique in which objects are defined by their bounding faces. It represents the model by specifying some or all of the surfaces on the component. The representation of surface models generally involves a series of geometric entities, each surface forming a single entity. These are often constructed from surface edges and curves on the surface, so surface representations are often mixed with or developed from wireframe representations.

However, surface modeling goes one step further than wireframe modeling. For example, surface modeling contains the information of a wireframe model as well as some other information such as the connection of two surfaces. A surface model can be used to determine cutter path in CNC machining, whereas a wireframe usually cannot. In

surface modeling systems, the user may input the vertices and edges of a workpiece in a manner that outlines or bounds one face at a time.

The most basic surface type is the flat plane. It may be defined between two parallel straight lines, through three points or through a line and a point. Other examples of commonly used surface types are as follows:

A *Tabulated Cylinder*, which is defined by projecting a generating curve along a line or a vector,

A *Ruled Surface*, which is produced by linear interpolation between two different generating curves or edge curves. The effect is that of a surface generated by moving a straight line with its end point resting on the edge curves,

A *Surface of Revolution*, which has been generated by revolving a generating curve about a center-line or vector. This surface is particularly useful when modeling turned parts, or parts which possess axial symmetry,

A *Swept Surface,* which is in a sense an extension of the surface of revolution, where the defining curve is swept along an arbitrary curve instead of a circular arc.

A *Sculptured or Curve-Mesh Surface*, which is among the most general of the surface types. It is defined using a family of generating curves, or two families intersecting in a crisscross fashion so creating a network of interconnected surface patches.

A *Fillet Surface*, which is analogous to the fillet arc in curve construction, and is defined as a surface connecting two other surfaces in a smooth transition (generally of a constant, or smoothly changing, radius of curvature).
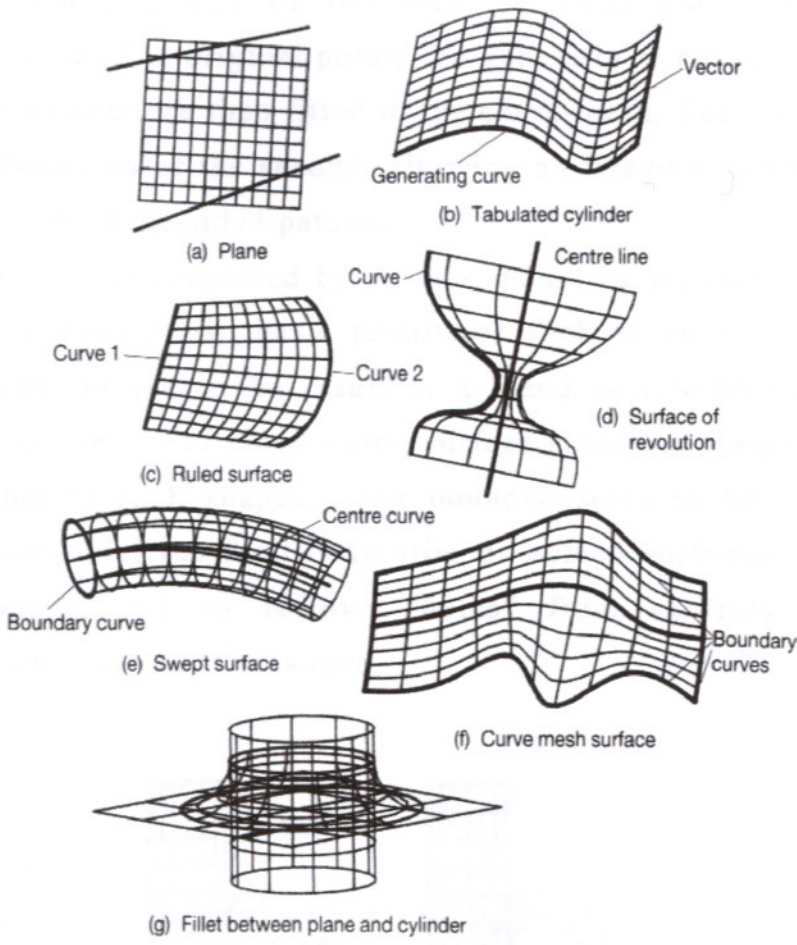
figure 2.8: Examples of surface types (McMahon C., Browne J., 1995, p.34)

In each case, the surface is drawn as a mesh of intersecting curves on the surface. This is because of the surfaces which are continuous with every point on the surface defined by mathematical relationship used in its definition, as well as display purposes.

Generally, real artifacts are constructed with surface modeling techniques by an assembly of surface "patches". A complex object, a car body for example, may require several hundred patches.

There are three major approaches for modeling such complex objects with surface modeling techniques. First, working initially in terms of a set of plane cross-sectional curves not all being necessarily in parallel planes. The system then "lofts" or "blends" the cross-sections resulting a smooth surface. Secondly, an array of points in space, which

are fitted into two sets of intersecting curves are used to get a curvilinear mesh. The original points are generally at curve intersections and surface patches are then fitted to the curve-mesh. The third approach is just an extension of the second, allowing an irregular mesh of curves containing some three-sided patches.

Many objects generated by surface modeling techniques are often much more complex than basic primitives such as cylinders, cubes or spheres. Even for these, the result of a blend or intersection is not a basic form anymore. For many years, surface modeling systems were not able to generate such shapes using bounded surfaces like fillets and chamfers. However, the facility to trim or extend surfaces to curve or surface bounds, and to remove "holes" from surfaces, has been introduced with many 3D packages.

(a) Unbounded   (b) Bounded surfaces
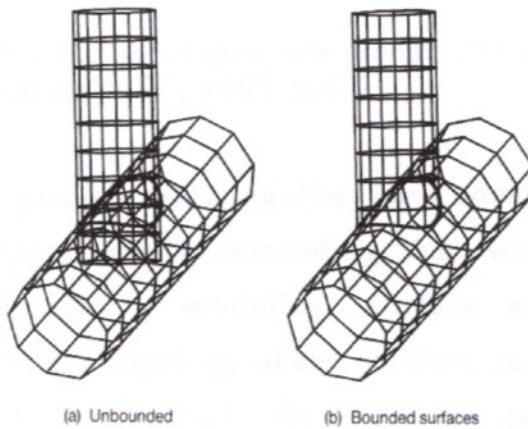
figure 2.9: Intersecting cylinders represented by bounded and unbounded surfaces. (McMahon C., Browne J., 1995, p.35)

Surface modeling systems offer better graphic interaction than wireframe geometry, but the models are more difficult to create. Sometimes, the creation of an intermediate model is necessary. For example, the generic surface below is created by editing a simple cube block. With the references of the cube, it is much easier to input the control points that are used to define the shape.
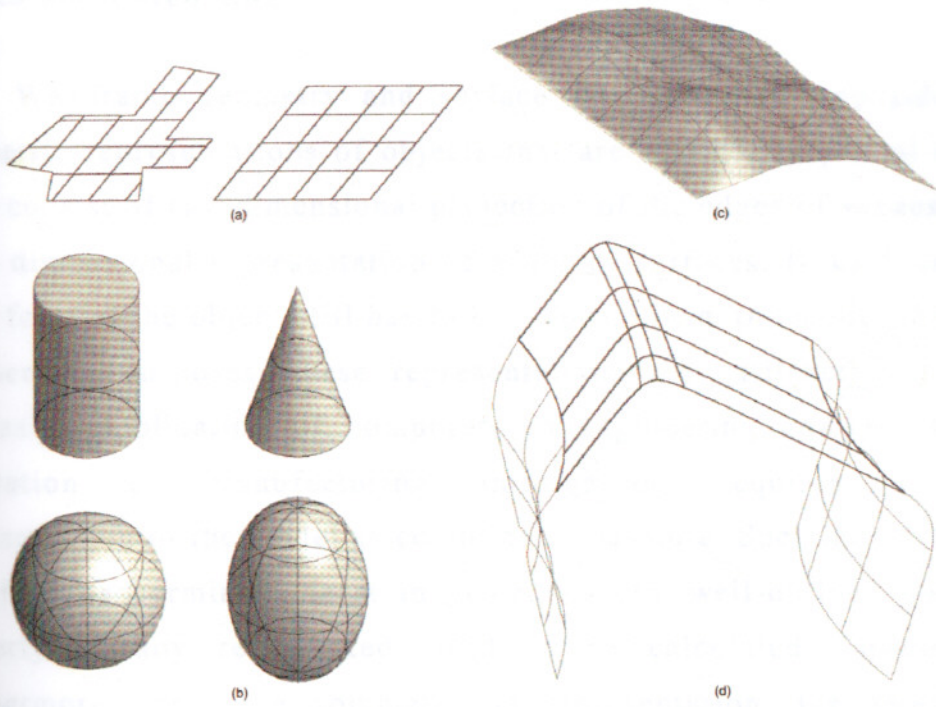
figure 2.10: Surface types: *(a)* planar, *(b)* quadrics, *(c)* free-form, *(d)* blends (LaCourse D. E., 1995, p.5.7)

However, surface modeling does have some drawbacks. In general, it is more computationally demanding than wireframe and requires a more advanced skill of modeling. Surface models do not provide information about the topology of the entities, such as the concept of the component's inside and outside. As a result, a user may still not be able to distinguish the interior and exterior of an object on the screen.

There is also, similar to the case of wireframe geometry, a chance of generating erroneous models. Surfaces may be discontinuous, may intersect with themselves or with each other. Representation of an object is simply in terms of a collection of surfaces with no further level information about the solid object. Visual inspection of the model is required to identify and eliminate physically impossible geometry.

2.1.4.3 Solid Modeling

Wireframe geometry and surface models can be considered as geometric representations of objects that are essentially partial models. They consist of two dimensional projection of the edges of shapes, or the three dimensional representation of edges or surfaces. In each case, the solid form of the object still has to be inferred from the model. For many engineering purposes, these representations are satisfactory, but the increasing application of computers to engineering analysis and the generation of manufacturing information, requires an ideal representation of the model as complete as possible. Such models, can be described as permit (at least in principle) any well-defined geometric property of any represented solid to be calculated automatically. Furthermore, the more complete the representation, the smaller the requirement for human transcription between models, and thus the smaller the risk of errors in transcription (McMahon C., Browne J., 1995).

Solid modeling has been a major theme for study over the years. It finds wide applications such as finite-element analysis and fluid flow analysis in the conceptual design of products, NC part programming for computer aided manufacturing and even visualization of the product. Furthermore, solid models can be used to evaluate the size, shape and weight of objects during the conceptual design phase.

Solid models are the least abstract and most realistic of the three forms, they require much more computing power for the creation and management of a geometry. With solid modeling, the construction of complex models, especially the ones lacking symmetry, are generally much faster than surface modeling methods. A complex object can be decomposed into a smaller number of solid components (called primitives) than surfaces, lines or points. In solid modeling systems, generated objects are defined directly by these primitives, sometimes called building blocks. An independent surface, line or point does not have any meaning in solid modeling. With much fewer parts to manipulate, a model can usually be constructed much faster. This is the

essential of solid modeling a complete and unambiguous representation of objects.

However superior its characteristics, some shapes can be represented only by surfaces but not by solids. Thus, many designers are forced to resort to surfaces for certain complex objects. Many solid modeling systems closely integrate surface and solid capability in one package.

The most important aspect of solid modeling is that their integrity can be determined by computer: solid modeling software, with the aid of the computer, can tell if a constructed geometry is a legitimate solid or not. Thus, the objects designed in solid modeling systems will be manufacturable, at least from the spatial integrity point of view.

There are many different methods proposed for solid modeling. These are:

- Boundary Representation (B-Rep)
- Constructive Solid Geometry (CSG)
- Sweep Representation
- Primitive Instancing
- Cell Decomposition
- Analytical Solid Modeling

Boundary representation and constructive solid geometry are dominating the development of practical systems. These two are partially successful at the requirements such as assuring complete and unambiguous geometry, being appropriate for the world of engineering objects and practical to use with existing computers. However, for different applications, one may be more suitable than the other. For example, B-Rep is more suitable for representing complex designs, whereas with CSG, models are easier to create but are usually used in relatively simple objects. Many modelers, use a hybrid scheme of these two is widely used.
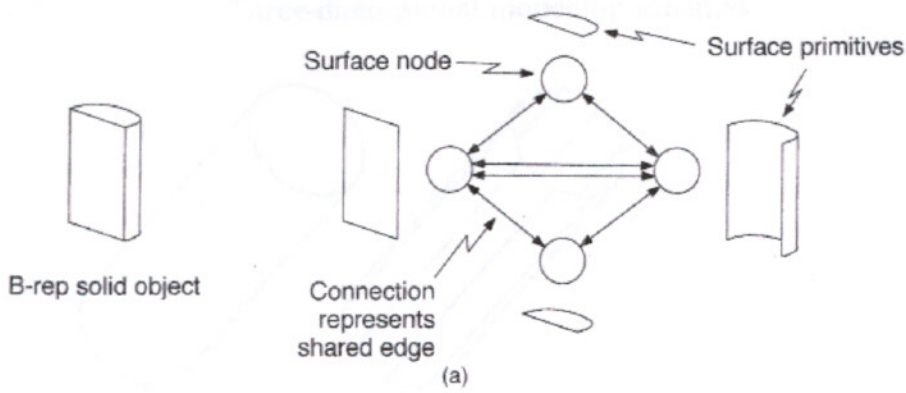
figure 2.11: B-Rep representation of a solid half-cylinder: nodes represent faces (surface primitives) and connections represent common edges (LaCourse D. E., 1995, p.4.16)

B-Rep to a certain extent, is an extension of the surface representation scheme. Surface models contain no information about connections between surfaces, nor about which part of an object is solid. If the information of connectivity between surfaces (which are called *faces* in B-Rep modeling) and the solid side of any face is identified, then this forms the elements of the boundary representation scheme. B-Rep describes the geometry of an object in terms of its boundaries, vertices, edges and surfaces. These elements forms an explicit "tree" of boundaries for the whole geometry: a solid is bounded by surfaces, a surface is bounded by lines, a line is bounded by points.

The simplest form of a boundary model is the one representing all faces as flat planes, or facets. A curved surface such as a cylinder is represented in such a model as a series of facets approximating the surface. B-Rep is relatively straightforward in terms of hardware resources, and therefore has performance advantages. It is clearly limited in modeling curvilinear shapes (such as engineering components) but with today's parametric surface technology incorporated, B-Rep modelers can create any object theoretically.
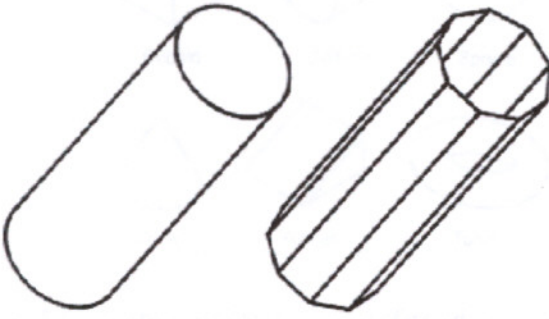
figure 2.12: Faceted representation of a cylinder (McMahon C., Browne J., 1995, p.39)

In order to represent a solid object by its surfaces, the orientation of each surface that defines the inside or outside of the object is required. Usually, the inside is the material part and the outside is the void space. The direction of the "face normal" is usually used as the orientation of the face, and the face that carries the orientation information is called an orientable surface. A solid is bounded by orientable surfaces, thus, a solid can be defined by a set of faces.

It is very important to understand how B-Rep representation differs from a conventional surface modeling scheme. A nonsolid CAD system must also guarantee that the surfaces form a complete partition of space, even after being extensively modified. This is a major challenge in CAD systems; if this separation of space fails for any reason, the model becomes invalid and the solid modeling system has made a serious error.
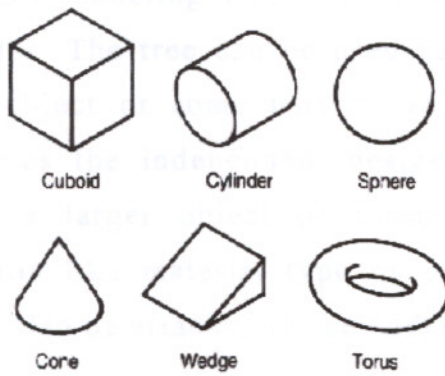
figure 2.13: Some primitives offered by solid modeling system (McMahon C., Browne J., 1995, p.30)

Constructive solid geometry (CSG) is the other popular method in solid modeling. In this method, models are constructed as combinations of simple solid primitives (also called entities or bounded solid primitives). These primitives include cuboids, cylinders, spheres, cones and the like. All primitives are arranged in a tree structure using Boolean operations (subtraction, union or addition of solids) to construct a solid model. In this structure, the primitives are the leaves and the Boolean operations represents the branches of the tree.
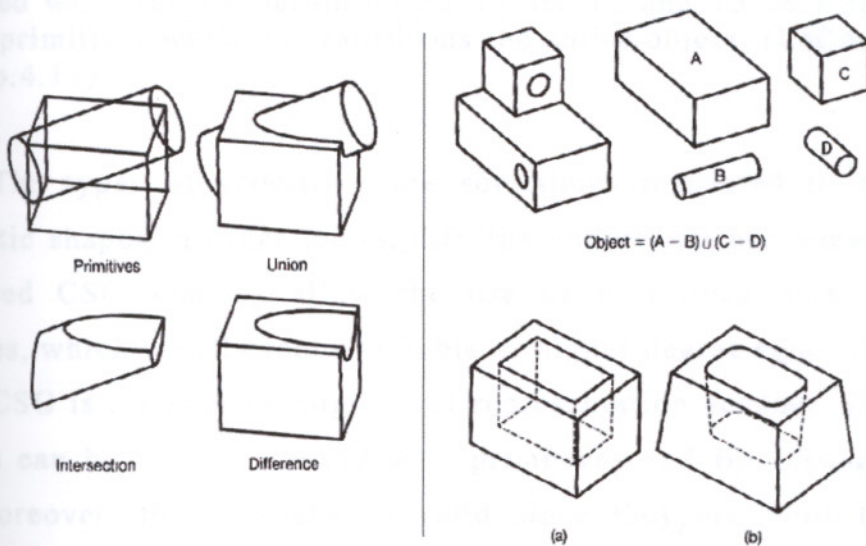
figure 2.14: Boolean operations on block and cylinder; constructive solid model of a simple block and solid models of a simple block (McMahon C., Browne J., 1995, p.41)

A typical CSG modeling tree can be extended by the usage of transformation nodes. The tree can be used to change the location and orientation of an object or some part of an object represented by a subtree. This enables the independent design of a part and its later incorporation into a larger object or assembly as a subtree. Some auxiliary information like material type or previously computed mass properties data can also be attached to the nodes.
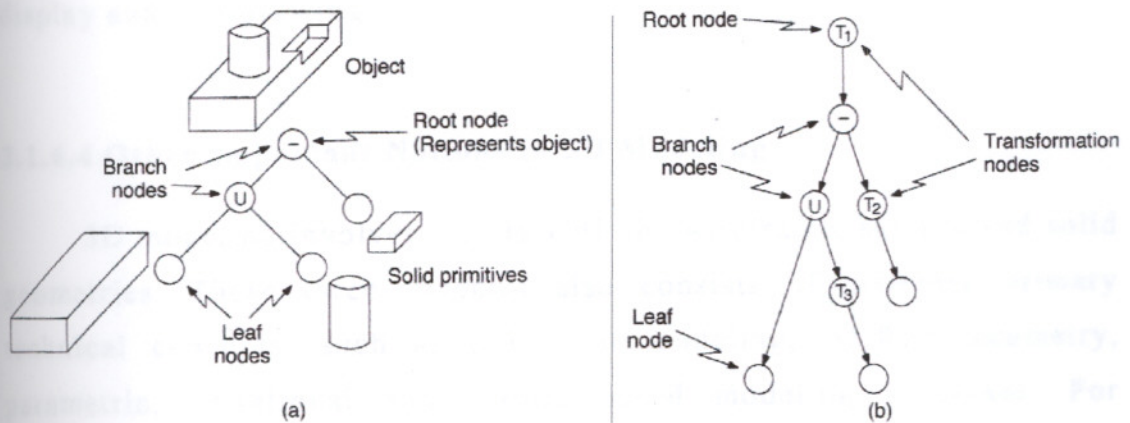
figure 2.15: CSG data structure: *(a)* a tree structure is used to represent a three-primitive CSG object; *(b)* the CSG tree can be further extended with transformation nodes. Nodes T2 and T3 each transform a single primitive, while T1 transforms the entire object. (LaCourse D. E., 1995, p.4.13)

The types of primitives are sometimes restricted to planar and quadratic shapes in order to simplify the underlying mathematics. Some advanced CSG systems allow the use of primitives with sculptured surfaces, which usually requires cubic or higher degree equations.

CSG is a powerful, high level representation scheme. Constructed models can be rapidly created with primitives and Boolean operations, and moreover, they are always valid since they are built from solid elements. Boolean operations are simple to implement and take little processing time in solid modeling. Also, many designers find the addition and subtraction of solid primitives to be an intuitive design paradigm that parallels manufacturing operations like welding and drilling (LaCourse, Donald E., 1995).

However, a pure CSG representation of a geometry is severely limited in many solid modeling situations. An object's faces, edges and vertices are not available in explicit form (mathematical equations), and if they are necessary for an application, the system computes this information explicitly, which is a time consuming process. This limitation is effective though while displaying a CSG model. For displaying a CSG model, it is usually converted internally into a B-Rep. This is one of the main causes of the systems providing both B-Rep and CSG: CSG provides easier input and B-Rep provides faster interactive display and line drawing.

2.1.4.4 Other Important Notions in 3D Modeling

3D modeling involves mainly with the wireframe, surface and solid geometries. These three schemes also consists of different primary technical concepts, such as polygonal modeling, NURBS geometry, parametric, variational and feature based modeling processes. For example, a solid modeler can be based on NURBS geometry and can include parametric and feature based modeling capability whereas a surface modeler can have both polygonal and NURBS modeling techniques with a parametric structure. There are many different variations possible, thus it is a vital aspect to be familiar with this subset of important concepts in 3D modeling, in order to use 3D programs properly.

2.1.4.4.1 Polygonal Modeling

Polygonal modeling is probably the most common technique in 3D technology. Polygonal geometry is based on interconnecting triangles, called *faces*, of various sizes and orientations. These triangles forms the geometry, whether a simple primitive or more sophisticated. The arrangement of faces leads the designer from the creation of a very simple 3D model to a very complex one.

The principle for a detailed model is straightforward: the more faces existing in a given location of the model, the more detail there is. By adding more detail, the model can be shaped easily. As the viewer gets closer, the difference in detail levels will become noticeable. Unlike some new technologies such as NURBS, polygonal models do not get a higher "resolution" while rendering. Once modeled, the polygonal model will be transformed, edited, animated or rendered with the same number of faces, unless more faces are added manually.
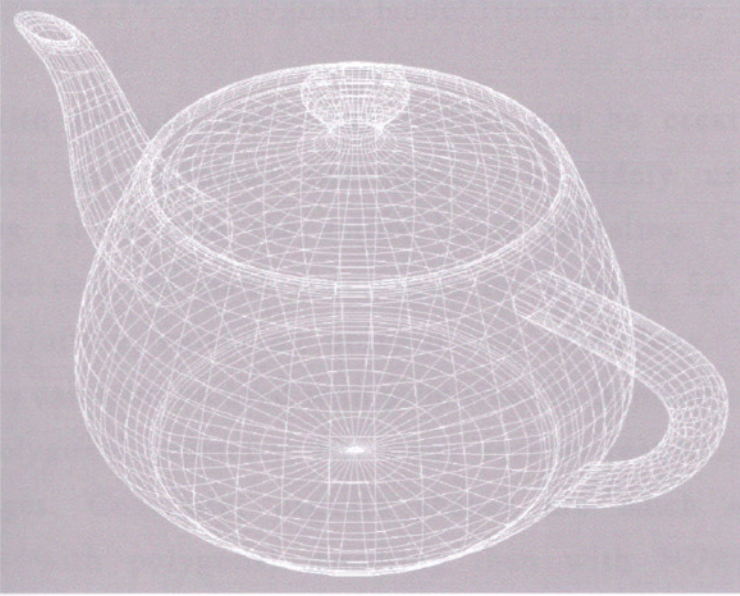
figure 2.16: A polygonal teapot model consisting of faces.

A polygonal model's face consists of two elements called vertices and edges. Edges are the three sides of a face, and vertices are the points connecting the edges. The construction of a polygonal model essentially involves the connecting of vertices. If all of the faces of a model share an edge with at least three other faces, the model is a "closed" geometry. If a model contains faces that do not share edges, the model is considered "open". Generally, polygonal models are generated as closed models, because open ones can cause some difficulties at further tasks such as modeling, rendering or rapid prototyping.
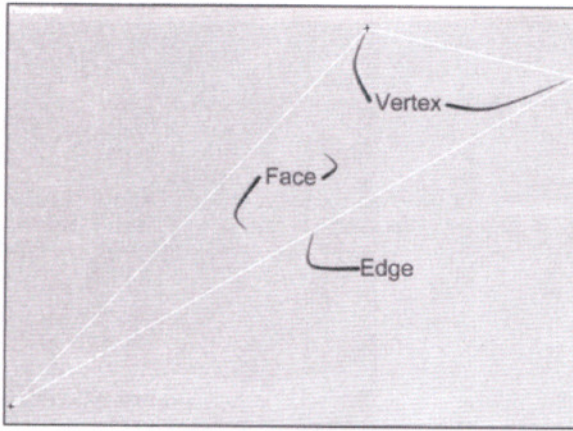
figure 2.17: A polygonal model triangular face

With enough detail, any surface can be created via polygons. Primitives and Boolean operations are widely used in polygonal modeling, along with the spline based modeling. Curves (commonly Bezier curves) are many times used for creating 2D shapes to be the basis of lofting, extruding or revolving operations. This spline based geometry can later be used with primitives in Boolean operations.

Polygonal geometry, has many serious restrictions as well as its advantages. Generally, organic shapes are much more difficult to generate with polygonal modeling than with NURBS. Furthermore, adding detail where needed and editing the final detailed model can become a very difficult task for the modeler. Also, a polygonal model usually cannot be converted to NURBS geometry, but the NURBS model can easily be transformed into a polygonal geometry with any desired "resolution" of the model.

2.1.4.4.2 NURBS

NURBS is one of the most popular modeling technologies that ever existed. The acronym NURBS stands for "Non-Uniform Rational B-Spline", which is a highly technical description of it's capabilities. Although this description sounds meaningless to many designers, it includes very important clues about NURBS modeling potentials.
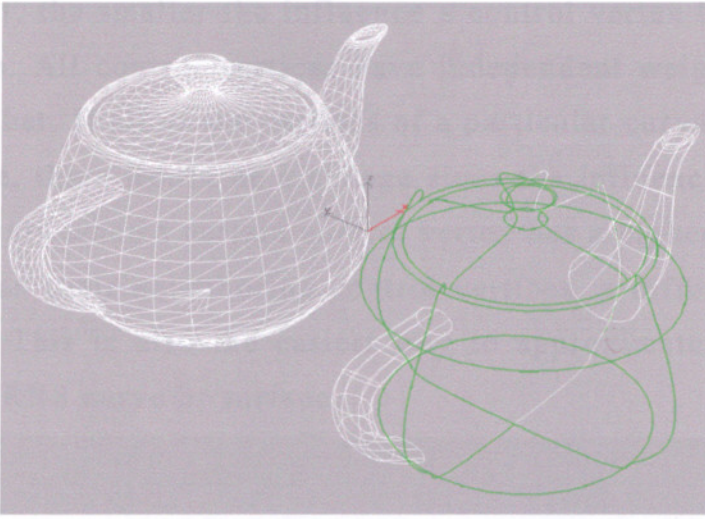
figure 2.18: Polygonal model vs. NURBS model

Non-Uniform means that different areas along NURBS objects (curves or surfaces) can have different properties (weights) and are not completely identical. *Rational* means that a NURBS object can be defined with mathematical formulae, and *B-Spline* is the description of any line in three dimensional space having the ability to curve in more than one direction.

NURBS modeling excels at smooth surfaces, but can generate sharp edges as well. However, these sharp edges can be created with two or more separate NURBS faces, since it is almost impossible to create a hard edge within a single NURBS surface.

Surfaces are always defined by curves in NURBS modeling, whether they are visible or not. The generated surfaces are extremely smooth and organic, in addition, these surfaces will adjust themselves in order to maintain their defining curves.

NURBS curves can be defined by either points or control vertices. The closest comparison for points are vertices of polygonal models: they lie on the curve itself and directly affect the shape of the curve. Control vertices act different than points, since they are actually part of a lattice acting like a magnet, instead of lying directly on a curve. Control vertices are more suitable for both organic and hard-edged shapes, because they have an additional control over the curve. Control vertices have weights that control the influence of itself on the curve; the lower

the weight, the smaller the influence a control vertex has over the curve or surface. All control vertices have independent weights being relative to each other. If all of the vertices of a particular curve or surface have a high value, there would be a change since the influence over the surface is even. Only when a certain control vertex has a higher or lower relative weight than their neighboring control vertices, a different result can be achieved. This is also the easiest way to approximate a hard edge in a single NURBS curve or surface.
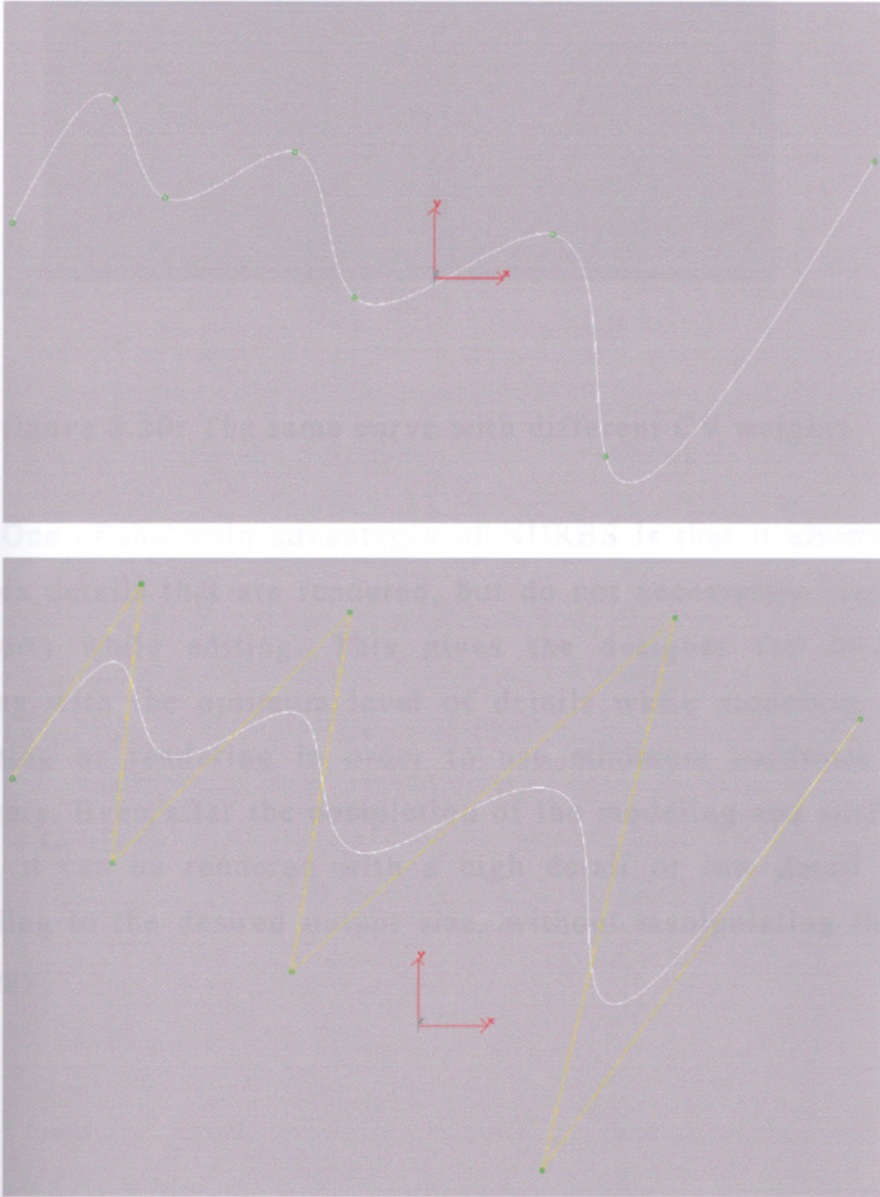
figure 2.19: A NURBS Point Curve and CV Curve

Control vertices and points are the basis for everything in NURBS, whether curves or surfaces. But, they are mutually exclusive: a surface or curve is made up of one or either the other, never both.
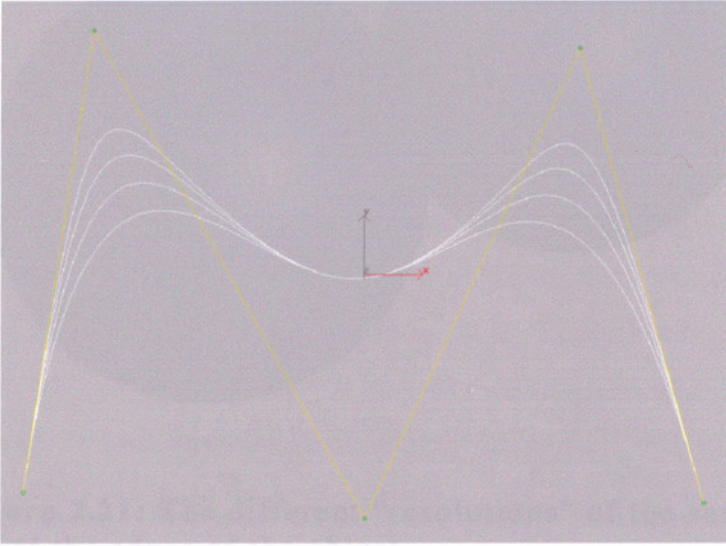
figure 2.20: The same curve with different CV weights

One of the main advantages of NURBS is that it allows to create complex details that are rendered, but do not necessarily display in the viewports while editing. This gives the designer the flexibility of working with the optimum level of details while modeling, texturing, animating or rendering in order to use minimum hardware resources necessary. Even after the completion of the modeling and surfacing of a shape, it can be rendered with a high detail or low detail resolution according to the desired output size, without manipulating the model's topology.
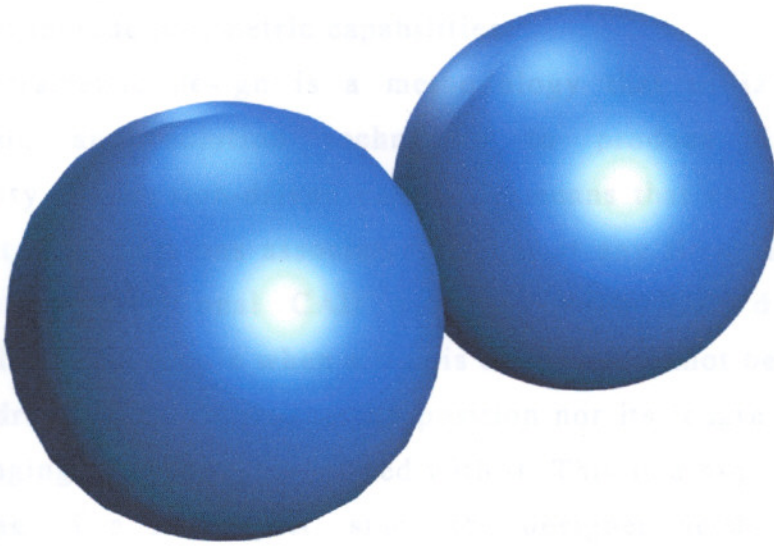
figure 2.21: The different "resolutions" of the same model can be observed at the edges of the object.

NURBS is an industry standard technology, working great for high detail smooth models. Anything can be modeled and animated via NURBS technology, from mechanical parts of a machine to an organic creature, such as a human being. NURBS is probably one of the best modeling issues for a designer, because it requires building block mentality: starting with simple shapes and deriving more complex ones from them. But in the case of rigid-looking surfaces and simple shapes, polygonal modeling should be the first choice. NURBS usually requires more computational resource than polygons, also creating and editing simple shapes are generally much more easier with polygonal geometry.

2.1.4.4.3 Parametric Modeling

Parametric solid modeling was first commercially introduced in late 1980s by Parametric Technology Corporation. By 1994, there were at least seven significant parametric systems, more kept appearing every few months. This is a direct result of the impact of Parametric Technology Corporation's products, and it is doubtful whether any

CAD/CAM package will ever be produced from that time forward, that does not include parametric capabilities.

Parametric design is a methodology that utilizes special case searching and solution techniques to produce dimension-driven capability. Dimension-driven capability means that an object is defined by a set of dimensions associated with it at any time during the design process. In traditional CAD systems which lack dimension-driven capability, for example when a line is drawn, it cannot be changed unless it is redrawn. That is, neither its position nor its length can be changed by changing the values associated with it. This is a big restriction in the modeling of a 3D object, since the designer needs to change the dimensions of the part in later stages of modeling, in order to achieve the predicted results.

Parametric modeling approach, describes these attributes by mathematical expressions that relate the dimensions to the values of variables and/or to other parametric dimensions, instead of describing the dimensional attributes of the modeled geometry by numbers. The values of variables may be entered by the user, or may be tabulated. This allows a model to be defined in terms of a general shape and topology, and changes in the geometry can be explored very quickly, simply by changing the values of key variables. As an example, a parametric model of a simple connecting rod can be considered. The figure shows the dimensions of the rod and a series of simple expressions that relate the values of these to key dimensions- in this case, the bore of the holes in the link and the distance between their centers. Parametric system includes the facility of updating automatically the geometric and topological arrangement of the model. It also updates the change of dimensions automatically.
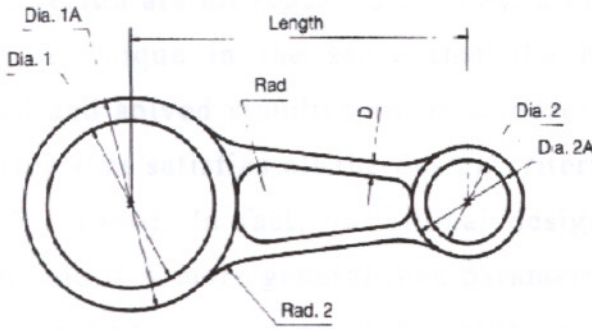
Example rules:
Dia. 1A = Dia. 1 + 5
Dia. 2A = Dia. 2 + 4
D   = - 4
Rad.   = Dia. 2 * 0.35
Rad. 2 = Dia. 1 * 0.5

figure 2.22: A link as a parametric part. (McMahon C., Browne J., 1995, p.180)

Parametric modeling capability is introduced with high-end CAD/CAM packages for a much more accurate and less time consuming modeling processes. Generally, every CAD/CAM system, includes parametric modeling technology, and many 3D animation and visualization packages are designed with such capabilities. They can store the dimension data about the model during the creation phase, and at later stages of design, these can be changed, usually without any data loss in the construction history. Many modifiers applied to the object such as "scale", "rotate" or "bend" can also be stored in the parametric history of the object, enabling further editing.

2.1.4.4.4 Variational Design

Variational geometry is another technology which is compared with the parametric geometry in many ways, and although they have much in common, the differences are significant. Variational geometry essentially involves the simple modification of the dimensions of a solid model, in order to produce variations of the model.

In variational design, geometry, engineering equations and dimensions of the design are all regarded as constraints. This constraint-driven capability is unique in the sense that the constraints can be arbitrarily coupled and solved simultaneously if necessary to arrive at a design configuration that satisfies all the design criteria specified by the engineer (Singh N., 1996). In fact, variational design is a superset of parametric design, and it is more general than parametric design.

Variational systems have an equation solver which allow a set of engineering equations to be used in order to set the value of dimensions. These are based on either engineering parameters or values of other dimensions, and in addition these equation solvers take into consideration the condition of parallelism, perpendicularity, colinearity etc.

A robust variational solid modeling system provides an essentially unlimited number of engineering relationships to be associated with the solution of the positioning and relational equations. These relations and constraints such as area, volume, analysis of degrees of freedom etc. is the essential of variational design, rendering it a very powerful and rich solution. Many designers prefer to use a variational system instead of dimension-driven parametric modeler, because it can be considered that more emphasis is placed on form rather than on function in consumer products. For example, a vacuum cleaner moves and filters a certain amount of air to be effective. Once the motor has been designed for this purpose, the major design process dealing with the final form of the cleaner begins.

2.1.4.4.5 Feature Based Modeling

A *feature* represents the *engineering meaning* or *significance of the geometry* of a part or assembly. The feature can be thought of as building blocks for product definition or for geometric reasoning. A feature model is a data structure representing a part or an assembly mainly in terms of its constituent features. Each feature in the model is an identifiable entity that has some explicit representation. The shape of

a feature can be expressed in terms of dimension parameters, or construction steps needed to produce the geometry corresponding to the feature.

Feature modeling provides for the addition of pockets, slots, holes, bosses, ribs etc and user defined features to any face or faces of a model. The designer, instead of performing a Boolean operation on the model to open a circular hole, "inserts" the "hole" with desired radius and length over the desired location of the model. This is a user friendly task for the designer also resembling the traditional model making methods.

The term "feature" is used to denote modeling a wide variety of physical characteristics of parts. Therefore it is useful to distinguish various types of features by using a sub-classification of features such as From Features, Tolerance Features, Assembly Features, Functional Features and Material Features. Form, tolerance and assembly features are all closely related to the geometry of parts, and are hence called *geometric features*.

Feature based systems offer a dramatically increased performance over traditional solid modeling systems due to the intelligence imparted by features. A necessity in any feature based solid modeling system is a user defined feature, which allows the designer to define the geometric and topological characteristics of a feature and apply them to existing solids. Many parametric solid modeling systems also provide some features including constant offset pockets, circular and rectangular array of holes, free slots (straight or two-point slots, three-point T and L slots, four-point U slots, circular slots, slots parallel to a boundary), necks or protrusions and flanges.
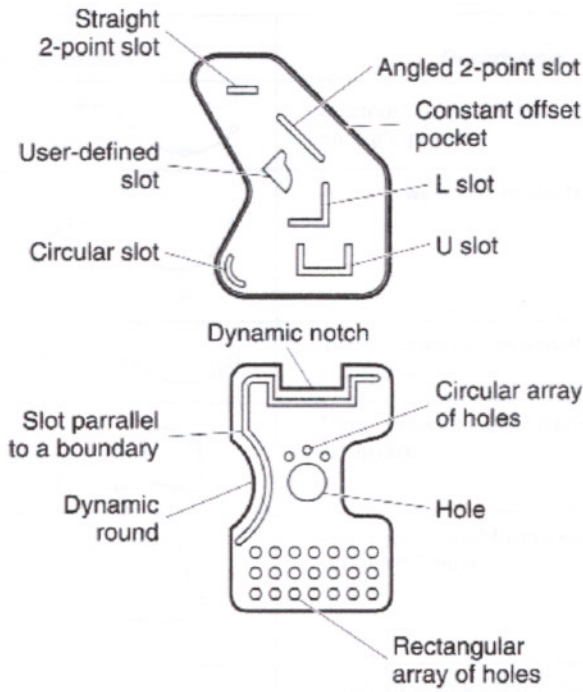
figure 2.23: Example of common "hardcoded" features. (LaCourse D. E., 1995, p.8.11)

Feature modeling provides many advantages such as the possibility of inserting "intelligent" parametric geometry into a model without creating intermediate construction geometry. Also, a variety of information about portions of a model can be associated and features with unique attributes to specific requirements can be created. Moreover, time consuming Boolean operations are eliminated and embedded feature characteristics are conveyed more intelligently to manufacturing applications such as numerical control: simply holes are holes, pockets are pockets, etc. instead of raw surface geometry.

2.1.4.4.6 Modeling Strategies

The tables include the most common modeling strategies provided by a modeling software. These are used priorly in solid modeling, but the same techniques are also appropriate for surface modelers.
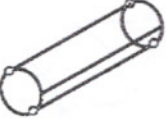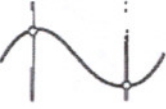
Curve techniques		Description	SM-related concerns
Through points		A curve that passes through multiple points	(1) (3) (9)
Control points		A curve weighted by control points	(1) (3) (9)
Concatenate		Two or more curves joined end to end	(1) (2) (3) (9)
Project		Curve projected onto a plane or surface	(3) (4) (9)
Edge		Curve generated from existing surface boundary	(1) (5) (9)
Surface intersect		Curve of intersection between two planes or surfaces	(3) (4) (5) (9)
Silhouette		Curve generated from the silhouette of existing surface	(6) (9)
Through tangent		Curve whose endpoints are tangent to given vectors	(1) (3) (7) (9)
Offset		Curve offset from existing curve	(1) (7) (8) (9)
Blend		Curve blend from two existing curves	(2) (3) (7) (9)
Isoline		Curve generated from isoline of existing surface	(3) (4) (5) (9)
Segment		Curve generated from existing curve segment	(1) (3) (9)

table 2.1: Curve generation techniques (LaCourse D. E., 1995, p:5.6)
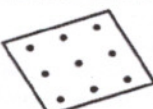
Surface techniques		Description	SM-related concerns
Sweep		Sweep a curve along a specified trajectory	(1) (2) (3) (4)
Revolve		Rotate a curve about a specified axis	(1) (2)
Rule		Rule a surface between two curves	(1) (2) (3) (4)
Offset		Offset a surface by a specified distance	(1) (2) (4)
Grid		Surface through a regular grid	(2) (4) (5)
Extrude		Extrude a curve along a linear trajectory	(2) (3) (4)
Loft		Loft a surface between dissimilar curves	(2) (5)
Mesh		Mesh a surface through control curves	(2) (4) (5)
Patch		Patch a surface between boundaries	(2) (3) (4) (5)
Control points		Surface through regular or irregular control points	(2) (4) (5)
Rolling ball		A constant or variable fillet between two dissimilar surfaces	(2) (4) (6)
Corner		A tangent corner patch between three surfaces	(2) (4) (7)

table 2.2: Surface generation techniques (LaCourse D. E., 1995, p:5.9)

83
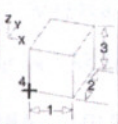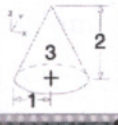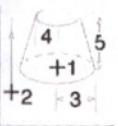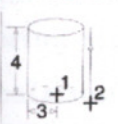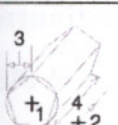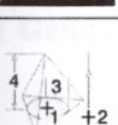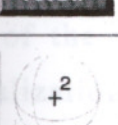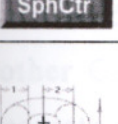
Primitive	Description	Typical input required
BoxPln	**Box** A box is a right rectangular hexahedron. That is, it has six rectangular faces.	**Box** Length, width, height, and location. The center point and orthogonal edge vectors as well as two diagonally opposite corners are specified with some systems.
ConePln	**Cone** A cone has a base circle, a curved exterior surface tapering to a point, and an axis of revolution normal to the base circle. All lines on the curved exterior surface between the base circumference and the apex are linear.	**Cone** Base radius, height or length, and the base center point as a location.
FrusDir	**Frustrum** A frustum is typically defined as the portion of a cone that lies between two parallel intersecting planes.	**Frustrum** Bottom center point for location, an axial direction, bottom radius, top radius, and length.
CylDir	**Cylinder** Cylinders are defined by a constant diameter bounded on each end by right-angular, parallel circles of equal radius. The axis is normal to the ends.	**Cylinder** Direction, base point or location, radius, length.
PrsmIns	**Prism** A prism is similar to a right rectangular box, except that it has more faces.	**Prism** Base point or location, directional vector, the radius of the defining circle, and length. Prisms may be inscribed or circumscribed about the defining circle. Some systems also allow the number of equilateral edges or facets on its base to be specified.
TetCir	**Tetrahedron** A tetrahedron has an equilateral triangular base and three triangular sides.	**Tetrahedron** Base point or location, directional vector, the radius of a defining circle, and length or height. The base may be inscribed or circumscribed about the defining circle. A variation is known as a *pyramid*, defined by four sides and a rectangular base.
SphCtr	**Sphere** A sphere is the volume generated by a semicircle revolved about an axis passing through its end points.	**Sphere** Spherical radius and the center or polar point.
TorDir	**Torus** A torus is generated by revolving a circle about an axis in the plane of the circle. The axis must not pass through the center of the circle, and must lie outside the circle in most SM systems.	**Torus** Radius of the circle, the radius from the center of the circle to the axis of revolution, and the direction of the axis must be defined. A hollow tube is created when two concentric circles of differing radii are revolved.

table 2.3: Sample group of primitives (LaCourse D. E., 1995, p:6.2)

2.2 THREE-DIMENSIONAL VISUALIZATION

Visualization is a very important stage of the whole design process. Whether sketching the first idea or rendering the final product, it has immense impact on people according to the quality of visualization.

Computers are far best known for their imaging capabilities. They have introduced a new tool for designers enabling them to create a virtual object, perfectly simulating real-world conditions. This virtual object does exist in the computer with three dimensions, and with a range of genuine practical and manual skills; the objects acts as if it is real.

There are some different types and stages of visualization, each requiring similar or unique tasks. Still images, animations or multimedia presentations are basic forms of visualization for the designer. In fact, computer aided visualization has opened a wide range of new career opportunities for designers including interactive media design, interface design, web page design, game design or computer animation.

2.2.1 General Concepts

3D visualization mainly includes three important tasks; modeling, texturing and lighting. Modeling is not just a visualization task, it is also one of the most important facts of CAD and CAM processes. But in visualization, different modeling techniques than those for CAD/CAM can be used as well, such as *metaballs* or *patches*. The texturing process includes widely 2D raster image editing tasks, which are not found in any other CAD/CAM processes. And finally, the lighting, is the easiest to associate with real-world experimentations, but also one of the hardest to achieve correctly, including all visualization tasks.

2.2.1.1 Modeling

3D modeling is the essential part of product visualization. The techniques used are generally similar to those of wireframe modeling, surface modeling or solid modeling, but since the final output is a screen presentation or paper print, some different modeling approaches can be used as well.

In product visualization, if no rapid prototyping or NC machining is required, low detail models can be suitable for many different purposes. These low detail models can be further edited with textures, lights and scene composition for a realistic image. High detail models are also used in visualization, if some detail renderings are aimed.

Visualization packages are generally based on surface modeling with polygonal and NURBS capabilities. The modeling process can be considered as similar to the high-end modelers in many ways. But some additional modeling strategies are existing in visualization programs. These can be integrated within the package or can be added externally to the software in the form of a "plug-in".

Metaball and patch modeling are some techniques widely used for visualization purposes. Metaballs are suitable for modeling organic shapes and their animation. This technique is based on meta-primitives, generally spheres. The modeling is done according to these primitives and their relative positions in 3D space. These primitives act like mercury; if two primitives are close enough, they begin to push or pull each other. The tension, interaction distance and the direction of the force can be different for each primitive. Many different primitives can be used in a model, which helps to create some very complex geometry. Also these complex shapes can be animated as well with the relative change of position of primitives, but this can be a time consuming process, because of the necessary final output geometry calculations of the model, for each frame of animation.
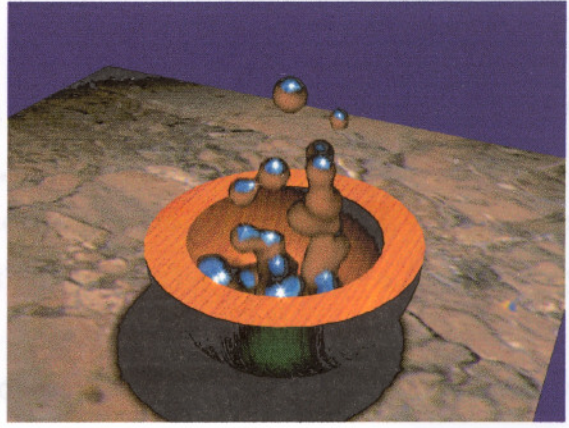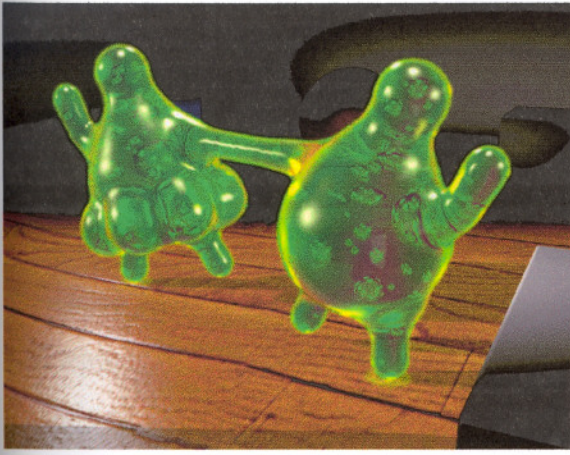
figure 2.24: Metaballs are used widely for organic modeling and animations

Patch modeling is another modeling strategy based on patch surfaces. With the deformation of 2D patches and connecting some different ones together, very complex models can be generated. Patch modeling requires a high experience of modeling and can take too much time for a complex shape. But the ease of adding detail where needed is a very important advantage of patch modeling.
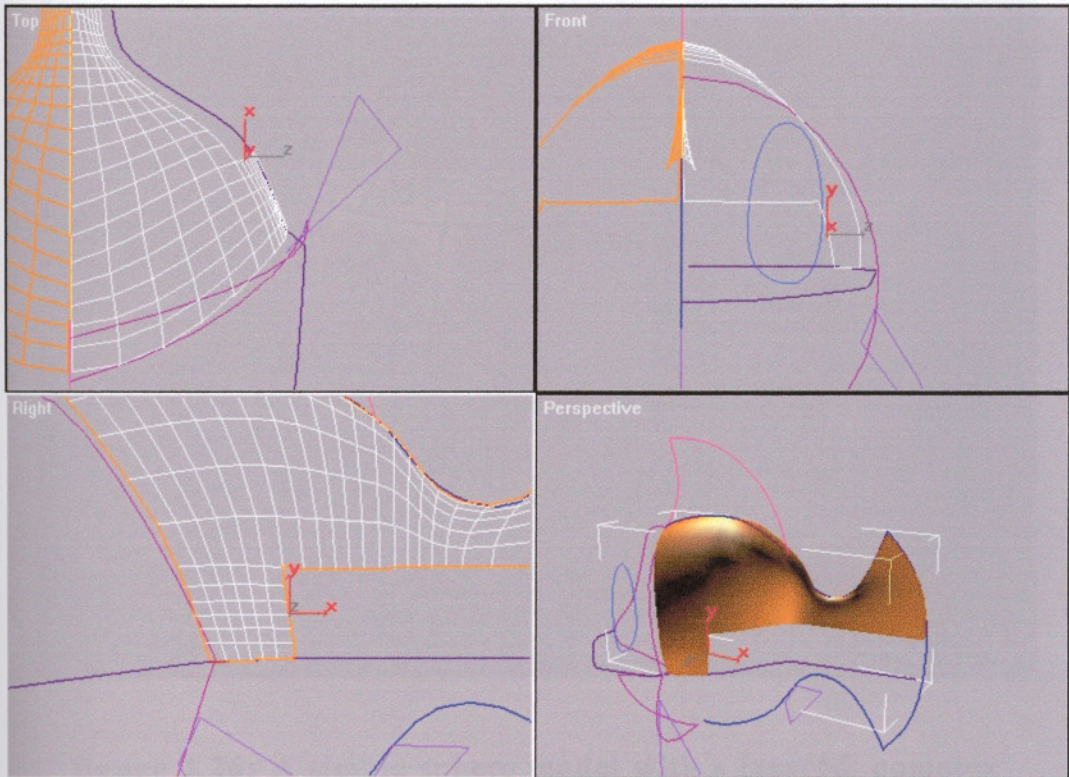
figure 2.25: Patch modeling is another technique used for complex surfaces.

2.2.1.2 Texturing

Texturing is one of the most critical elements of visualization. A 3D model, whether detailed or not, has no materials unless a texture is added by the modeler. A surface can be shiny, dull, reflective, transparent, translucent or any other property imaginable. It is very important that the model has just the right surface properties. A glass object is very different from a wooden one in terms of transparency, color, surface texture, reflection or refraction. Thus a designer must have a keen eye to create the right material for his design.

A well-designed texture can incredibly increase the quality of renderings. Many times, low detail models with a good texture can be enough for presentations. This is especially true for interactive real-time applications, such as computer games, virtual reality or multimedia applications. In fact, the most basic rule for 3D modeling is "never put any detail on a model if you can get it with the texture".
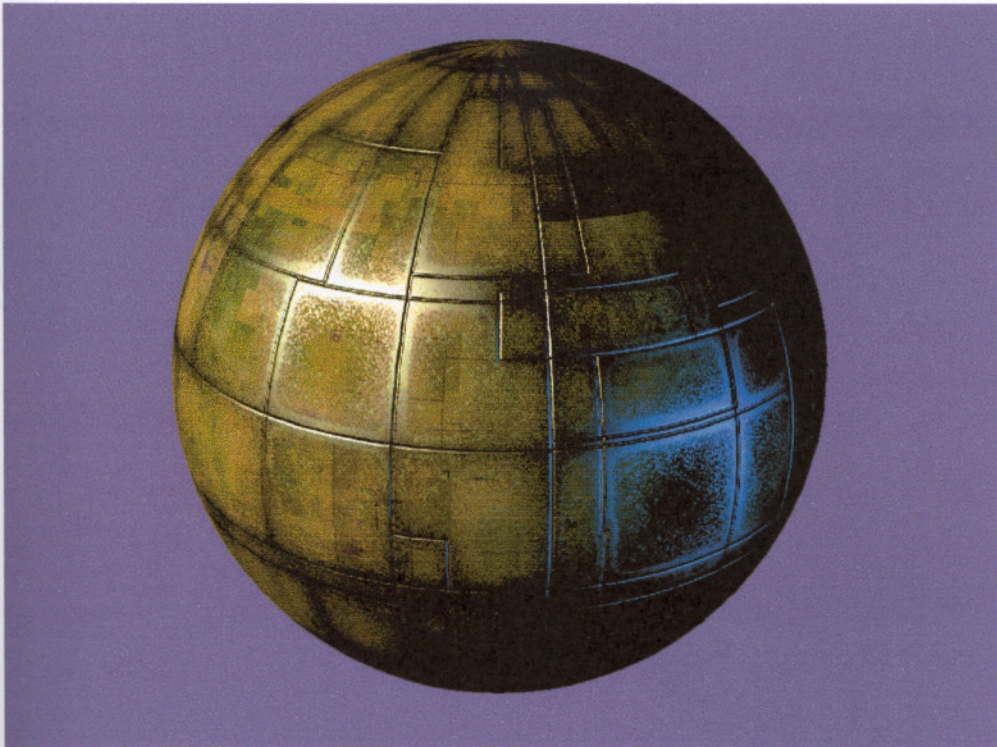
figure 2.26: A simple sphere model with a layered, complex material to obtain a high-tech object. (Bell J. A., 1998)

The textures are created with shaders within the software. Shaders, are essentially mathematical algorithms that, through various parameters, can make surfaces on geometry appear as water, wood, glass, plastic, metal or even fur. The user will adjust many different settings to get the right material. Depending on the software, the interaction in the user interface could be visual or strictly through numbers. For example, the reflection rate of a metal surface can be adjusted with a slider to get the appropriate result, but a definite value can be entered for refraction indices of water, glass or diamond.

In a typical rendering software, there are three basic shading modes. These are one of the most dominant properties of the whole material tree. When rendering polygonal models (or even NURBS models, because while rendering they are converted to polygonal models automatically), the flat surfaces sharing the same smoothing group, renders as smooth. This saves great time; for obtaining a smooth surface, very high numbers of faces are not required every time.
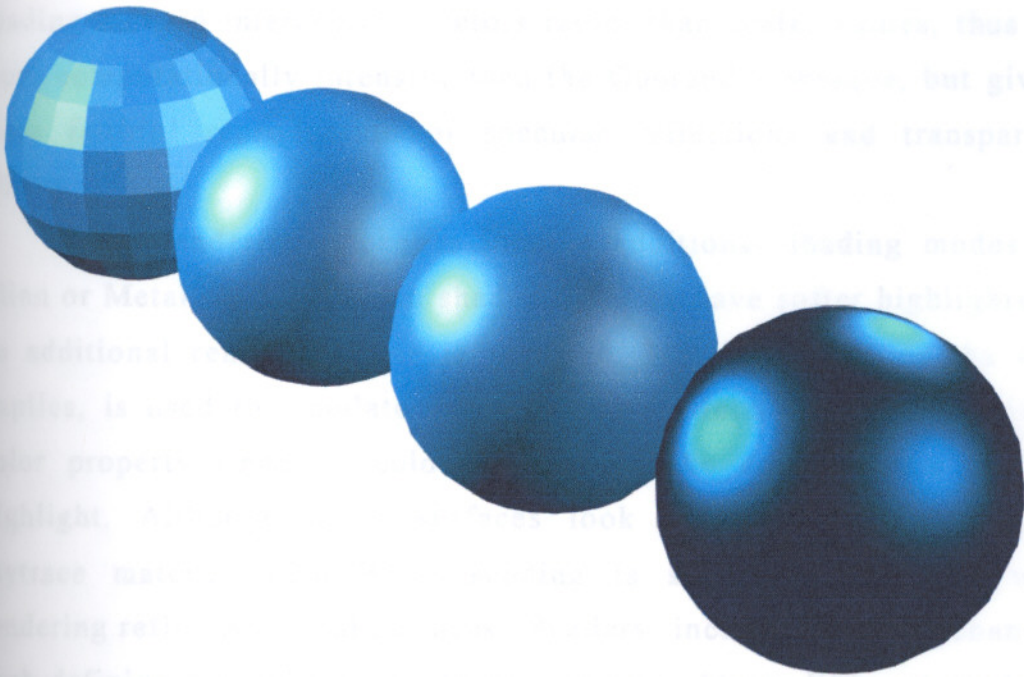
figure 2.27: Effects of different shadings (Flat, Gouraud, Phong and metal shadings respectively.)

Flat shading mode is an exception to this rule however. While rendering objects with flat shaded material, any smoothing group is disregarded and every single coplanar surface (or facet) is rendered with the same constant color. This is not suitable for realistic renderings, but sometimes it's used in games, flat art works or some special conditions.

Phong and Gouraud shading modes are the other basic methods for interpolating the shading of adjacent polygons across each polygon, yielding smooth appearing renderings. This smoothness is generally deceptive because the shaded image is no more precise than the underlying polygonal surface. Nevertheless, it is much more visually attractive than flat shading, and often serves the purposes at hand. Gouraud shading (developed by Henri Gouraud in 1971) computes the average of surface normals at polygon vertex points and uses these to determine vertex intensities, which are then linearly interpolated across the polygon. Phong shading (developed by Bui-Tuong Phong in 1975) interpolates surface normal vectors across polygons and uses these interpolated vectors in shading models at each pixel in the image. Phong shading method interpolates vectors rather than scalar values; thus it is more computationally intensive than the Gouraud technique, but gives a more faithful reproduction of specular reflections and transparency effects.

Some rendering packages include additional shading modes like Blinn or Metal shading. Blinn shaded surfaces have softer highlights and no additional rendering time is required. Metal shading, as the name implies, is used to simulate metal surfaces. Metal shader uses diffuse color property (map or color) to dictate the color of the specular highlight. Although metal surfaces look good with metal shading, raytrace material with Blinn shading is superior in quality while rendering reflective metal surfaces. Shaders include various channels, each defining a special property of a texture. Many different rendering software can have different channels, or maps for generating textures. But ambient, diffuse, specular, opacity, reflection, refraction and bump maps are included in virtually every package.
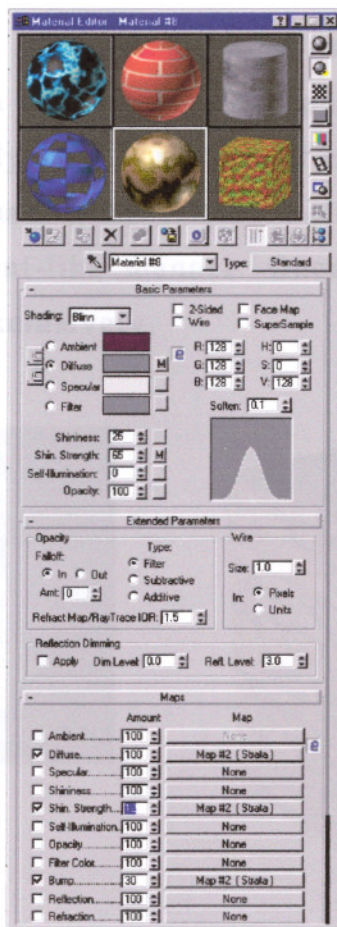
figure 2.28: The material editor of 3D Studio MAX. Different channels and several other parameters allow to generate complex materials.

Diffuse map has the most impact on the material's appearance and is the easiest to determine. The diffuse map is the color or texture, which is referred when describing a material in real life. It can be a solid color, a bitmap image, a procedural texture or a mixed one. The diffuse map, like ambient and specular maps, determines the object's material properties according to the lighting conditions. Specular map is apparent on some areas of surface, which is mostly affected by the light source; thus it is often described as specular highlight. The influence of the specular component on a material is directly related to the shininess of the material and the light source. Materials that have no shine cannot form a specular highlight. But if the material has shine and a highlight is formed on the related surface, the material's diffuse color mixes with the specular in an additive, or light-like manner.

Ambient map of a material describes the shades on a surface. Although it represents a material's shaded portion, it affects a great deal of a surface because only a small portion of an object is usually in direct light. As surfaces are shaded, the ambient color mixes with the diffuse in a subtractive or pigment-like manner. Once in complete shadow, the ambient color is used exclusively.
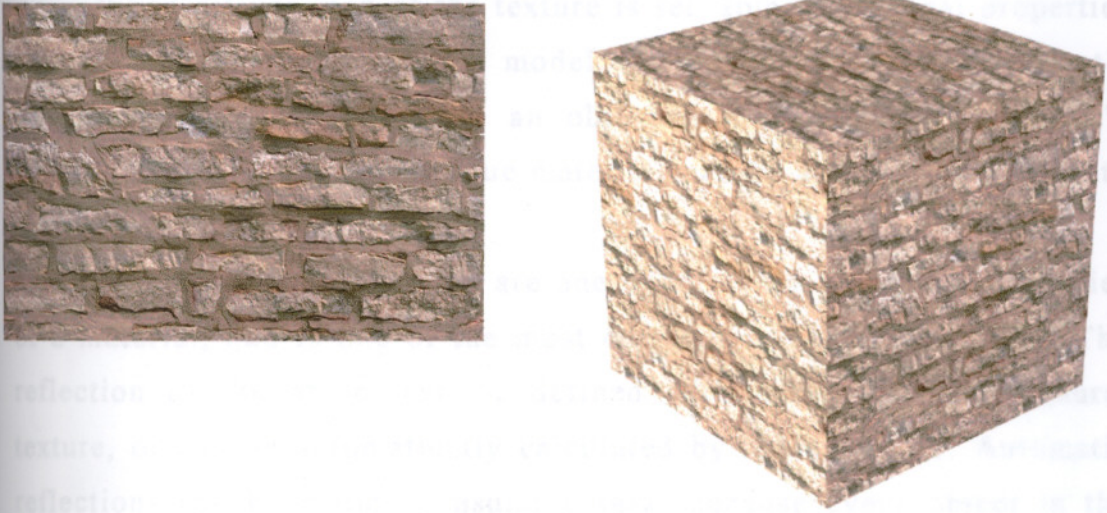
figure 2.29: The bitmap texture and the applied 3D model with proper mapping.

This three basic parameters (diffuse, specular and ambient properties), like the others, can be defined with a solid color, a bitmap or a procedural material. The solid color is adjusted in RGB, and then applied to the appropriate channel. A bitmap texture, which is a digitized photo, can be used as well to simulate real-world materials. For example, a brick wall picture can be scanned and then applied over a surface to mimic this wall. This is the most widely used technique in texturing. Any man-made or natural texture can be simulated with a bitmap and then applied to the model.

A different method for creating textures is defining procedural textures. In the digital imagery field, the term "procedural" has come to mean the automatic or computer generated way of producing images. Rather than being defined by bitmaps, procedural shaders work by

adjusting various numerical settings. Many different procedural shaders can be found in software, including noise, wood, water, marble, smoke or checker. Instead of using a straight bitmap as texture, a procedural shader can be effectively used for a higher control over the texture. For example, a marble procedural shader will enable some adjustments over the base color, vein color, vein size and width of the final marble texture.

When diffuse map of the texture is set, some additional properties can help to add realism to the model. Opacity may define the object's transparency value. The more an object is transparent, the less it's opacity value. Some semi-opaque materials can be achieved as well with the right opacity value.

Reflection and refraction are one of the other important properties of a material, and is one of the most complex to achieve properly. The reflection of the object can be defined with a bitmap or procedural texture, or can be automatically calculated by the computer. Automatic reflections can be a time consuming task, because every object in the scene must be handled in order to get the right result. The final image is generally much more realistic than the one prepared with bitmap reflections. Raytrace materials are used, if the reflection and refraction quality of the image is very important. Raytracing algorithms perform very complex calculations in order to get the most realistic reflections and refractions possible. But, because of the high processing time requirements, bitmap and procedural defined reflections can be a good choice for many cases.
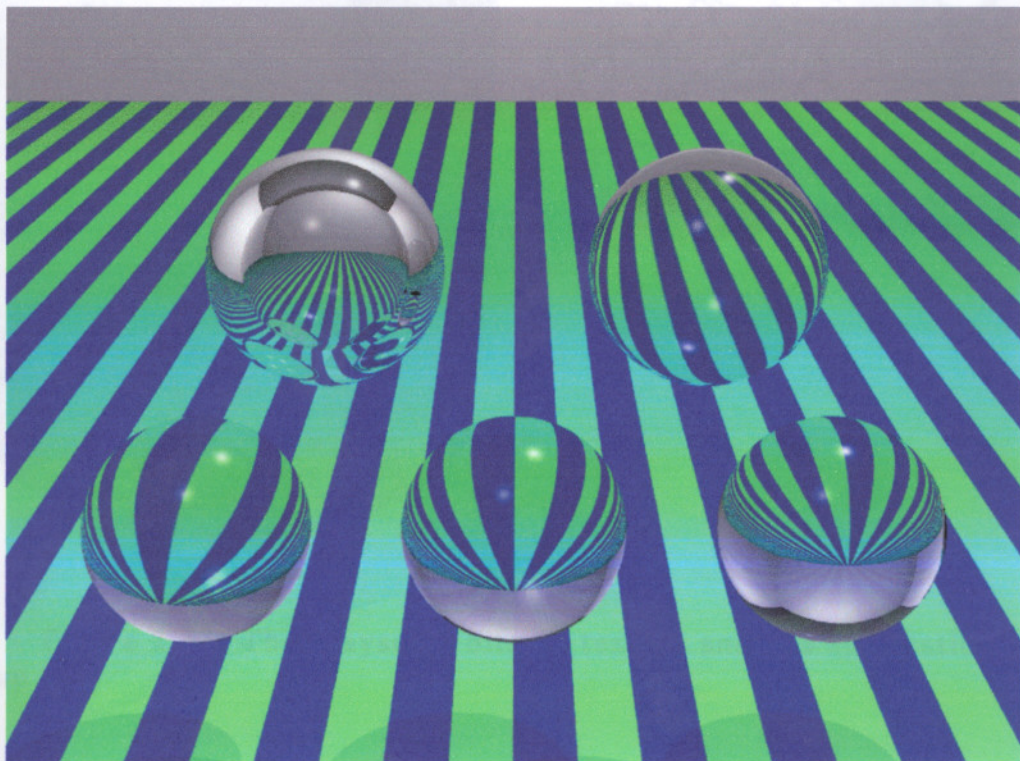
figure 2.30: Raytrace material applied to a set of spheres. Every sphere has different Index of Refraction (IOR). From left to right, top: underwater (IOR:0.7) and hot air (IOR: 0.98); bottom: water (IOR:1.33), glass (IOR: 1.5) and diamond (IOR: 2.42). (Bell J. A., 1998)

The bump map is used to define the small surface variations. For example, a tile over the wall, small noise bumps over a plastic material or small cavities over a surface can be achieved with bump maps. The applied bump map has no effect over the model's geometry, but with the help of light sources, it creates the illusion of limited surface relief on an object.
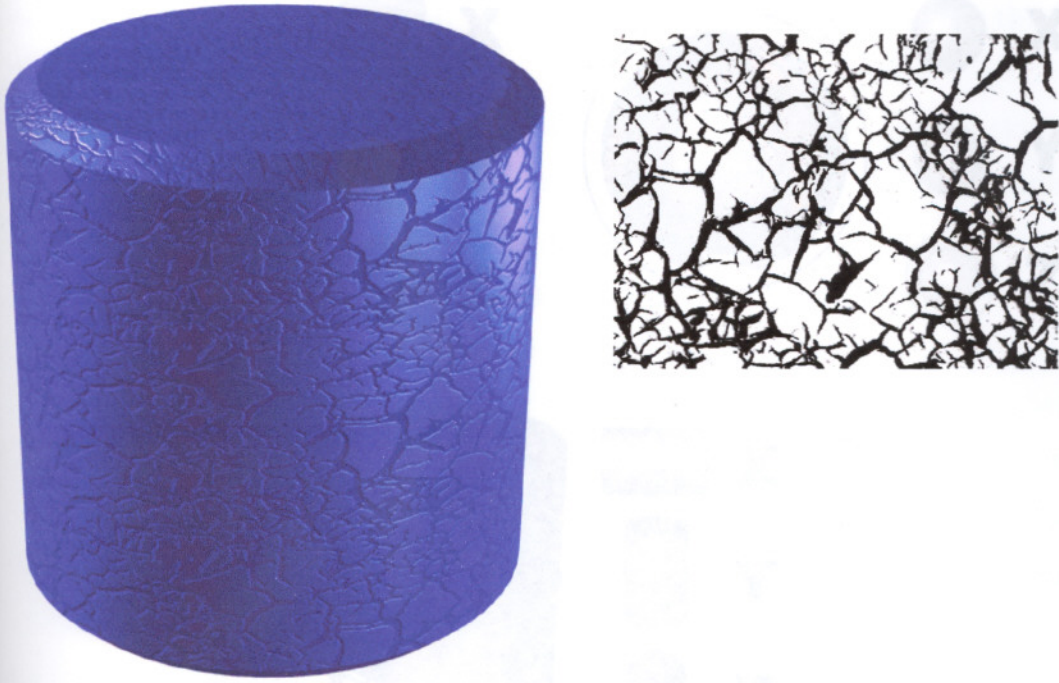
figure 2.31: The grayscale bitmap texture and it's application as a bump map.

The final placement of all mapped materials is dependent on the mapping coordinates assigned to a surface. Mapping coordinates can be assigned in a number of ways, through numerous projections, with the optimal choice depending on the object's geometry and desired surface effect. If a material includes a channel with a bitmap image, this material is placed properly over the model via the mapping. This procedure of assigning mapping coordinates, is the final stage of surface texturing.

Every model has to be mapped individually in order to get the right mapping coordinates. Sometimes, complex models are splitted into different parts for a correct texturing. The mapping procedure generally consists of three basic mapping types, which are planar, spherical and cylindrical. Although many 3D models are much more complex than these basic shapes, they work fine mostly. Some materials are also designed for a defined mapping type, which also helps in the mapping procedure.
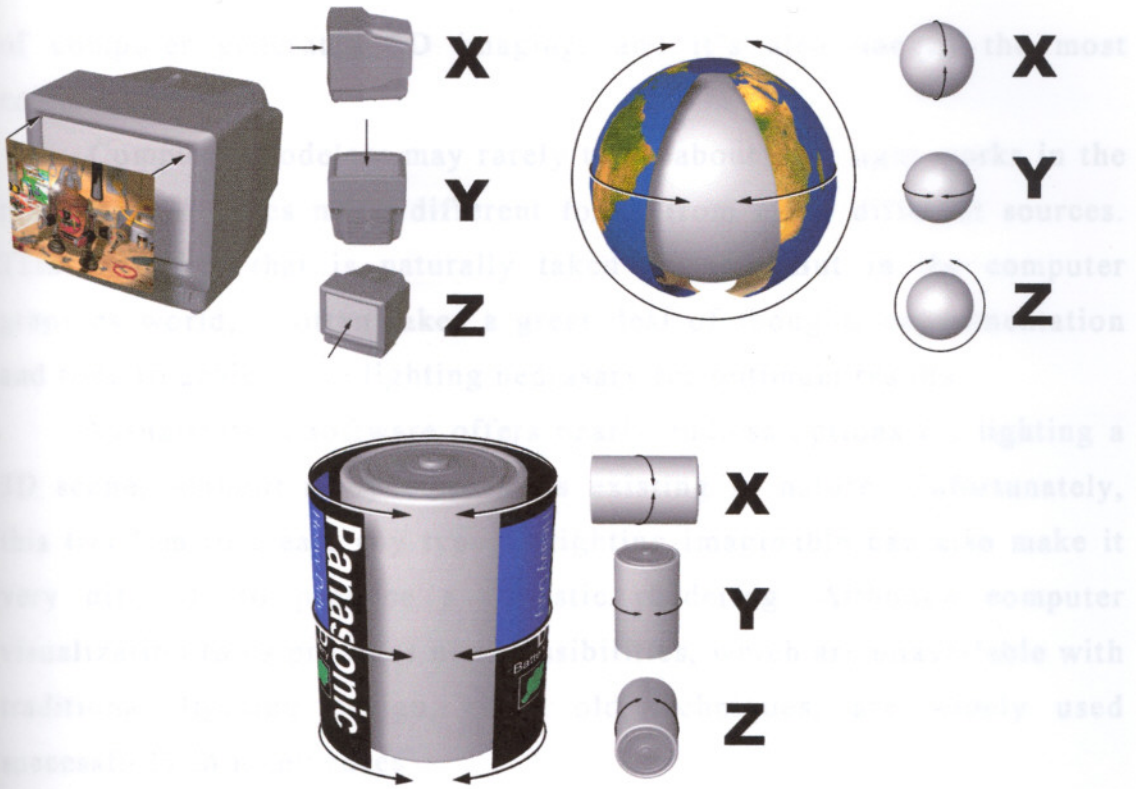
figure 2.32: Planar, spherical and cylindrical mapping techniques. (Fleming B., 1998, p.141)

In visualization, a model can be considered as finished if the material properties are defined also. Like modeling, designing appropriate materials can be a very time consuming task and can require a very good knowledge of different graphic software and hardware. Material databases are used commonly in renderings, which are prepared beforehand for later uses. This is a great time-saver in the modeling and rendering stages also, because it eliminates the need to create a brand new material while previewing the model and preparing the final renders.

2.2.1.3 Lighting

Lighting is the last step of the four basic visualization procedures, which includes modeling, texturing, animation and lighting. Although many designers disregard this fact, it's one of the most critical aspects

of computer generated 3D imaging, and it's also one of the most complicated.

Computer modelers may rarely think about how light works in the real world. It tales many different forms from many different sources. This is a fact that is naturally taken granted. But in the computer graphics world, it often takes a great deal of thought, experimentation and time to achieve the lighting necessary for optimum results.

Visualization software offers nearly endless options for lighting a 3D scene, without many constraints existing in nature. Unfortunately, this freedom to create any type of lighting imaginable can also make it very difficult to produce a realistic rendering. Although computer visualization tools provides new possibilities, which are unavailable with traditional lighting design, these old techniques, are widely used successfully in many cases.

In computer visualization, many additional programs are commercially available for enhancing and even automating the modeling, texturing and animation processes. But this is not the case for lighting which often leads incredible complications in getting a high quality final rendering. Regardless to the model or scene complexity, every light should be manually placed in order to express the idea in a best way possible.

In lighting, the environment which contains the object to be visualized is considered first. Then, according to the mood desired, the lighting elements are placed. There are three basic categories in lighting task including natural lighting, artificial lighting and the combination of the two.

Natural lighting typically refers to the sun, whether the scene is outdoors or indoors. Indoor lighting generally requires additional light sources to get a natural result, unless a special technique called *radiosity* is used. This can be also the case for outdoor scenes, even in common photographic lighting techniques. Many times, even in brightly lit outdoor shots for films, the cameraman and lighting technicians may use reflectors or supplemental lights. This technique can be simulated also in

computer visualization, which is the combined use of natural and artificial lights.

Actual Light Colors and their 3D Equivalent
Light numeric values expressed in Kelvins (light temperature)

ACTUAL	LIGHT SOURCE	3D LIGHT
1500	CANDLE FLAME	1500
1600	INCANDESCENT HOUSE LAMPS	1600
1700	INCANDESCENT HOUSE LAMPS	1700
1800	INCANDESCENT HOUSE LAMPS	1800
1900	INCANDESCENT HOUSE LAMPS	1900
2000	INCANDESCENT HOUSE LAMPS	2000
2100	INCANDESCENT HOUSE LAMPS	2100
2200	INCANDESCENT HOUSE LAMPS	2200
2300	INCANDESCENT HOUSE LAMPS	2300
2400	INCANDESCENT HOUSE LAMPS 1500-3000	2400
2500	60-WATT, GAS FILLED, TUNGSTEN-FILAMENT LAMP	2500
2700	100-WATT, TUNGSTEN-FILAMENT LAMP	2700
2900	500-WATT, TUNGSTEN-FILAMENT LAMP	2900
3000	1000-WATT, TUNGSTEN-FILAMENT LAMP	3000
3100	500-WATT PROJECTION LAMP	3100
3200	FLOODLAMP	3200
3300	WHITE, NO.1, NO.2, OR NO.4 FLOODLAMP	3300
3400	REFLECTOR FLOODS	3400
3500	WARM, WHITE FLUORESCENT LAMP	3500
3700	SHREDED-FOIL, CLEAR FLASHLAMP	3700
3900	HIGH-INTENSITY SUN ARC	3900
4000		4000
4100	DIRECT SUNLIGHT BETWEEN 10 AM-3PM (AVERAGE)	4100
4300		4300
4500	COOL, WHITE FLUORESCENT LAMP	4500
4700	DAYLIGHT (BLUE) FLOODLAMP	4700
4900	WHITE-FLAME CARBON ARC	4900
5100	M2B FLASHLAMP	5100
5300		5300
5500	HIGH NOON SUNLIGHT	5500
5700	DIRECT SUNLIGHT IN SUMMER	5700
5900	BLUE FLASHLAMP	5900
6000	DAYLIGHT FLUORESCENT LAMP	6000
6300	SUNLIGHT WITH CLEAR SKY AT NOON	6300
6700	LIGHT FROM OVERCAST SKY 6800-7000	6700
7300	HIGH-SPEED ELECTRONIC FLASHTUBES	7300
7700	LIGHT FROM HAZY SKY 7500-8400	7700
8100		8100
8500		8500
8900		8900
9300		9300
9700		9700
10000	LIGHT FROM CLEAR BLUE SKY	10000
11000	LIGHT FROM CLEAR BLUE SKY	11000
12000	LIGHT FROM CLEAR BLUE SKY	12000
13000	LIGHT FROM CLEAR BLUE SKY	13000
14000	LIGHT FROM CLEAR BLUE SKY	14000
15000	LIGHT FROM CLEAR BLUE SKY	15000
16000	LIGHT FROM CLEAR BLUE SKY	16000
17000	LIGHT FROM CLEAR BLUE SKY	17000
18000	LIGHT FROM CLEAR BLUE SKY	18000
19000	LIGHT FROM CLEAR BLUE SKY	19000
20000	CLEAR BLUE SKY OVER WATER 20000-27000	20000

table 2.4: The light color chart and its equivalent 3D lighting. To simulate real-world lights in computer scenes, the appropriate colors should be used. (Fleming B., 1998 p:291)

Artificial lighting is probably the most common of the three types for a designer. It can be consisted of electric light, firelight, or both. A typical studio light setup is a very good example, which is widely used in two basic illumination styles: *triangle* and *zone* lighting.

Triangle lighting (or three-point lighting), as the name implies, uses three lights to provide illumination. The primary light, called the *key* (or *kick*), is the brightest and illuminates most of the scene. The key

is usually the light that casts a shadow. A secondary *backlight* is used to separate an object from its background to reveal more depth. Backlight is generally behind and above the object with a lesser or equal intensity t the key. A third light, the *fill*, is used to fill dark areas missed by the key. The fill controls the contrast between the brightest area of the scene and the darkest. A bright fill creates even lighting whereas a dim fill increases the contrast and makes the scene more uneasy.
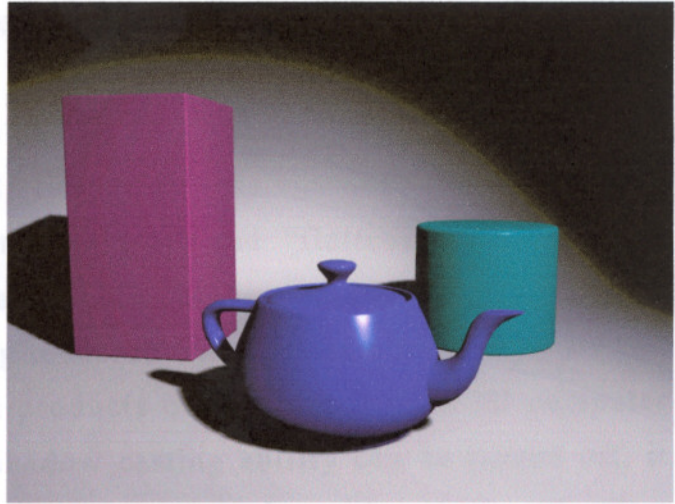
figure 2.33: A basic triangle lighting setup (Bell J. A., 1998 p.28)

When triangle lighting is inadequate for larger scenes, a slightly different method can be applied. *Zone lighting* is the second basic lighting strategy, which occurs when an area is broken down into zones. These zones are then illuminated individually. The selection of zones can be based on areas of importance or similarly, and after a zone is selected, basic three-point lighting can be applied. Sometimes, however, this does not create the proper mood so a free form lighting scheme is used. With careful use, accent lights can be effective to illuminate key objects or areas.

A typical visualization software includes four basic lights: *omni, directional, spot* and *ambient* lights. Omni lights, which are mostly used as fill and backlight, are point light sources very similar to a naked bulb hanging on a wire, or a star in a solar system. An omni light traces its illumination from its center to all object faces that are oriented toward it. A directional light is best thought of as being the sun. All the light

beams are parallel to each other which can be observed easily in the shadows appeared.

A spotlight is a combination of the two casting the light beams in the form of a cone, in one center to a primary destination. The shadows formed are thus a little or ver distorted, according to the distance of the light source and the object. Spot light and directional lights are primarily used in key lighting, but they can serve many other purposes as well. The final basic light type is the ambient light that is not a physical object in a scene unlike the others. The ambient light is universally applied to all objects, which means that the relative positions of the objects in three-dimensional space are disregarded. Increasing the ambient light level reduces the contrast and "flattens" the image. A scene illuminated solely by ambient light has no contrast or shading, with every side and facet being rendered with the same intensity.

Shadows are the natural products of light, so it is in 3D computer graphics. Although a light's shadow casting ability can be turned off, it is used to increase the realism of the scene and to enhance the 3D effect of the final rendering. 3D visualization software offers many options to control a light's shadow casting ability. In many cases, this can be very confusing because of the uncommon way that virtual lights work. A light in a visualization program can have any color possible, can project any image or animation as light source and can have any intensity, including negative intensities. When all these controls combine with the shadow's softness, bias and resolution adjustments, shadows can require immense effort to set them properly.

There are three basic rendering engines closely integrated with lights and their shadow casting characteristics. Although different visualization software can include different engines, these three techniques are widely used in many mid-range or high-end programs.

Scanline rendering is the default option for programs like 3D Studio MAX. This engine is built in the program and uses shadow maps in shadow casting task. Scanline rendering engine prepares the entire scene prior to the actual rendering process. It calculates all light sources, their shadows, and reflective surfaces, as well as texturing. The

preparing of the rendering can take from less than a second to several minutes depending on the complexity of the scene, but the rendering process itself is very quick. During the rendering process, the scanline renderer works its way down an image line-by-line.
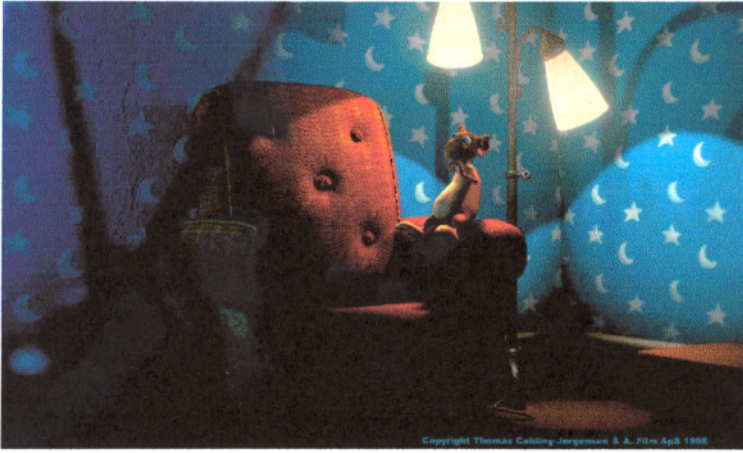
figure 2.34: A shadow mapped render.

Shadow mapping capability of the scanline renderer is one of the most important of its properties. The main purpose of a shadow map is to create soft shadows. This is a more realistic effect than raytraced shadows but it can be difficult to achieve because its control consists of a critical balance of its map parameters. Casting shadows requires memory but renders much faster than raytraced shadows, especially a complex scene. The trade-off, however, is that shadows maps take preparation time and constant testing to ensure their accuracy and appropriateness. Also, the transparency of the object, if there's any, is disregarded while calculating shadows, which makes it an unsuitable choice in objects with transparency effects.

Raytracing is the second important rendering technique. It can be found in every visualization package as a built-in rendering engine, as a plug-in or both. Raytracing engine works a bit different from scanline; depending on the implementation, there is usually some up front processing by the raytracer prior to the rendering process. But the main difference is that some items like reflections and refractions are calculated when the renderer reaches the pixel containing a reflection or

refraction. In raytracing, the path of a ray of light from the source to the viewer's eye position is traced for each pixel of a display. The full path of the ray is computed, yielding secondary and tertiary reflective effects. This technique takes into account the transparency, reflectivity and refractivity of the objects, thus resulting highly realistic images. But it consumes enormous quantities of computational resources. If a complex scene is lit completely with raytraced lights, rendering process can take incredible amounts of time.

Many visualization packages include a hybrid raytracer, or selective raytracing capability. Because of the immense calculations needed to resolve, raytracing only some necessary part of the scene will be enough in many cases. This can be achieved with the applied raytrace material yielding the same high realistic transparency, reflection and refraction effects for the desired objects only.

figure 2.35: A raytracer is especially capable of generating refraction/reflection effects and realistic shadows of the transparent objects.

The third and the most complex rendering engine is radiosity. It has a different approach than a standard renderer or raytracer: a radiosity solution provides diffuse light interaction in an environment.

Technically, it is based on the radiant heat transfer in which the light emission from each surface in a scene is computed in terms of all of the other surfaces and sources of light. Radiosity calculates physically the various bounces that light makes as it travel from the light source until all of the energy is absorbed in the environment. This type of rendering typically takes too much time but it easily re-creates the most difficult aspect of lighting, which is extreme realism.

An important benefit of this physically based rendering engine is that real-world luminaire light types can be specified in a scene. Any lighting simulation can be accurately done with radiosity rendering. And once the radiosity solution is computed in a scene (which is a very long process taking between several hours to some days), any rendering is easily done including animations done with camera transformations. This is because of the nature of radiosity; the computed solution depends on the light sources and the objects, not on the viewer's position. Radiosity rendering is also finding it's way into films because it can more accurately match lighting setups on location.

figure 2.36: A radiosity render with a superior photorealistic quality.

Radiosity renderers are generally available in a form of a plug-in or as a standalone radiosity software. Because radiosity is a very complex system that has a very specific use, much visualization software does not include this capability.

Lighting of a scene is also a good means in creating some special effects. Glows, volumetric lights or even lens flares can be achieved with the help of lights, to make the scene much more realistic.

Lighting of a 3D scene is a very complex matter, involving dozens of processes and components. According to the mood required, lighting design of a virtual model can depend on numbers of different solutions and tasks. But once done correctly, it enables a good model to be rendered in a highly realistic fashion.

2.2.2 Still Image Rendering

3D graphics is very different from other visual arts. The press of a button is enough to capture an image in the camera or drawing from rough outlines to a finished picture with a brush through continual refinement ends up with an artistic oil painting. But creating virtual images with a computer is an entirely different process: models are created like a wood worker, materials are applied allowing a simple sphere to become a glass ball or a planet in a solar system, the model is then animated through time and then lit. The final process involves a transformation of these facts into a final image, called rendering.

The rendering process is often seems simple enough, but it isn't as simple as clicking "Render" button and hoping for the best. There are many essential elements in rendering including the type of output, it's size and it's uses. Rendering is the creation process of the only concrete product in visualization whether a still image or animation.

Visualization packages offer a wide range of controls over the rendering of the final image. These can vary according to different software, but many of them include the same capabilities. As mentioned before, there can be different rendering engines like raytrace or

radiosity, but these are independent on the desired output media types. A scene can require a standard renderer or a radiosity renderer and the final image can be used in screen presentations or printouts. But the final image itself must have been specified according to the output media type.

The most important thing when rendering is to decide which output media type is aimed. Screen presentations or prints require different resolutions and color depths. These two also affect the nature of the final image, how clear, crisp or large it will be.

Color bit depth refers to the number of colors in a computer-generated image. As computers must convert any information into numeric sequences, they must number and store colors. Several common bit depths are used in computer imagery, including 8-bit adjustable palette, 15- and 16-bit fixed palette, 24- and 64-bit color depths.

8-bit images contain only 256 colors out of the entire color spectrum. The exact colors can differ between images as well because the palette is adjustable on an image by image basis. 256 colors are not enough for realistic renderings, but is quick to load, display and has small file size. The main uses of 8-bit palette are; multimedia projects, Web publishing, disk-based presentations, computer games of informational kiosks. 8-bit color is supported by many programs, and low-end VGA standard supporting 8-bit color at 640x480 resolution is still used on some systems.

15- and 16-bit fixed palette images contain 32,768 and 65,536 colors respectively. These color depths are less common than 8-bit and 24-bit, but are a good trade-off between large file size and color realism. It contains a fixed palette thus no confliction occurs in the colors used, which is useful in real-time applications such as computer games and multimedia applications.

24-bit color images are the most common true color image types with 16,7 million colors containing sufficient color to reproduce any image viewable to the naked eye. Still images or animations, whether rendered for film or video is almost always rendered in 24-bit color.

Interactive applications and real-time graphics however use 24-bit less often due to its larger storage size and slower display times.
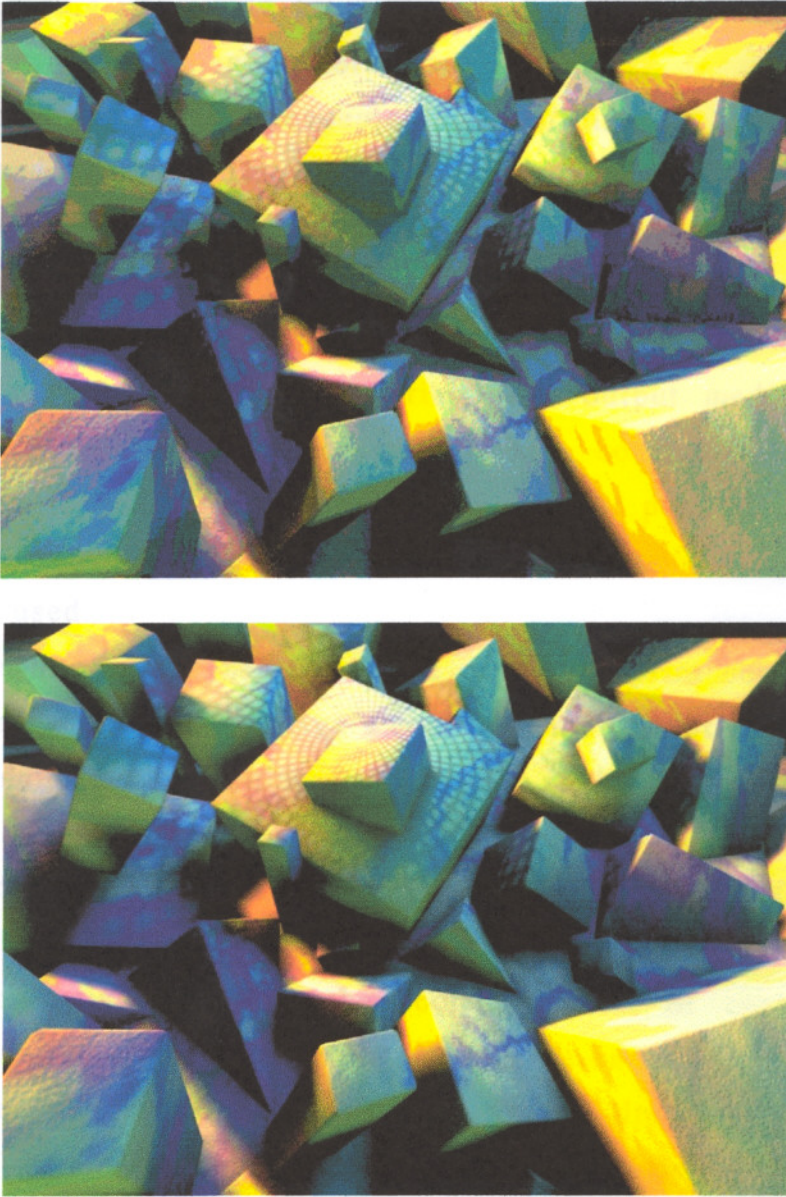
figure 2.37: The difference between 8-bit and 24-bit images.

64-bit images are pretty uncommon, but some visualization software renders images at 64-bit color depths and dithers down to lower color depths from there. 64-bit is not displayable on common computer screens; this color depth can be used in the anti-aliasing process of the

image. This color depth can also be saved into the RLA file format for later uses.

True color or 24-bit rendering is actually much easier than 8-bit color rendering. Reducing an image's color palette to 256 colors and obtaining a quality image is not an automated task. It takes forethought and a good knowledge on concepts like color distribution, banding, anti-aliasing and dithering. But 24-bit true color rendering always produces top-quality images enabling the designer to consume more time on models, materials and lights.

The media, size of the image and the resolution of the image should also be clear when rendering. The output media leads to a necessary resolution of the image. For computer screen based presentations, the optimum resolution is 72 dots per inch (dpi). But in printing processes, the resolution requirement varies according to the technique used.

Continuous tone prints are the easiest to print because the sole determining factor of the image's quality is the resolution supplied. The most common type of continuous tone print is the standard photographic print. Outputting a rendered image to photographic film involves using a film recorder to expose the image on conventional 35 mm film or 4"x5" large format film, including standard or transparency films. Dye sublimation printers are another common form of continuous tone printing available for computer images. These can be desktop or E-size production printers ranging from 100 to 400 dpi of resolution. The quality of the final continuos tone image is determined by the density of pixels Per printed inch, which is subjective and varying from one image to the next.

When outputting to a 35 mm film, the size of the prints should be considered rather than the size of the film. For high-end reproductions, lowest pixel to scanline ratio possible should be used. The standard resolution for photographic resolution is considered as 3072x2048 after the introduction of Kodak PhotoCD.

Screened print is another media type that can be used for high-quality prints. It is produced by dithering the original image to achieve

true color. "Screening" is essential for many processes because the printing inks would bleed and blend together in pools of mottled color. The screens place the color components (cyan, yellow, magenta and black) onto separate layers of the printed page. The pattern of the dispersed color dots is created by the screen.

Screened images are commonly used for mass production purposes, such as magazines, marketing brochures or advertisements. Screened images also are used with noncontinuous tone printers. The latter includes most varieties of laser, inkjet, electrostatic plotters, thermal vax, and thermal dye transfer printers. All of these devices require screening the image for printing (Elliott S., Miller P., 1996)

The shape, density and angle of screens used by commercial printers are considered proprietary information. Most printers prefer to work with 200 to 400 pixels per printed inch images. The print size has the biggest impact on the required resolution of the image. After selecting the media and determining the pixels per inch ration, the final image's resolution can be calculated easily:

(ppi) x (print width in inches) = Width resolution (dpi)
(ppi) x (print height in inches) = Height resolution (dpi)

Setting the proper resolution is a very important aspect of the rendering process, because with lower resolutions than necessary causes low quality images, whereas higher resolutions requires unnecessary disk spaces and processing times.

2.2.3 Animation

Still images can be sufficient in static subjects like graphic design. But industrial design is related to three-dimensional products, thus still pictures cannot fully convey the design. Many designers are tempted to use animations to make their presentation as realistic and communicative as possible.

Formerly, mock-ups were the primary means in representing a three dimensional product. Designers pays great amounts of money to commission a quality mock-up from a professional model maker and if they wish to avoid such expenses, the only choice is to make the model themselves. This generally causes some different troubles; besides the cost, they also had to allow a considerable amount of time for mock-up drawings, surface specifications and the coordination of cutting and painting jobs among several people.

Computers are extremely useful in such situations, like the presentations of a three dimensional product with it's full characteristics. Once the model is complete with its surface materials and environment, it is ready for animation.

Computer animation requires some different tasks than modeling, but because both processes are integrated within the same package in many visualization software, these tasks are pretty common to the modelers. Animation requires some fore planning, especially while modeling. Some models are difficult to animate in some ways but easier in others. If the animation is planned before the modeling process, many troubles can be eliminated in the animation of the virtual model.

Traditional animation is based on a technique called *keyframing*. Keyframing is what a master animator is doing when he draws the most important frames of an animated sequence, the keys. These works are then passed to an assistant animator to finish the frames between the keys, in other words to "fill in the blanks". Depending on the difficulty of the animation, the master animator might draw many closely spaced keys or maybe only a few of them.

Computer animation software works in much the same way. The user is considered as the master animator, which specifies exactly what he or she wants to happen and when it should happen, by creating animation keys at specific times. The software then acts as the assistant animator taking care of the animation that occurs in the time between the keys. This process is also called keyframing just as in the case of traditional animations.

Some visualization software supports also another type of animation called *parametric animation*. The animator doesn't need to set keys with parametric animation technique, because it is a preset animation effect. Specifying the start and stop times for the effect and setting its parameters are enough for parametric animation. A typical parametric animation effect is noise; when assigned to an object's position, it makes this object jump around randomly, or if assigned to an object's scale, it makes the object quiver like a gelatin struck with a spoon.

There are many different parametric animation effects within animation software and all these can be used with keyframe animation technique as well. For example, an object's position in 3D space can be animated with a keyframe, but its scale parameters can be animated simultaneously with a parametric animation effect, such as noise.

Transformation animations are among the easiest to achieve and can be applied to any model. Transforms include moving, rotating or scaling, the very basics of computer modeling and animation. Moving can be done freely or with a 2D or 3D spline which is assigned to the object as motion path. Lights, cameras, two dimensional shapes or particles can also be assigned to a path for animation. Cameras are generally animated with such a 3D spline assigned to it as a path, to view the targeted object from different angles.
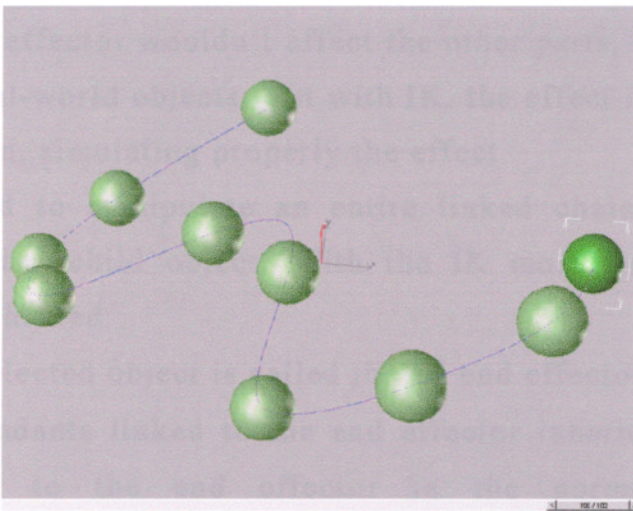
figure 2.38: A simple animation with a 3D spline as a path.

Transformation animation can be done with the coordinate system basis or user defined coordinate system basis, and the objects can move or rotate in the 3D space independently or relatively to each other. If different elements are forming one object, like a car with it's doors, or a robot arm with different parts moving and rotating relatively, it's a good idea to apply a hierarchical linking between them.

Hierarchical linking consists of *parent* and *child* objects, being parents at the top of the hierarchy. In the example of the car, the body is the parent with four child elements, the doors. When the body is animated through a path, the doors will follow their parent, but when the doors are opened and closed with the rotation around the hinge, the parent is not affected. This is the main rule of hierarchical linking, the parent affects the children but the children affect not the parent. This is called as *Forward Kinematics*, and it is useful in many situations, but it does not closely simulate jointed objects in the real world.

When real objects are linked together, moving one linked object affects all of the linked objects based on their positions and the characteristics of their connecting joints. This behavior can be simulated with *Inverse Kinematics* (IK). As in the case of the robot arm, the object on the hierarchy's top is the whole system's rotating base. It is followed by the first linear part with a certain joint attribute. Then this second is followed by the third and so on. In forward kinematics, moving or rotating the end effector wouldn't affect the other parts, which is not the case with the real-world objects. But with IK, the effect is spread in both ways of the chain, simulating properly the effect.

IK is used to manipulate an entire linked chain by moving or rotating a selected child object. With the IK mode active, following results can be achieved:

- The selected object is called the IK end effector
- Descendants linked to the end effector inherit the transforms applied to the end effector in the normal fashion for hierarchies.

- Ancestors of the end effector define a kinematic chain back to the root of the hierarchy or back to a special "terminator" object. Moving or rotating the end effector moves and rotates all of the ancestors in the kinematic chain based on their IK parameters.

IK is an invaluable tool for simulating mechanical objects with joints. It works great for almost any task, only a few situations are just beyond its capabilities. Different animation packages requires different IK strategies to apply, but any problem can be resolved manually along the IK chain.

In some special cases, simulation of the real world objects affecting each other with collisions and gravity, can be necessary. This effect can be animated manually, by defining all the keys necessary, but this won't help simulating realistically the case and the task will be a heavy burden in complex scenes. *Dynamics* utility can help to solve this problem automatically. By definition, dynamics is "the branch of mechanics in physics that deals with the motion of bodies and the action of forces in producing or changing their motion". This is exactly what dynamics will serve in an animation software. According to object's surface properties (mass, density, static and sliding friction, bounding coefficient) and it's motion and speed, dynamics calculate its interaction with other objects. Some real-world effects like gravity and wind can also be included in the final dynamics solution. Once the collisions and additional effects are calculated, the necessary animation keys are inserted automatically.
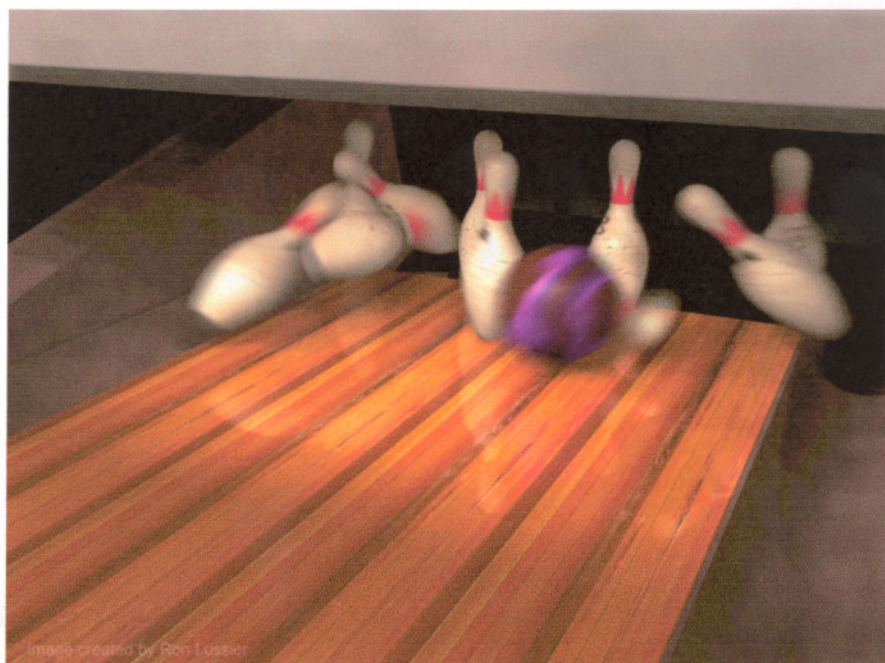
figure 2.39: Dynamics calculates automatically the collisions of objects according to their surface and mass properties.

Dynamics are usually used for rigid bodies, which is where the term "rigid body dynamics" is derived from. Soft objects (like air balloons) require a bit different system called "soft body dynamics". They both simulate realistically real-world collision, gravity and wind effects with minimum effort possible.

For some additional realistic effects in animations like the simulations of dust, smoke, rain, fire, explosions or even a group of bee flying around, *particle systems* are used. A particle system is a collection of particles that, when emitted can produce a variety of animated or still image effects. The number, size shape or color of the particles can be defined, and they also can be assigned to a spline as a path. With proper materials applied, they can simulate the rain or a waterfall, or when assigned with proper light effects and materials, they can create a very realistic smoke and explosion effects. Although they are of very little purpose in modeling, they assure a unique tool for creating such effects that increases the realism of a scene.

Neil Blevins '97
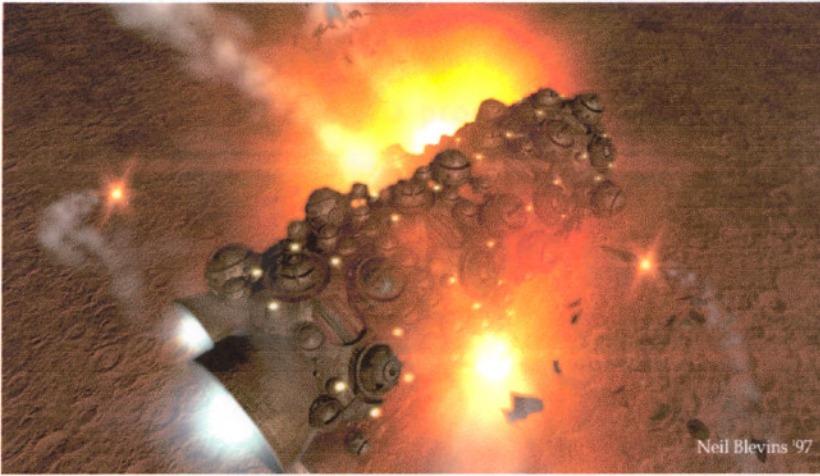
figure 2.40: Particles used for special effects such as fire and smoke.

Animations have many other tools to generate a realistic series of images, including motion blur, scene blur, bone systems, and morphing. Animations are gaining more importance in the final visualization o a product, enabling to communicate the idea in a better way. Although 3D software is the basic tool to generate an animation, some other tools can be required, according to the complexity of the animation. A basic complete toolset consists of an animation rendering software (Alias PowerAnimator, SoftImage, 3D Studio MAX, Maya or LightWave), Movie special effects software (After Effect, Video Fusion), Nonlinear editing software (Adobe Premiere, Avid Video Shop), Output equipment (Video Vision Studio, Media 100) and Video recording and playback equipment (Betacam, Laser Videodisc, S-VHS). This is a highly special and professional set of tools for many design offices. Many times a single powerful PC with some additional software will be enough to produce, record and play basic product visualization animation.

2.3 Supportive Applications

Apart from concepts like modeling, drafting or visualization, several other important notions exist in computer aided design processes,

114

such as CAM, databases and networks, as the most important ones. Although CAM is usually taken as a notion in it's own right, it can also be considered as a subset of CAD process. Database an networking are also important applications, which are very useful in both design and manufacturing processes.

2.3.1 Databases

The database is the part of a CAD system which the designer sees on the screen to create, modify and analyze a design. Databases are closely integrated with the CAD systems in terms of interactivity, communication and data conversion. A powerful CAD system can manipulate safely the design database and enable substantial reuse of the data, both in other designs and elsewhere in the design and manufacturing process.

"A database is rather an abstract term. In the broadest sense, it captures all relevant information about the company's products and all information needed to put a product into production. When a product is complex and composed of various sub-assemblies and component parts, each individual product element will have manufacturing and engineering information associated with it." (Simon R.L.)

CAD community considers databases as an ideal medium to integrate a variety of CAD packages around a common pool of data. This structure increases the consistency of the data, speeds up communication among the different design packages and avoids tedious and error-prone data conversion. The most important goal in CAD/CAM areas is to make the design and production process more efficient through an integrated use of computer. Integration means that all information concerning the product, is collected and processed in the computer by a certain subsystem at a certain time, to all other subsystems which may require it. The gradually computer generated model behaves as an information carrier through all the phases of the design process, integrating all phases in a common information flow. In integrated product creation

115

systems (CAD/CAM systems), the product model plays a major role in building-up the total model together with non- or semi-geometric information, such as design data, standard data, tolerances, material data, capability data, process data and so on. Such information constitutes all together the database of the product creation process , and every sub-system like design systems, stress calculations, process planning or operation planning, must be connected to it.
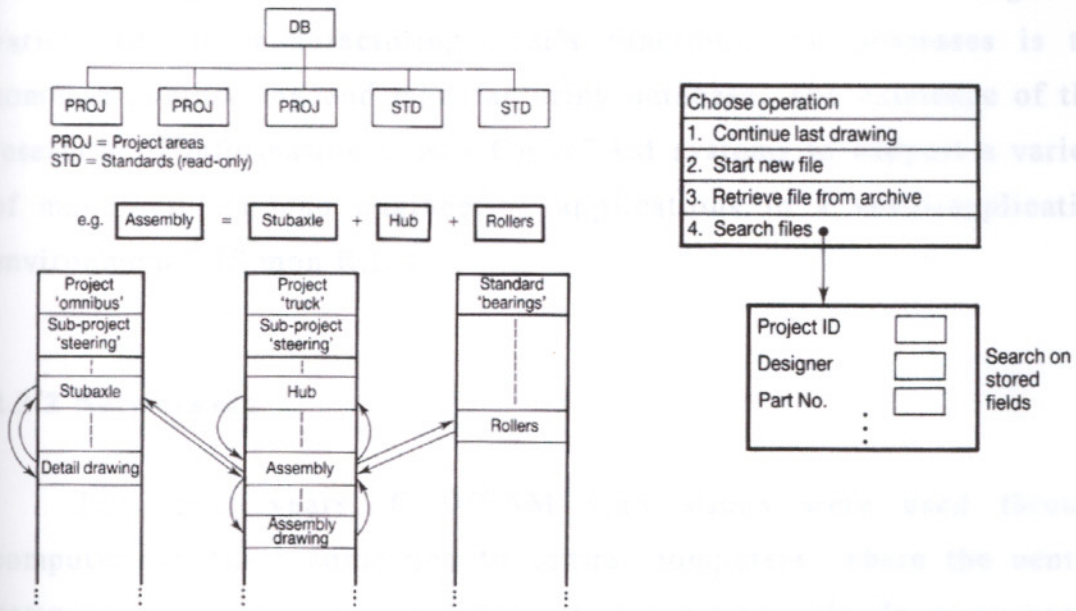
figure 2.41: A project-oriented database organization. (McMahon C., Browne J., 1995 p.141)

The product model is the most important connection between the design and manufacturing activities.. In some earlier modeling systems, the emphasis has been on pure geometric definition of parts. These were integrated in a way with process planning systems in order to determine how a part is to be manufactured. These process planning systems were mostly stand-alone programs requiring a large amount of user interaction. The user had to input the details of the geometry of the part to be manufactured; the process plan built-up by the system was based on the user responses in this man/machine dialogue.

In an integrated design and manufacturing system, this was a big gap. The part model in the computer should contain sufficient information to answer process and planning queries automatically; the need for the user to reinterpret the design data should be eliminated. Thus, the necessity of a fine product modeler that can also convey technological and functional information has become apparent: the development and integration of databases with CAD/CAM systems enabled a suitable information flow through all the design and manufacturing systems. "The key to CAD/CAM's ability to integrate a variety of the manufacturing firm's functions and processes is the common engineering and manufacturing database. The existence of this reservoir of information allows CAD/CAM systems to support a variety of manufacturing and engineering applications in a multi-application environment." (Simon R.L.)

2.3.2 Networking

For many years, CAD/CAM applications were used through computer terminals connected to central computers, where the central computer resource was shared between these terminals. In many cases, the communication's speed between terminals and central computers imposed a serious limitation on the system performance. This fact caused a gradual counteraction by incorporating local computing power into the terminals for the handling of graphical processes and user interaction. This has today developed in such a way that computing resources are mostly distributed, where each user terminal is a computer in its own right. This is the practice adopted in personal computers and high-end workstations, in which a CPU, main and backing storage units, and a display processing unit are combined with a display in a single unit. Workstations and personal computers may be linked together to allow the data exchange, sharing of programs and peripherals through *networks*.

A communication network is a collection of equipment and physical media, interconnecting two or more computers together.

Networks are often classified into three categories based on the geographic area covered.
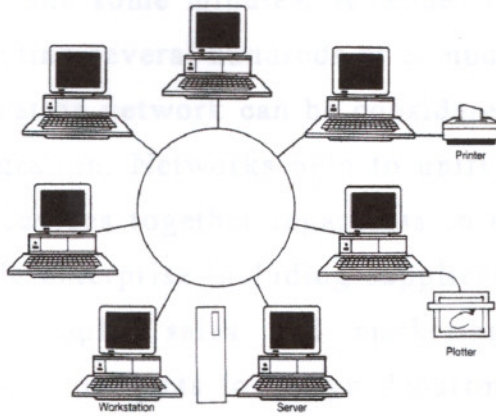
Local Area Networks (LAN) are used to link computers within the same building or organization, and to transport data at speeds up to 100 megabytes Per second (Mbps). *Metropolitan Area Networks* (MAN) are essentially large LANs that cover a large city or suburb. They are used to interconnect LANs within a metropolitan area. *Wide Area Networks* (WAN) are used to connect sites and equipment located long distances apart. They use common carrier facilities over long distances with speeds in the range of 1.5 Mbps.

Although a workstation can be powerful stand-alone solution for CAD/CAM applications, it is most effective when several workstations or personal computers are tied together via a communication network. When this network is supplemented by an operating system that permits a transparent sharing of programs, data and drawings, as well as some hardware peripherals like plotters, storage units and even CPUs, a user at one computer can, with appropriate access codes, reach a data from

another workstation easily. Some applications demanding large computational power can use networks to split the task between several computers. This is a technique widely used in 3D renderings of animations; a complex scene can require many hours, even days to render a single frame in high resolution, but within a "render farm", this process may only take some minutes. A render farm is actually a local area network including several hundreds of computers.

A communication network can be considered also as the backbone of enterprise integration. Networks help to unify a company by linking all computerized devices together regardless to their location. Through networks the whole enterprise including suppliers and customers can be integrated. For example, sales and marketing can send customer requirements for new products to design department. A CAD generated bill of materials can then be transferred to material requirements planning systems. Product design information can be transmitted to manufacturing for use in process planning. Designers, engineers and operators can directly access these process plans as well as machine operation and inspection sheets as they are needed. In this process, all kinds of data are being transferred between a variety of computer systems. A ready access to information facilitates rapid interdepartmental responses to changes in design and production schedules. A well-developed enterprise network can be mapped onto a communication hierarchy including and enterprise level, plant level, cell level and equipment or device level.

The communication needs of these levels are different, and therefore their network requirements in terms of communication devices, distance, physical transmission media, bandwidth an protocol functions will also be different. To unify the enterprise, three types of network technologies are required: device-level subnetworks at the shop floor that connect individual devices like CAD/CAM systems, robots and NC machines; plant-wide networks that connect cells and other departments; enterprise-wide networks that can globally link various plants/sites and interconnect corporations through electronic data interchange. (Singh N., 1996 p.580)

2.3.3 CAM

Computer Aided Manufacturing (CAM) is the final stage o the computerized production of mechanical parts. In fact, Cam existed before CAD, as it initially required no graphic interactive mode of operation. Cam emerged from the need of systems which enables the control of machine tools.

The research on Numerical Control (NC) at MIT in the early 1950s was an important step for CAM to bring it to life. After the production of the first NC machine tool, it was realized that NC part programming is a source of errors. As a result, a part programming language was developed. Automatic programmed Tool (APT) language was able to control machine tools, but could only handle relatively simple geometry. But further efforts enabled APT the handling of more complex geometry. Early NC systems did not have controllers with memory for strong NC part programs, punched paper tapes were used for this purpose, in which storage and administration was very difficult.

Direct Numerical Control (DNC) is originated from NC: DNC means one central computer with several NC machine tools. DNC systems were developed in order to replace the paper tapes, but this approach was not successful, because a centralized system was unsafe. In the late 1960s, Computer Numerical Control (CNC) machine tools were introduced, which is more flexible then NC as the latter is hard wired and the first is equipped with a micro-processor based computer. CNC controllers have a memory and special interfaces for loading NC programs, tools offsets and so on. DNC is then evolved into Distributed Numerical Control which consists of one central computer connected with several CNC machine tools. The computers local to the machine tools made the system less vulnerable as there were data buffering possibilities. Moreover, it was more flexible as it allowed programming at the machine tool.

Presently, machine shops are usually equipped with different CNC machine tools. Due to the varying orders, varying batch sizes and the demand for short throughput times, shop floor control (SFC) has become indispensable.

figure 2.43: A 486-computer based desktop CNC system.

Automated inspection is also part of CAM. The planning of inspection can be considered as a part of the process planning function. On the CAD model basis, inspection instructions can be generated, such as programs for controlling Coordinate Measuring Machines (CMM). CMM measure a discreet number of individual coordinate points of the object under inspection.

figure 2.44: A CNC desktop lathe and mill.

CAM systems are increasingly applied in combination with production planning and control systems such as Shop Floor Control systems. Many post processors for converting machine independent NC

part programs into machine dependent programs are available. Present CAM systems include interactive programming aids for operating and controlling the machine tools as well as tool management software. Particularly in small batch manufacturing, scheduling as well as monitoring and diagnostic functions are also emerging. The monitoring function includes checking the progress of work in a workstation, whereas the diagnostic function determines amongst others the performance of a complete manufacturing cell.

Some of the main problems in CAM today, are related to the post processors for generating NC part programs. Solutions are very specific, especially for non-traditional machine tools. This is due to the fact that a lot of the process technology is embedded in the machine and cannot be programmed in a standard way.

2.4 LEADING 3D GRAPHIC SOFTWARE DEVELOPERS

Computer graphics applications is a fast growing market. Software business have become a huge industry, and graphic software is one of the major section of it. Especially in the last decade, several companies gained great success with their graphic software products. They have created very important programs for designer and engineers, and they are frequently updating their products. Usually, a single software cannot fully cover all the necessary tasks that a designer contributes. For that reason, designers use a set of software which are developed by several different companies. These companies have generally a wide range of product line, including CAD, CAM and CAID (Computer Aided Industrial Design) tools. The most important companies in this field are SGI, Autodesk and Parametric Technologies, which are the makers of primary design programs like Alias|Wavefront Studio, AutoCAD and Pro/ENGINEER.

2.4.1 SGI

SGI is one of the best known hardware and graphics software company, supplying many high-end products for visualization, entertainment and design industries. At the beginning, Silicon Graphics Inc. was primarily a 3D graphics company, but the two-thirds of the company's revenue comes from non-graphic products, such as servers and services. To reflect more clearly the company's vision, Silicon Graphics has changed it's company identity; SGI is the new brand for this well-known corporation.

SGI production line includes desktop workstations, servers and supercomputers, delivering advanced computing and 3D visualization capabilities to scientific, engineering and design applications. In addition, SGI creates high-end software for design, Internet and entertainment applications. SGI provides solutions in several key industries, including manufacturing, government, entertainment, communications, energy, sciences and education.

Alias|Wavefront, a subsidiary of SGI, is focused mainly on software development. Alias|Wavefront software are widely accepted among designers around the world for it's high-end capabilities, from initial sketches to final product. It is also considered as the leading developer of Computer Aided Industrial Design (CAID) software, with the *Studio* package.

2.4.1.1 The Studio Family

The Studio family is a set of CAID applications, providing a comprehensive set of tools for every stage of design, from early ideation sketches through the final model that will be released for engineering and manufacturing. The package aims a complete integration throughout the entire shape definition process bridging the gap between design and engineering. Sketching and conceptual modeling can be performed digitally with the Studio tools. As concepts are refined, several

techniques can be used to evaluate and assist in the design selection process. Advanced animations and physical prototypes can also be generated.
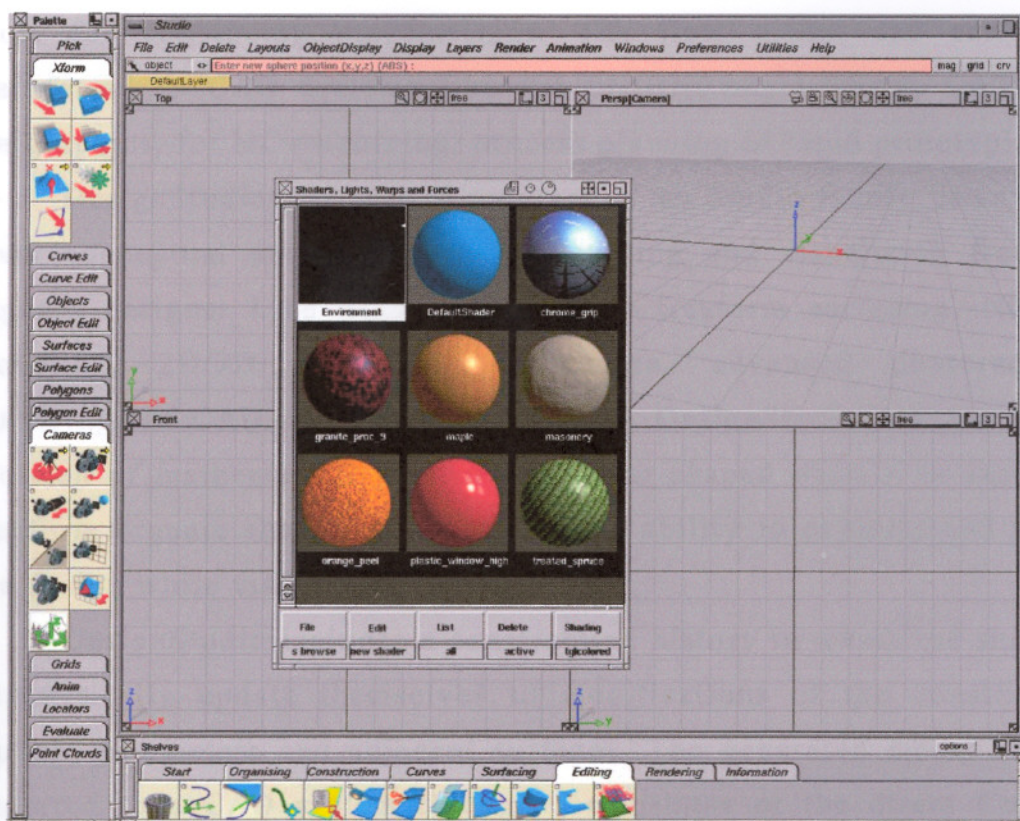
figure 2.45: Studio interface

Studio family consists of four integrated software which are Studio, DesignStudio, SurfaceStudio and StudioPaint. Studio provides some advanced design tools for precise surfacing, with conceptual modeling and rendering capabilities in one integrated package. The software delivers freeform surfacing, NURBS modeling, 2D/3D integration, animation, advanced photorealistic rendering and CAD integration.

Studio offers important features in four key areas: advanced tools, interface, rendering and data transfer. Some advanced tools are; curvature continuity for complex blending, surface quality evaluation tools such as real-time diagnostics, dynamic cross-sections and direct render. The interface is a flexible and customizable one based on

graphical icons. It includes personal toolshelves for favorite tools, hot keys and marking menus. The interface also allows the designer to shift easily among modeling, surface evaluation and visualization. Studio includes a photorealistic renderer, with scene lighting and surfacing tools for convincing presentations. The final model can easily be transferred to CAD systems like Pro/ENGINEER, I-DEAS, CATIS or Unigraphics, for NC machining, process planning or rapid prototyping.

DesignStudio, the second program of the Studio family, is an entry level conceptual design system for building and visualizing freeform organic designs. Like Studio, it delivers freeform surfacing, NURBS modeling, 2D/3D integration, animation, advanced photorealistic rendering and CAD integration capabilities. DesignStudio is based on the creation of mathematically accurate regular-shaped objects as easily as freeform organic shapes. It also gives the ability to evaluate and refine the design while visualizing the models.

DesignStudio includes a construction history in which the surfaces automatically update themselves to modifications of the construction curves, parameters and adjacent surfaces. The generated model can be exported to a CAD system through a translator or the direct Connect option. DesignStudio also outputs to a variety of media, including color hard copy, high-resolution film, video, stereolithography and plots.

SurfaceStudio is a surface modeler offering advanced modeling and reverse engineering tools, real-time diagnostics and scan data processing technology. It offers a complete set of tools for generating precise surface models for integration with engineering and manufacturing processes.

SurfaceStudio includes advanced technical surfacing tools. In addition to NURBS-based surfacing capability, it allow users to modify surface patches in a Bezier-like patch fitting modeling paradigm. It is a well-suited package for bath "math-lead" workflows and "clay-lead" workflows.

StudioPaint is a digital sketching and painting system with familiar tools like real-time pens, brushes and airbrushes. This digital paint box, is used in the ideation phase of design development.

StudioPaint operates in conjunction with a pressure sensitive tablet and stylus. It includes advanced tools ranging from pressure sensitive brushes to lighting controls, hot keys, geometry control tools, user definable brushes, and texture creation and management capabilities.

StudioPaint, when used with the studio family of conceptual modeling products, offers tight 2D/3D integration that allows designers to shift freely between sketching, modeling, painting, animating and rendering applications. It works closely integrated with other Alias|Wavefront design tools.

2.4.2 Autodesk

Autodesk is the fourth-largest PC software company worldwide. The company's 2D and 3D products are used in many industries for architectural and mechanical design, mapping, civil engineering, surveying, film and video production, video game development and Web content development. Discreet, is the new division of Autodesk formed by combining Kinetix (a subsidiary of Autodesk) operations with the Discreet Logic acquisition. Discreet develops and delivers systems and software for visual effects, 3D animation, editing, broadcast graphics and feature films.

Autodesk is widely known for it's design and drafting tools. It provides an entire solution of products that can be used alone or in combination that include mainly AutoCAD, AutoCAD LT, AutoCAD Architectural Desktop, Mechanical Desktop, Genius CAD, AutoSketch, 3D Studio MAX/VIZ, fire*, smoke*, edit*, flame* and flint* as the most common software.

2.4.2.1 AutoCAD

AutoCAD is probably the most popular 2D drafting program to date. It is the flagship of Autodesk and sold over two million copies worldwide. It can be considered as a software phenomenon; its users far

outnumber those of any other CAD system. Since its introduction, AutoCAD has grown from a micro-curiosity to a full-fledged CAD system by any set of standards. It has also grown from a relatively simple program to a large and complex one.
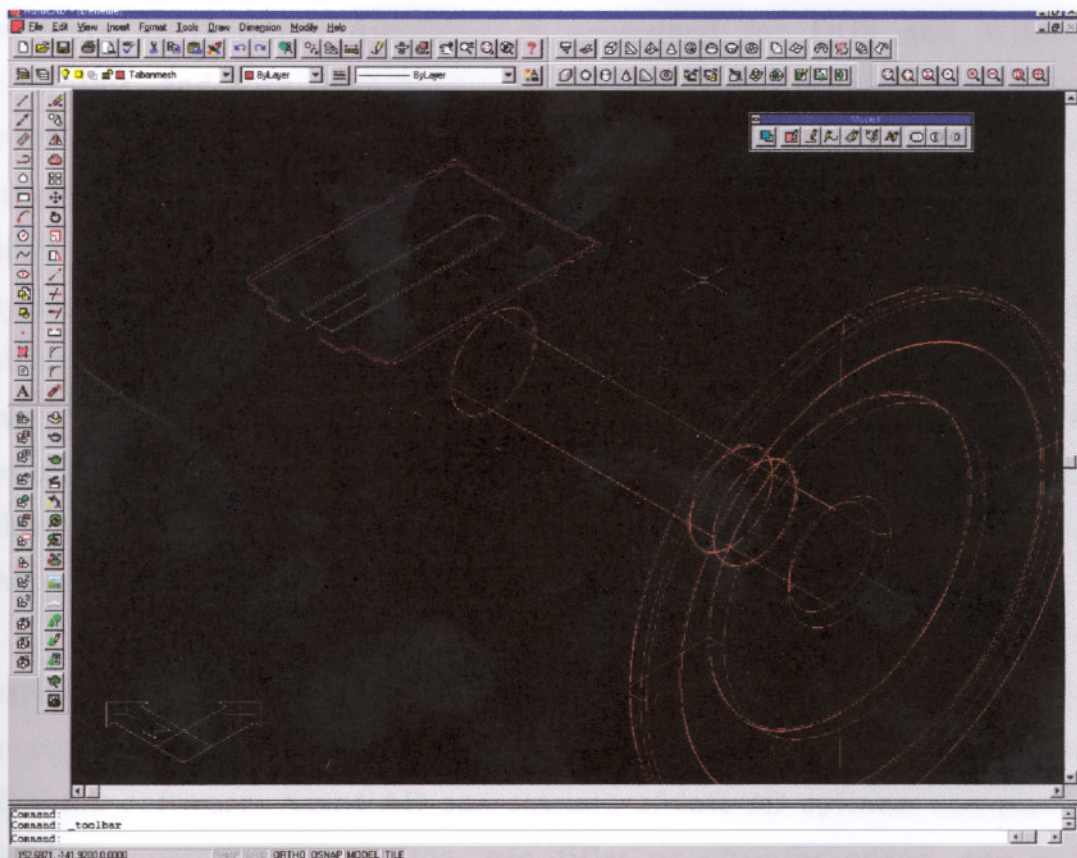
figure 2.46: AutoCAD R14 interface

AutoCAD is used for several different purposes as a stand-alone program. Designers, architects, engineers, planners widely use this common tool to suit their needs. Although it is a powerful software on its own, it can be enhanced with some additional software. For example, with Mechanical Desktop, AutoCAD is capable to offer high-end mechanical solutions to engineers and designers. Architectural desktop provides many unique tools to intensify the role of AutoCAD in an architect's design process. There are other tools such as AutoMap, AutoCAD Land Development Desktop or AutoSketch, which are all integrated within AutoCAD. This concept of additional software is

especially good for people using just the software needed for the necessary task. Also, as AutoCAD is the core of the system, it is very easy to interact with well implemented additional software.

Since it's first release, AutoCAD introduced many important features and some of them are widely accepted and considered as the new standard CAD tools. AutoCAD is developed for DOS and Windows platforms, and with release 14, the primary platform is set as Windows 9.x/NT. The graphical user interface (GUI) of AutoCAD is very similar to many Windows applications, easing the adaptation of the users to the program. It uses several important core functions of Windows operating system such as standard toolbars and pull-down menus, dialog boxes and shortcut menus. AutoCAD also includes it's traditional command line input option, which works by typing the command via keyboard instead of clicking the appropriate icon. Some users feel more comfortable with this approach, but many of them prefer to work with the common GUI of AutoCAD.

Although AutoCAD is known for it's powerful 2D drafting capabilities, it has a set of important 3D features. It can be considered as a powerful solid modeler, even without the additional Mechanical Desktop software. AutoCAD can extrude of loft 2D splines, can perform Boolean operations on solids, can fillet or chamfer edges, can apply some modifiers like taper and bend, and also can apply a shell feature to the 3D model. The 2D and 3D functions of AutoCAD are NURBS based, thus it offers many industry standard tools for drafting and modeling.

AutoCAD can export drawings both in two-dimensional raster or vectoral, and in three-dimensional polygonal or NURBS. It includes advanced tools for getting a hard copy of a drawing. AutoCAD also introduced some new tools to share drawings via internet, facilitating communication worldwide.

2.4.2.2 3D Studio MAX/VIZ

3D Studio MAX and VIZ are developed by Kinetix, the independent multimedia business unit of Autodesk. 3D Studio MAX is

the best-selling 3D visualization and animation software to date. Both MAX and VIZ are developed for Windows NT workstations and Windows 9.x operating systems.

MAX is designed to offer high-end images, animations and special effects with relatively low prices. It does not require an expensive graphics workstations or supercomputers. It is based on a plug-in architecture which gives users the opportunity to develop their own custom codes. Some additional plug-ins can be integrated easily within 3D Studio MAX, whether they are commercial or free.
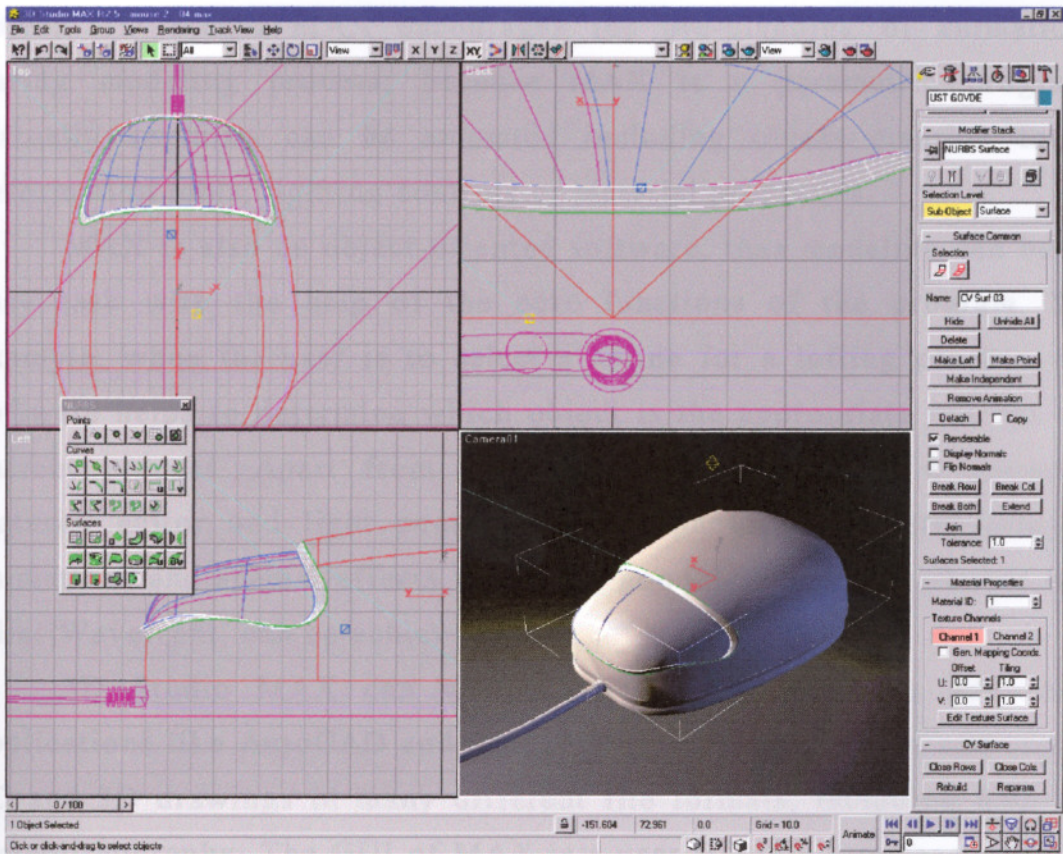
figure 2.47: 3D Studio MAX R2.5 interface

There are several types of plug-ins for MAX, including shaders, materials, lights, particles, special effects, modeling tools, modification tools or animation tools. This open architecture of MAX allow users to purchase only the tool they need. For example, an animator can purchase just Character Studio, a special animation plug-in for biped creatures, and he may not pay extra money for Cartoon Reyes, which is a special

shader plug-in. This approach generally cuts down the required total budget for a project.

3D Studio MAX includes powerful modeling tools. These are Bezier splines, NURBS splines, patches, NURBS surfaces and polygon models. There are various modifiers in the package easing the modeling and animation process. Modeling, animation, texturing and lighting processes are in the same environment, thus a special tool can be used in more than one core function. For example, the Bezier spline is used to generate a surface, it can also be used as an animation path for the same object. 3D Studio MAX encourages the pre-planning of animations during modeling process; because MAX is a parametric program, virtually anything can be animated including object creation tools, deformation tools, lighting controls or material properties.

MAX is also an object-oriented software, thus modeling can be an easy task with the help of the core functions of the program. For example, when the user is to select a spline for a lofting process, the software helps to determine which object is the appropriate one for the current process. Apart from modeling, MAX also have a powerful material editor and light control options; photorealistic still images, animations and special effects, nearly as good as high-end software like Alias|Wavefront, can be achieved.

3D Studio MAX can work closely interacted with additional applications like AutoCAD and Rhinoceros 3D. It can import and export 2D and 3D drawings in many different file formats, including STL for stereolithography. The GUI of MAX is a user friendly interface, helping to work easily, for modeling, animating, texturing or lighting a scene in one single environment.

3D Studio VIZ includes many capabilities of MAX, including modeling, texturing, lighting and rendering. It is developed for visualization purposes, thus it includes limited animation tools. It can work interactively with AutoCAD with "DWG link" facility, updating all AutoCAD imported two-dimensional drawings in real-time, even while working in AutoCAD.

2.4.3 Parametric Technology Corporation

Parametric Technology Corporation (PTC) is founded in 1985 and develops, markets and supports suite of integrated product development and information management solutions. The company's Pro/ENGINEER Solutions provide software tools to automate the mechanical development of a product from its conceptual design through production.

PTC began commercial shipment of Pro/ENGINEER product line in 1988, and it has emerged as the fastest growing company in the mechanical design automation market, with more than 186.000 seats of software installed. It has broadened its customer base to include many of the largest manufacturing companies in automotive, aerospace and shipbuilding industries. Parametric Technology Corporation is one of the largest independent software company of the world.

2.4.3.1 Pro/ENGINEER

Pro/ENGINEER is the flagship product of the PTC's next generation mechanical design automation software. It is built upon CAD/CAM/CAE solutions and extends the value of product design information to the desktop user and throughout the enterprise, providing access to product data at every stage of product development.

All Pro/ENGINEER solutions are fully associative, which means that when a change is made anywhere in the development process, all engineering deliverables including assemblies, drawings and manufacturing data are automatically updated. The software uses cognitive features as the building blocks of product geometry. These features are natural mechanical objects containing knowledge of their environment. For example design features have names such as shell, round and fillet which are familiar to the users and therefore easy to use. Products are also developed by assigning parameters (including non-geometric attributes as well as dimensions) to these features, then modifying the parameters to easily explore multiple design iterations.
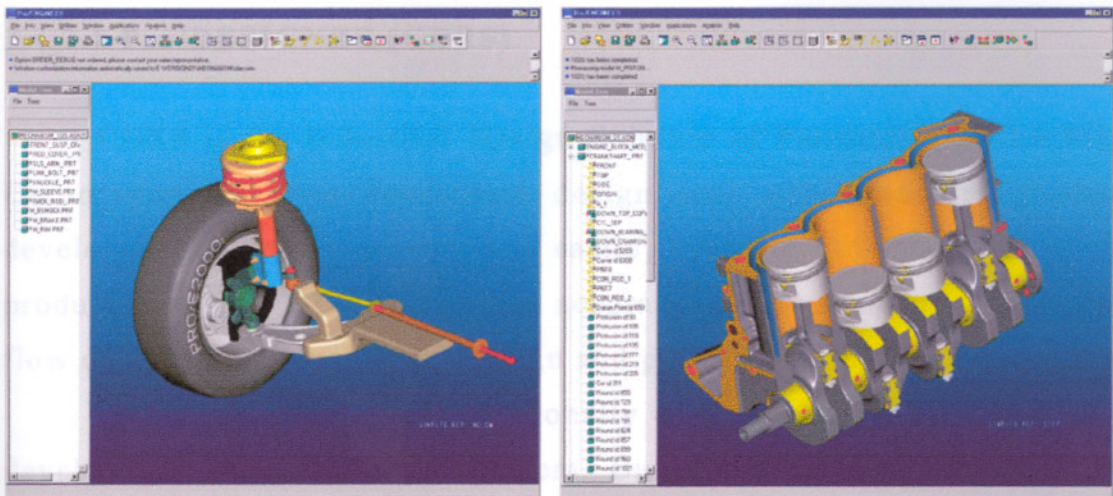
figure 2.48: Pro/ENGINEER interface

Pro/ENGINEER Data Management Solutions are designed to permit multiple engineers and designers to work on a product simultaneously. This is an important requirement for concurrent engineering processes, and Pro/ENGINEER can easily manage these simultaneous processes.

Mechanism Design provides kinematic motion simulation and behavioral insight into the assembly through the easy definition and animation of connections with Pro/ENGINEER, such as pin joints, ball joints and sliders. These connections and resulting assembly constraints facilitate the assembly of closed loop systems. Once assembled, engineers can observe how their mechanism design behaves geometrically through interactive part dragging and user-defined motion simulations.

One of the main advantages of the package is that it runs on all of the major UNIX, Windows NT and Windows 9.x platforms, maintaining the same look on every system. Thus users are free to select the most economical hardware configuration for their needs, mix and match any combination of platforms. This is not a restriction for data management; information can be easily exchanged from one platform to the other, with Pro/ENGINEER managing any architectural differences.

2.4.3.2 Pro/DESIGNER (CDRS)

CDRS is the Industrial Design Solution of Parametric Technology Corporation. It is a conceptual design tool which enables product developers to create quickly and easily, evaluate and modify multiple product concepts. CDRS generates accurate surface geometry which can flow directly into mechanical design and prototype manufacturing.

Pro/ENGINEER is a dimensionally driven solid modeling package developed for mechanical engineers. But CDRS aims to enter to the product and transportation designers market. It is as wireframe-based surface modeling software for free-form concepts and products.

In CDRS, the modeling process can be started with curves which are traced directly from scanned images or developed freehand in CDRS. It offers precise control over the curves because any point on a curve can be modified. A selection of a set of basic form-defining curves is generally enough for CDRS to create the appropriate surface.

The package is a bundle consisting of three modules: *DESIGNER* is a software containing a complete and integrated set of tools for creating free-form surface models that can be integrated into Pro/ENGINEER for further operations. *PHOTORENDER* is an advanced module containing powerful set of tools for quick evaluation of 3D models. It provides the ability to create photorealistic images of product models to check design quality, to produce presentation and support marketing efforts. *ANIMATOR* is the software module that allows users to animate a wireframe or rendered image. It further enhances product evaluations and presentations by enabling designers to create photorealistic animations of product models.

CDRS can be closely integrated with the *Pro/3D PAINT* software also. 3DPAINT enables the creation of full-color, detailed sketches and artwork directly on 3D models as well as 2D canvases. The combination of these tools results a high-end CAID software which is used by many design organizations worldwide. Like Alias|Wavefront's industrial

design solutions, CDRS takes the advantage of easing the integration of a wide range of programs, including the initial ideation sketching software and final CAD/CAM packages.

2.5 NEW TASKS IN DESIGN PROFESSION

The computer, as a medium takes the designers into new areas of work and expertise. These areas require very different attitudes and skills than many common tasks. These are all have been divided into two groups, which are intended to clarify the contribution they made to redefining the boundaries of design.

The first group is formed from media that are sufficiently distinct to be considered in their own right. It includes rapid prototyping, digital publications, shape grammar, generic algorithms and neural networks. All these represent particular views of the design future and they are based on areas between design and computing. The second group of likely new disciplines consists of interactive multimedia, virtual reality, interface or interaction design and design for visualization. Some designers have already getting more and more interested in these, as it is likely that they will gradually replace many of today's traditional design disciplines.

2.5.1 Interactive Multimedia

Until today, books are the media that have largely determined how information has been structured. They are convenient, relatively inexpensive and can be printed in thousands. They are also well integrated into our culture such as many people are collecting them. Because of the book's dominant position, it has been able to impose another method on the delivery of ideas. Film, radio and television are all inherited the "linear" approach of the books, that is to say that the reader had little control over the content of a book, or the viewer over the content, length, or timing of a film. This limitation has been

accepted as a part of our culture, as something to do with the very nature of films, books, plays and television.

The first major item that overturned this structure was the video cassette recorder. It allowed individual recording of television programs and destroyed the broadcaster's control over the schedule. Users have been more selective about what they watch and when they watch by simply pressing fast- forward, stop, play or replay buttons. Essentially, more control is placed in the hand of the receiver of information, and less in the hands of the deliverer.

This represents a significant shift in the control of information, underlining the importance of interaction. The computer made a final major impact on this by demonstrating how two or more pieces of information could be tied together, enabling the user making a path through the other data establishing further associations.

The idea was developed by Ted Nelson for his project "Xanadu" (1960s) and has achieved a software implementation with the now popular "Hypertext" systems. Hypertext linked many documents as the user jumps between them, taking relevant elements from each as the search continues. This non-sequential approach is applied to images, graphics, video and sound, producing a new interrelationship called *multimedia*.

According to Max Whitby, director of Multimedia Corporation in London, "a defining characteristic of interactive multimedia is that it allows the consumer to intervene in the presentation of information and to divert the flow or adjust the level of detail according to his or her interest and experience. This process of intervention seems inevitably to break the spell of engagement with linear media". The ability to connect traditional, media-rich materials is a potential value to many areas like education, training, business and entertainment. As the range of existing material that can be incorporated is extensive, multimedia can be seen as a hybrid form, combining the advantages of existing media with the new potential of the computer (Baker R., 1993)
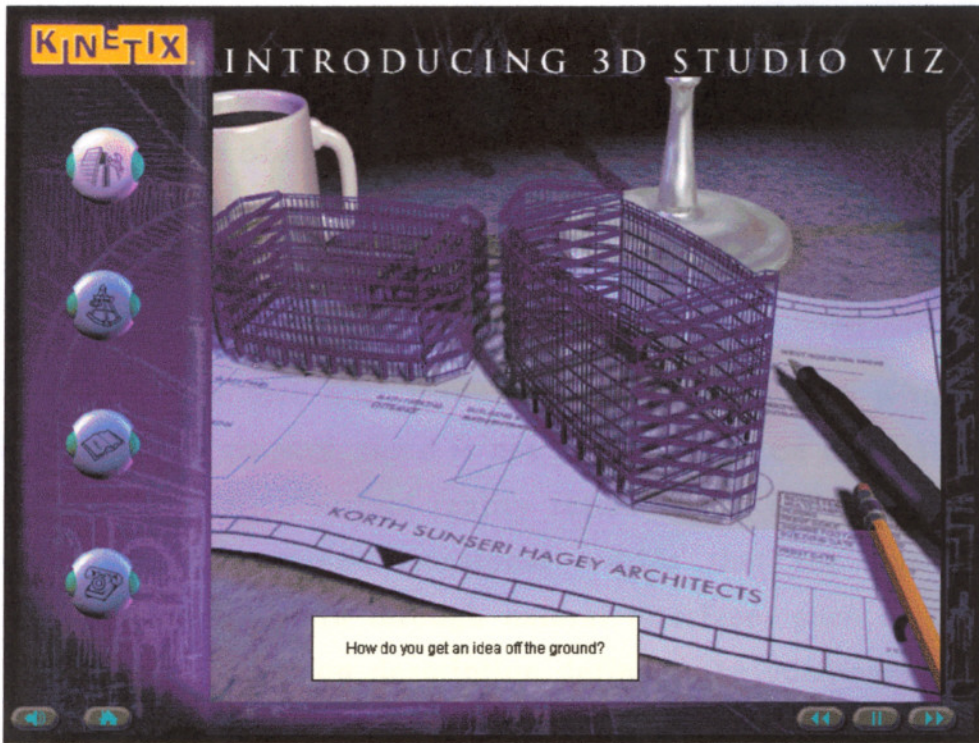
figure 2.49: An interactive multimedia GUI example.

Although interactive multimedia seems an ideal use for computers, there are some problems arising. Multimedia is based on on-linear approach, which means that the users must be able to find where they are and how to reach what they look for in the new virtual media. The users become lost and frustrated if they do not navigate towards their objective. For that reason, electronic guides in the multimedia design have gained great importance.

Multimedia has many important features for a designer. It can provide a whole new tool to represent their abilities or projects. Interactive multimedia can be an impressive medium as a personal portfolio as well as presenting fully a new projects with images, graphics, sounds, texts and animations. Moreover, the multimedia interface itself is a design product, reflecting the designer's attitudes and capabilities.

Interactive multimedia requires a different combination of skills from that of the traditional design education. It consists of a complex tasks of video or film sequence editing, still images, text, graphics and

animations all of which are computer-controlled. Despite this fact, art and design disciplines are the nearest in nature to the needs of interactive multimedia. Designers can adapt this discipline as their own and a combination of old and new skills must take place.

2.5.2 Virtual Reality

As it is the case with many of the new disciplines within which design has a role to play, there is not an agreement on the definition of virtual reality (VR). "Virtual reality refers to the ability to computer generated realistic three-dimensional worlds that the operator can explore and interact with through natural interfaces such as the glove and helmet" is a common description defining the components but not the experience. If a consensus view is aimed, then the definition becomes as general as to include and medium that simulates a real or imaginary world by electronic means and allows the viewer to participate in it. (Baker R., 1993 p.150)

The cause of lack of an adequate definition of VR is the move of VR from science fictions to the laboratory and then to the market in such a speed that there had been no time to absorb it into our culture. Many designers do not understand what VR and its abilities are. Three dimensional graphics, animation, interface design, parallel processing, sound and tactile feedback all exists as separate areas of development, but their linking is established with VR. This enabled VR to develop very quickly, exploding the imagination of the artistic and scientific community, as well as exciting much media attention.

The idea of using computers to simulate events and locations is not new. The military realized that such techniques could provide ideal training medium for tactical battle situations, without using expensive hardware and endangering human life. Also in the commercial field, simulation has been used by a variety of professionals, including architects, designers, engineers, planners and within the civil aircraft

industry. These simulations were mostly based on the visual component, allowing limited interaction along a linear path.

To make the simulated experience as realistic as possible, the main effort had been concentrated in creating a visually realistic representation excluding most other human senses by computer graphics. Initial VR applications corrected this imbalance by creating a synthetic computer environment, which demonstrated how sound and touch could also be incorporated to the visual environment. The main difference between a computer simulation and a virtual reality experience is that VR maps many more human senses onto the machine, creating a more convincing representation of real-life experience.

The fundamental contribution of VR has been described by science fiction writers for many decades. VR allows the users to feel they are within the system, rather than outside of it. Users find themselves among images, sounds, moving things allowing some interaction with themselves. They experience an immersive, all-round involvement and they are placed at the very center of things.

figure 2.50: A virtual reality system linked to a Apple Macintosh computer (Noblet J., 1993 p.386)

The most common devices of VR are the headsets, datagloves and datasuits, which cuts off the user from everyday world and enter the virtual world. The use of masks, gloves and suits as the input devices to the computer system, proves that the "natural interface" is beginning to

appear for the user. These are familiar objects for the user but VR gives them some additional meaning.

This electronic environment allows several users to participate simultaneously. All players have to use headsets and datagloves and they can be represented as themselves or any other thing they wish.
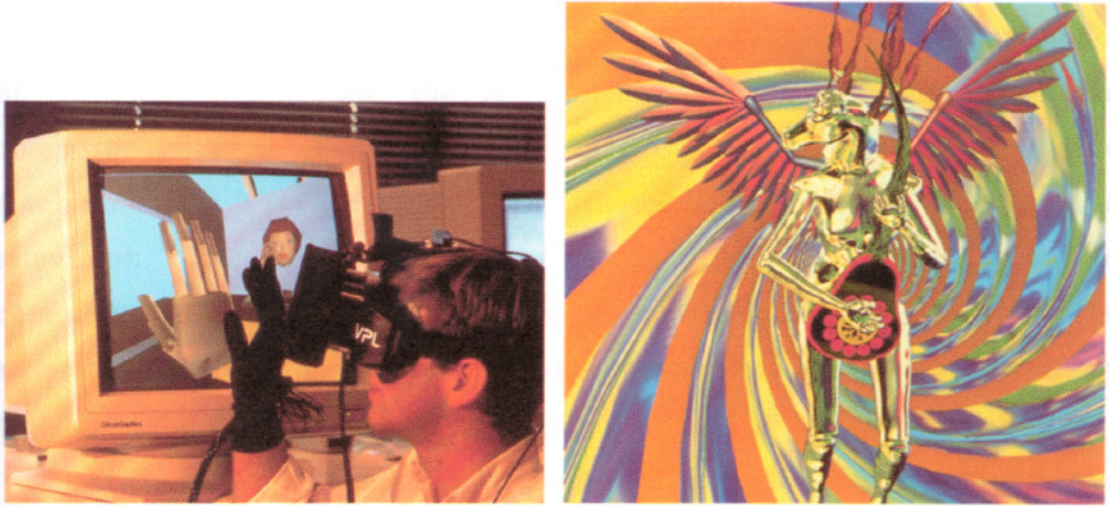
figure 2.51: Examples of virtual reality scenes (Noblet J., 1993 p.384)

There can be many different uses of VR, because technology are developing to be able to simulate anything the designer wishes. Entertainment can provide one of the most wide use of VR. Arcade games and theme park promoters see VR as an ideal tool for providing ever more intense experiences. Many scientific projects have taken the advantage of VR to interact with information in such a way that has never existed before. Clinical diagnostics is another area in which VR has significant implications for the future. One new use of VR is "telecollaboration" in which many designers work together online while they are physically in different locations, simultaneously working on 3D solids for the design of a car body. Such a VR network have already been established by some Japanese electronics companies.

Virtual reality is a completely new area of competence proving it's immense capabilities. It can pose some new design problems to designers, and can help as a new communication tool to use for the

traditional design discipline. As in the case of multimedia, it is the designer who clarifies his contributions to this new world.

2.5.3 Interaction Design

Many human activities are affected by the computer. As the impact of this machine grows, the relationship between the user and the computer changes in such a way that the user deforming less and machine more. This evolution exists in other technologies like car and television. The same process of "humanization" is happening to computers, but this does not happen automatically. The designer and the artist is the crucial part of this transition, which is not an aspect purely technical, but also social and cultural.

Many hardware and software suppliers has some efforts to improve the human-computer interaction by establishing research groups. Computer developers have ignored the need to fit the machine to the common patterns of human behavior. Bu the artist and the designer have made a significant contribution to the transition of computers to the "human-factored" product. They have some important qualities like visual skills, ability to synthesize, ability to understand the need of end-users, which helped them for the problem of humanizing the technology.

The graphical user interface (GUI) is an important feature for the interaction of humans and computers by some other means than keyboards. It enabled the user for the first time, to navigate into the machine using images and icons, rather than through complex text and number based instructions. The original GUI's, such as early Apple Macintosh computers, included a pointing device (typically a mouse) on-screen menus appearing and disappearing on the instruction of the pointer, and windows that graphically display what the computer is doing. Additionally, icons were used to represent files, folders and directories; dialogue boxes, buttons, sliders and a host of other functions like a wastebasket. (Baker R., 1993 p.143)
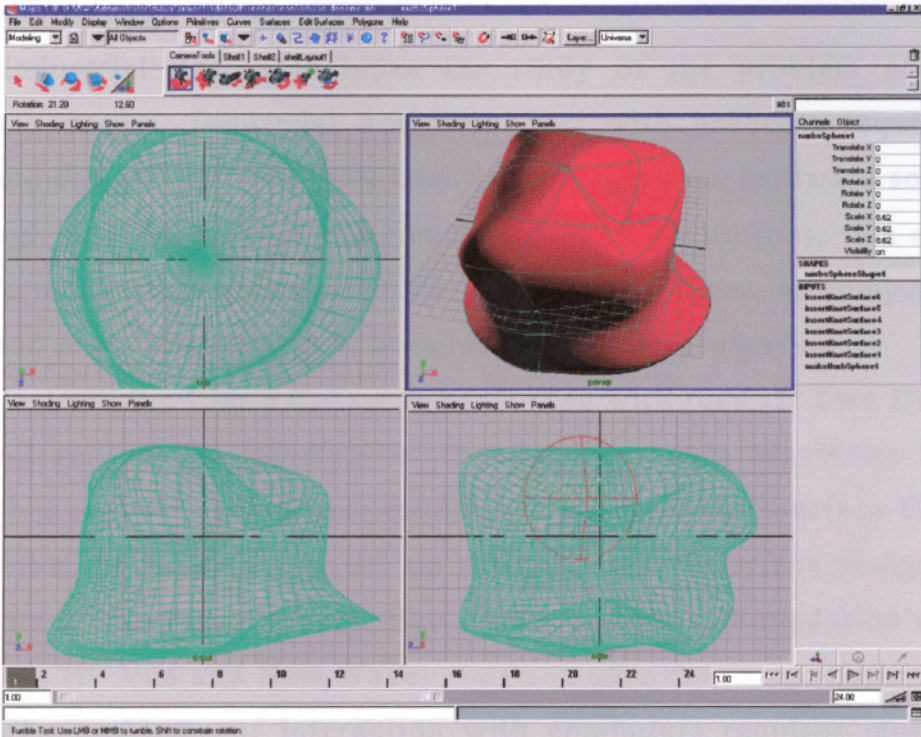
figure 2.52: The GUI of Maya, a new generation 3D visualization program. Although it can be considered as an icon-driven interface, it has many other advanced features, like virtual menus.

Several different GUIs are available in the market and although they may employ different styles of interaction, they are fundamentally very similar. There are some hybrids, but most consists of three major components: a windowing system, an imaging model and an application program interface.

The GUI was separate from the various applications like word-processing, drawing or three-dimensional modeling, but a consistency of use is established. Commands like "cut and paste" or selecting a block of text for example are the same in many different applications. As many other functions are standard across a range of software, users feel confident to use all these different programs. When using a word-processing program and get familiar with it, the user can go on using a database software and then generate a three-dimensional model, because

141

there is basically a single, straightforward way of interaction with the programs through GUIs.

Industrial design includes the study of the problem of human interface design. Industrial designers deal with products requiring an interface design, but they have traditionally based on hardware solutions. Although they have little experience in software solutions, this area has become much more common to the industrial designer, as computers get more and more dominant role in industrial design profession.

In 1988 the Claris Corporation worked with then ID Two Design as a consultant, on the interface of the Claris product MacWrite II. This was a big success, and Claris founded Claris Human Interface Group in 1989. Hewlett Packard also set up a similar user interface design group for many different products like Open Software Foundation's Motif interface, HP Vue and New Wave.

The problems of interaction with computers requires much more dense solutions than those of the past. The issues of metaphor, types of representation, cognition, sound, movement, graphics and text had been included in the problem. These skills are not totally included in a single design education like industrial design or graphic design. To provide the dense solution required, alongside the designer will be the cognitive scientist, the psychologist and the software engineer. Each has a contribution in the interface design process, bringing their particular skills and knowledge to the solution.

Industrial design, however, is one of the most convenient discipline for this task. As new devices are becoming available by the designers to interact with the computers (such as visors, gloves, headgear or pressure sensitive pads) and as the industrial designer gets more and more common with the computers, they become one of the most appropriate person in dealing with the important problem of human-computer interaction.

CONCLUSION

Computers have a role to play in the different stages of design process. This role can include artistic and abstract purposes, such as sketching or presentations, or can include quite factual procedures such as drafting, dimensioning or manufacturing of the product. In fact, the main accomplishment of computer systems is the integration of all the different design processes as a continuous sequence. Moreover, this set of sequences are basically applied in a single environment.

Computers are indeed astonishing machines, especially their ability to generate images. This is just a simple part of the computer's competencies, but it is the most amazing task for many people. Yet, designing for manufacturing is a much more complicated practice; although computers are reliable tools in this field, the process is not still fully automated, just as in the case of visualization.

Despite all of the improvements on the software and hardware technologies, computer aided design still requires a high level of technical knowledge. It can take even some years to get experienced with this tool, but once comfortable, it immediately becomes something unavoidable. However this can lead some another problems; computers can easily be the "aim" of the designer. In fact, it is just a for creating better products. The designer should be in well balance between the requirements of the industrial design profession and the technical knowledge about computers.

The designer should also be open-minded about the new technologies and their capabilities. Computers are still continuing to expand the possibilities for the designer. Although these machines can be considered still in it's infancy in many ways, they are unique tools for the designer.

17" LCD Monitor Design: A Case Study

This section consists of a LCD monitor design, with the help of several different graphic software. After the first conception stage, the whole design process is accomplished with the computer. The including software types are 2D raster, 2D vectoral and 3D modeling and visualization programs such as PhotoShop, CorelDraw, Rhinoceros 3D and 3D Studio MAX respectively.
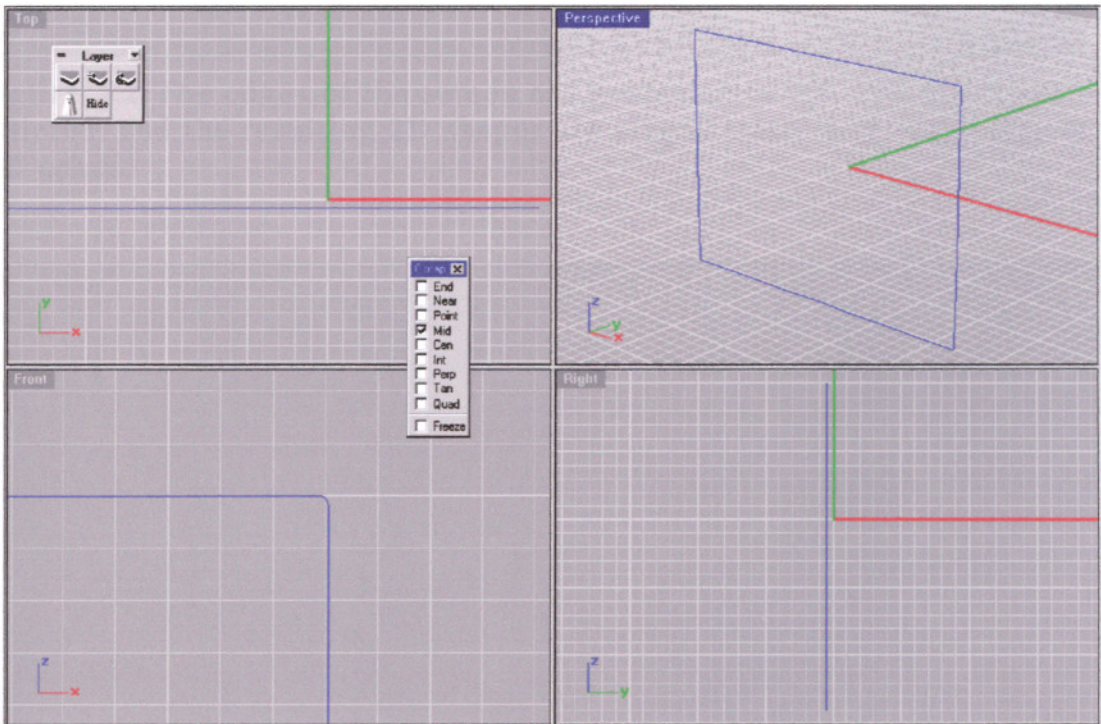
figure 3.1: The rectangle, which is the flat screen is drawn with *rectangle tool*, and the sharp corners are *filleted*.
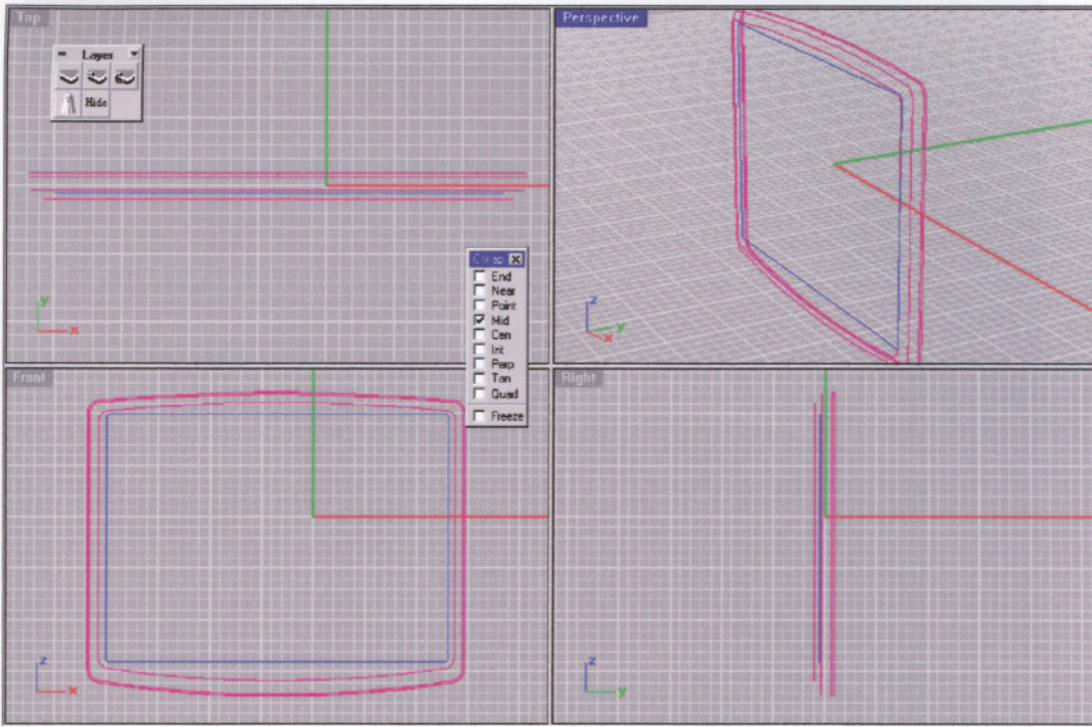
figure 3.2: The edges of the screen are generated in 2D. The edges are filleted, and the resulting 2D shapes are placed relative to each other in 3D space.
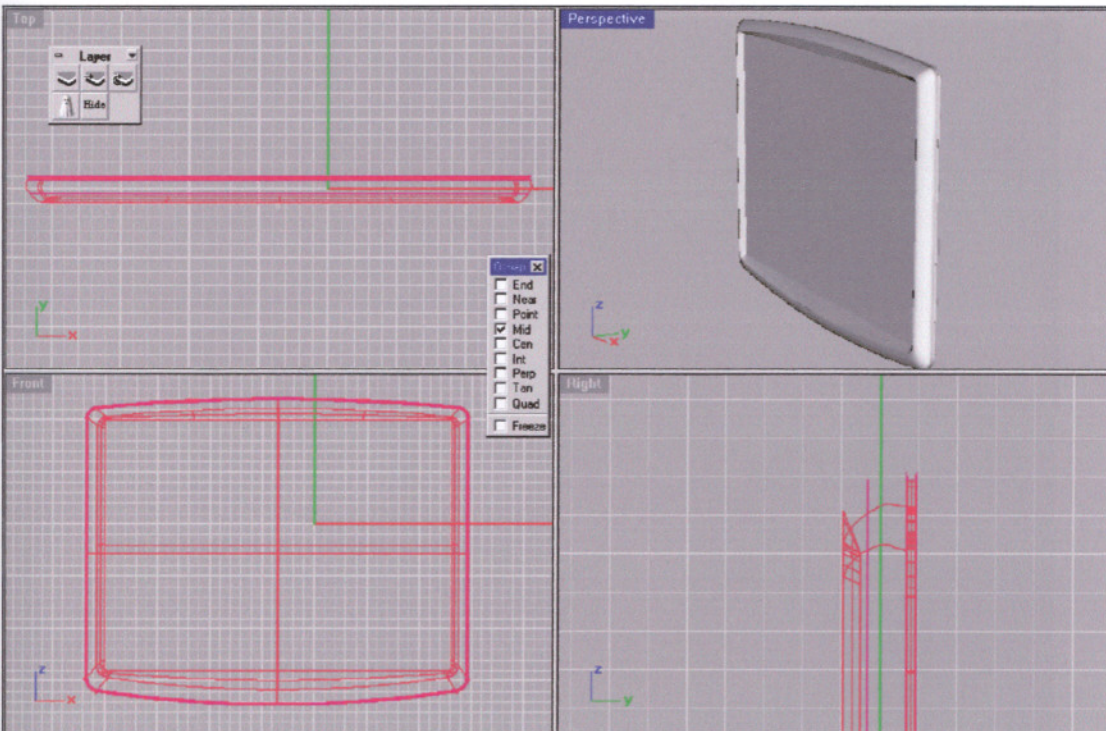
figure 3.3: 2D shapes are *lofted* with proper *tension* value, and the screen part of the monitor is generated as a surface model.
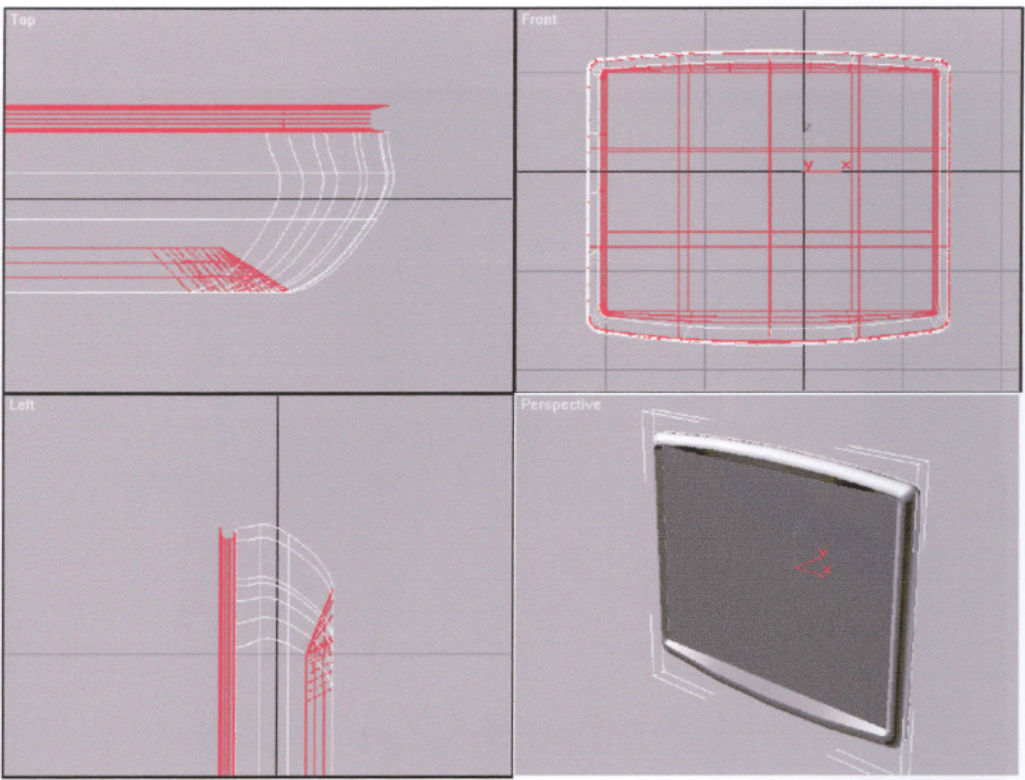
figure 3.4: The generated surfaces are saved as Rhino .3DM file with full NURBS capability. This file is then imported to MAX, with the plugin *Rhinomax25imp.dli*.
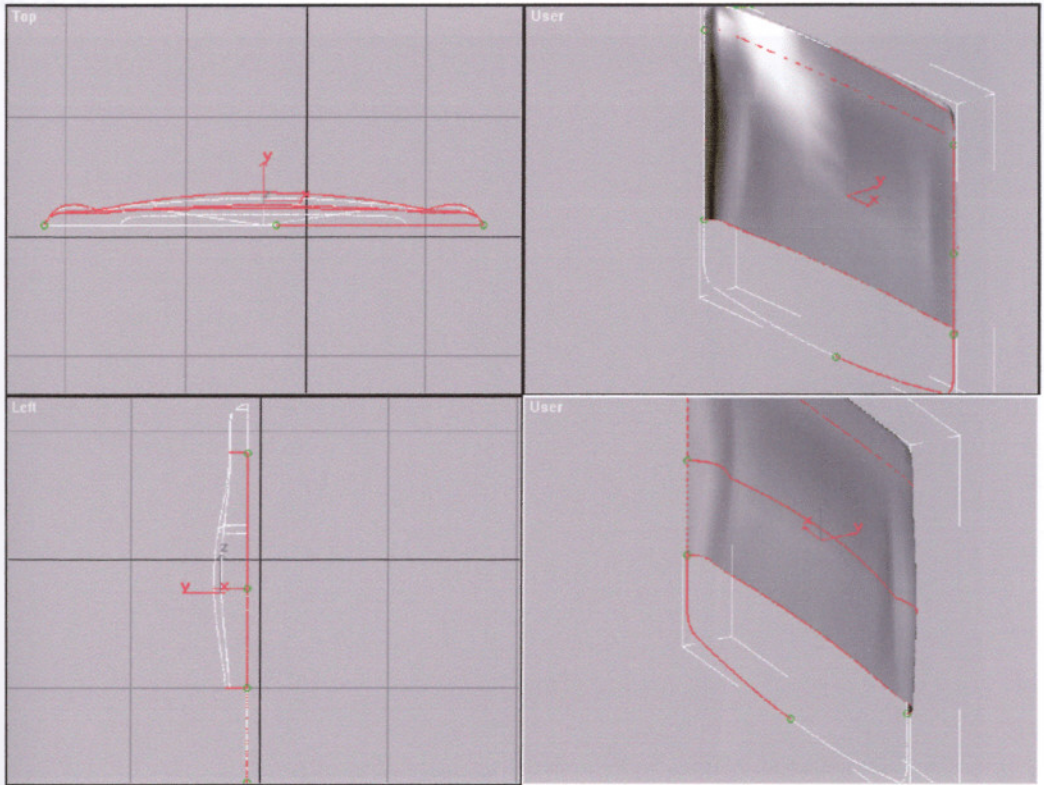
figure 3.5: To generate the back part of the screen, 3D NURBS splines are constructed in order to built a *Two Rail Sweep surface*.

146
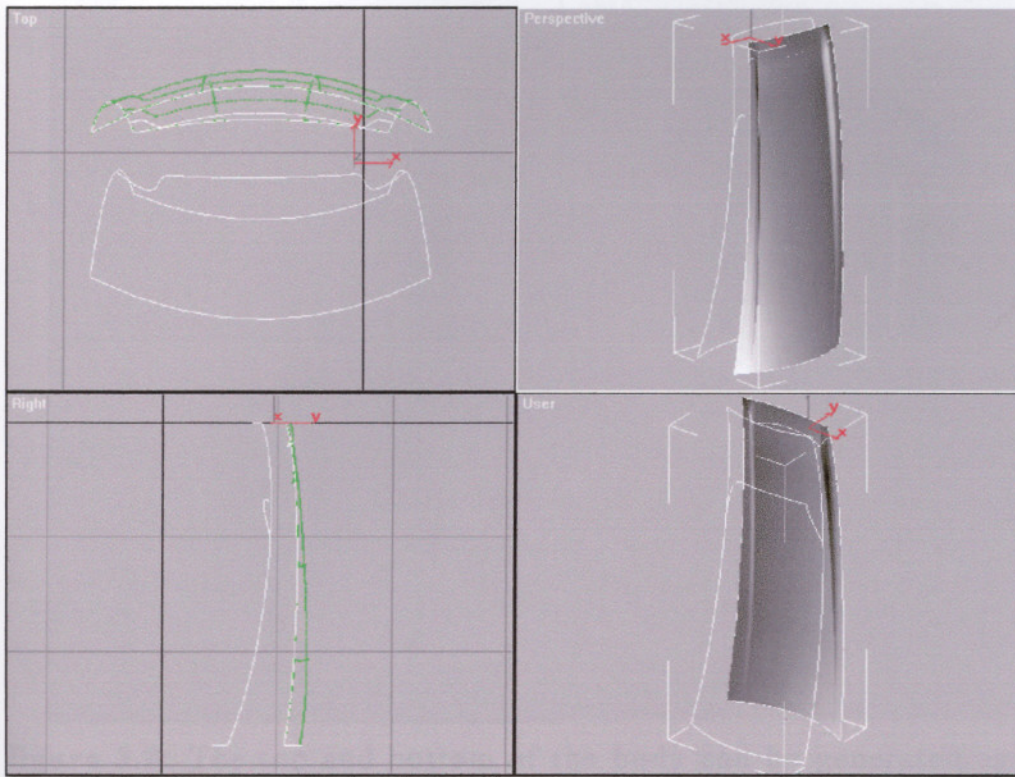
figure 3.6: For constructing the body of the monitor, appropriate NURBS curves are generated. Two rail sweep is used again for resulting surfaces.
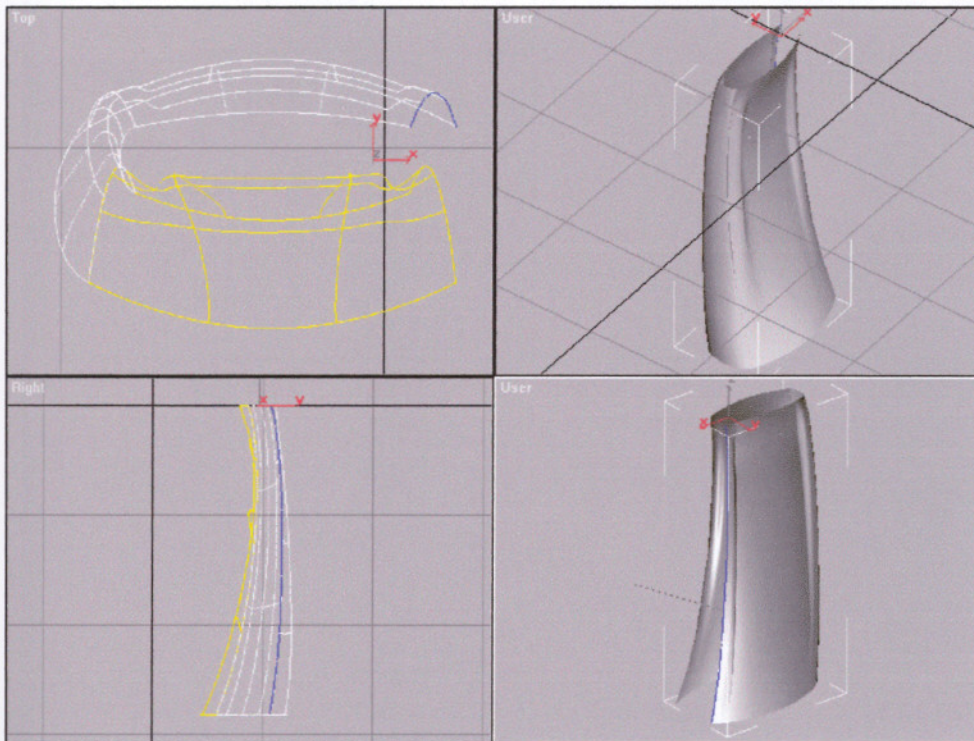
figure 3.7: Once both front and back sides of the body are completed, the sides can be generated by *blend surface*, with appropriate *tension* value.
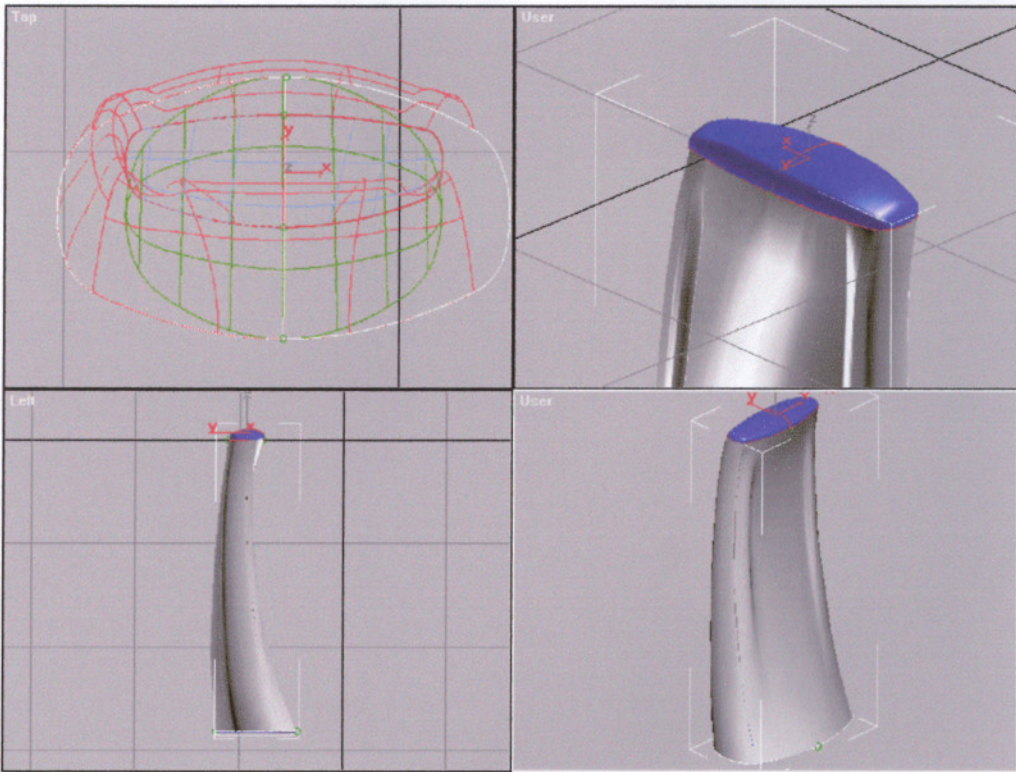
figure 3.8: The top and bottom of the body can be generated again with two rail sweep option. The base rail curves are derived from the existing surfaces, *with Create Curves/U Iso Curve* option of MAX.
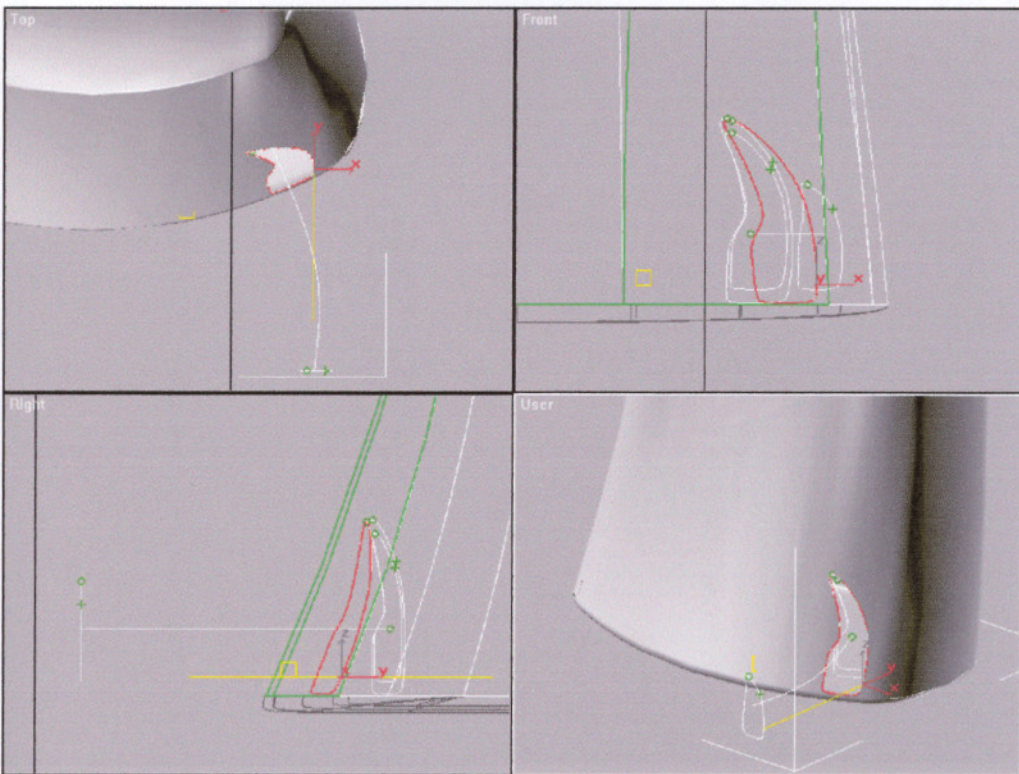
figure 3.9: To trim the body and construct the connection parts between the body and the front base, different cross-sections are drawn. The nearest cross-section is *projected* to the surface and *trimmed*.
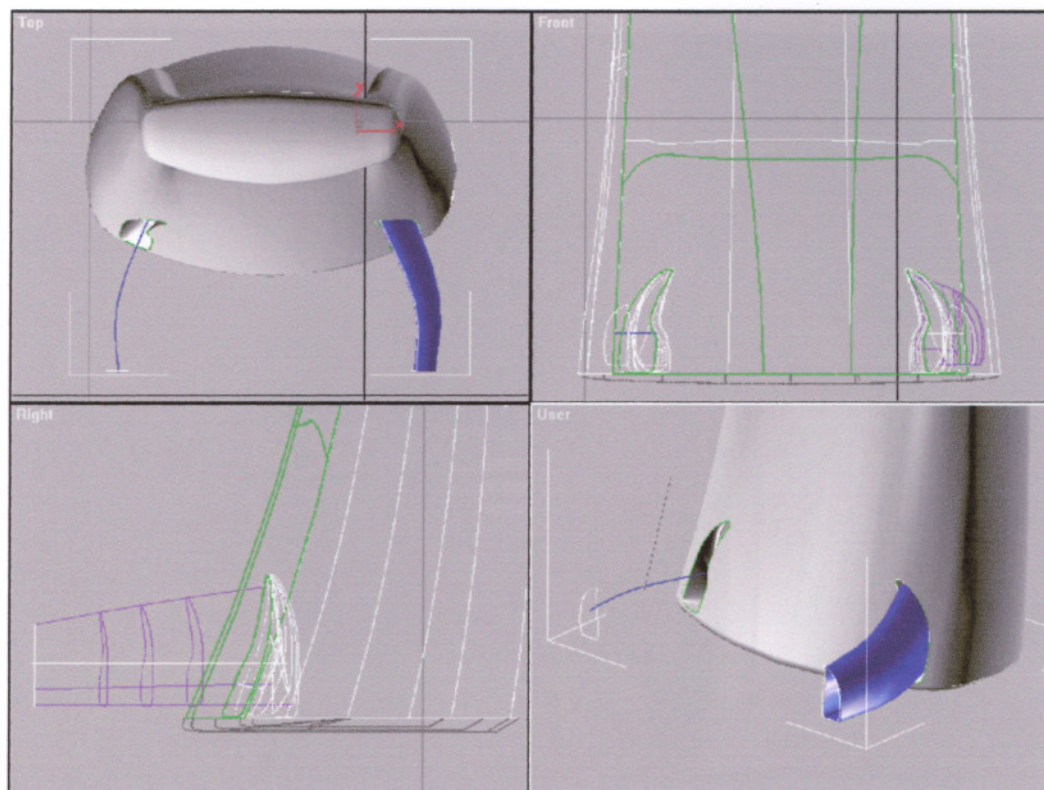
figure 3.10: The cross sections are aligned properly along a *path curve*, to generate *a One Rail Sweep surface*.
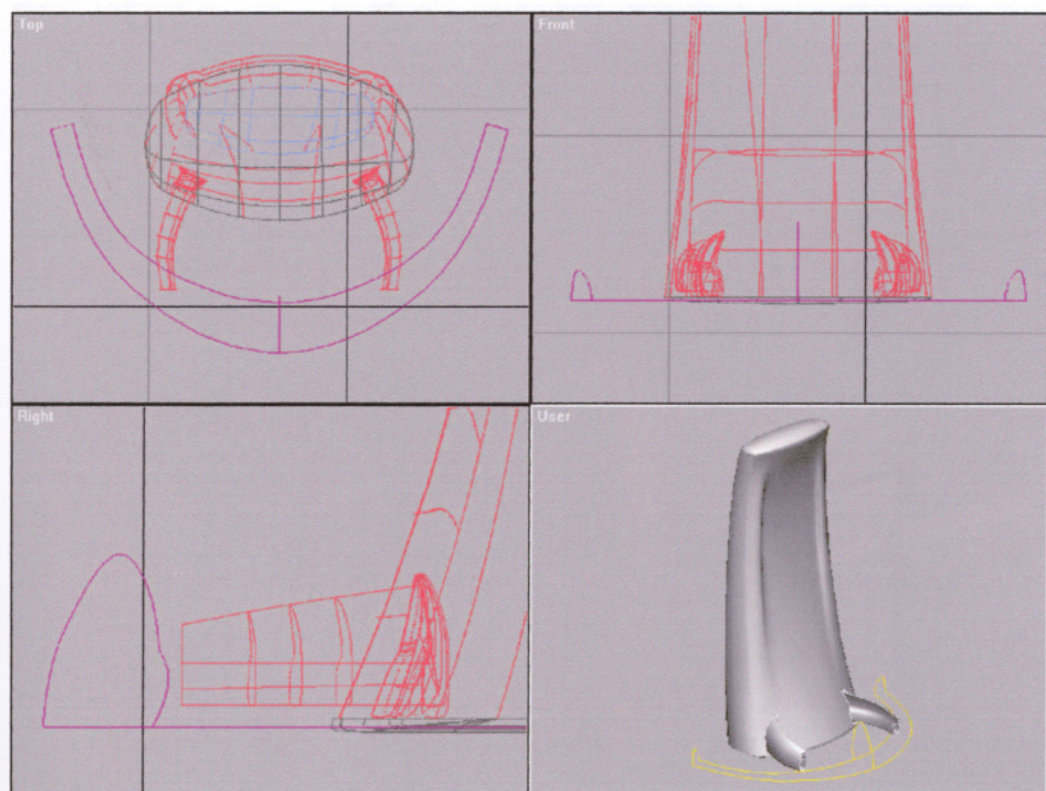
figure 3.11: The front base is generated again with two rail sweep. The two rail curves and three cross sections are constructed with NURBS curves. The cross sections are *snapped* to the rail curves to get them properly placed.
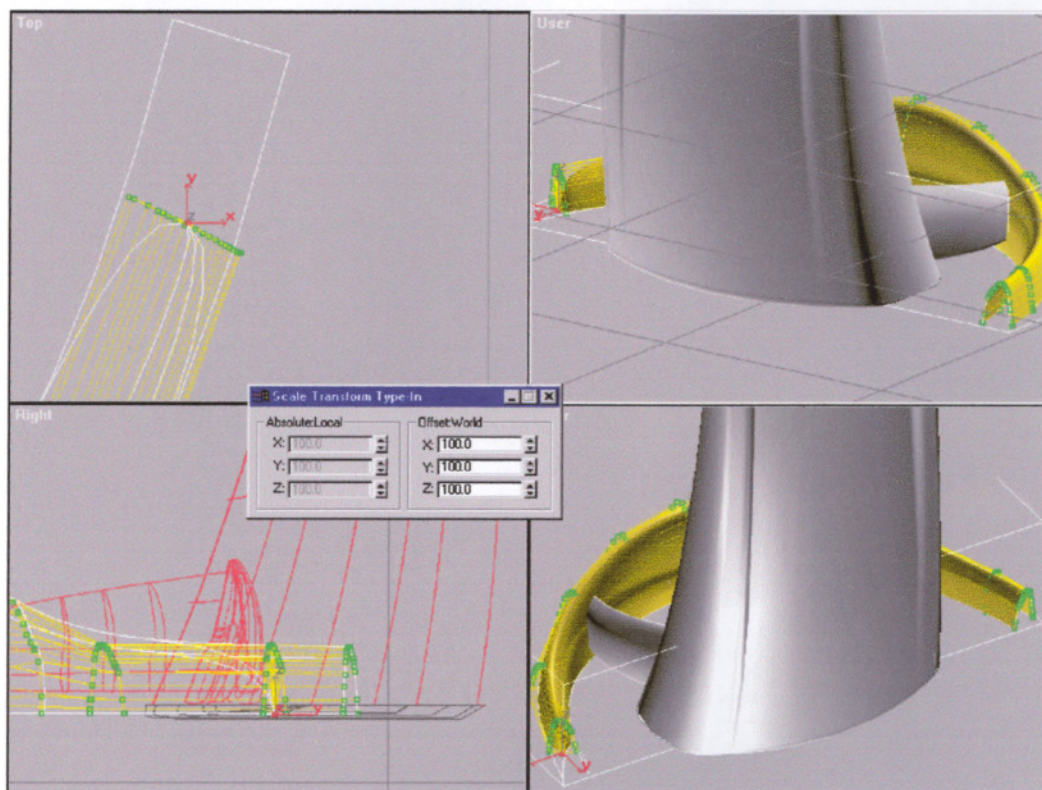
figure 3.12: The *Surface CVs* on the both open ends are *uniformly scaled* to get a closed end shape. The bottom is generated with two rail sweep.
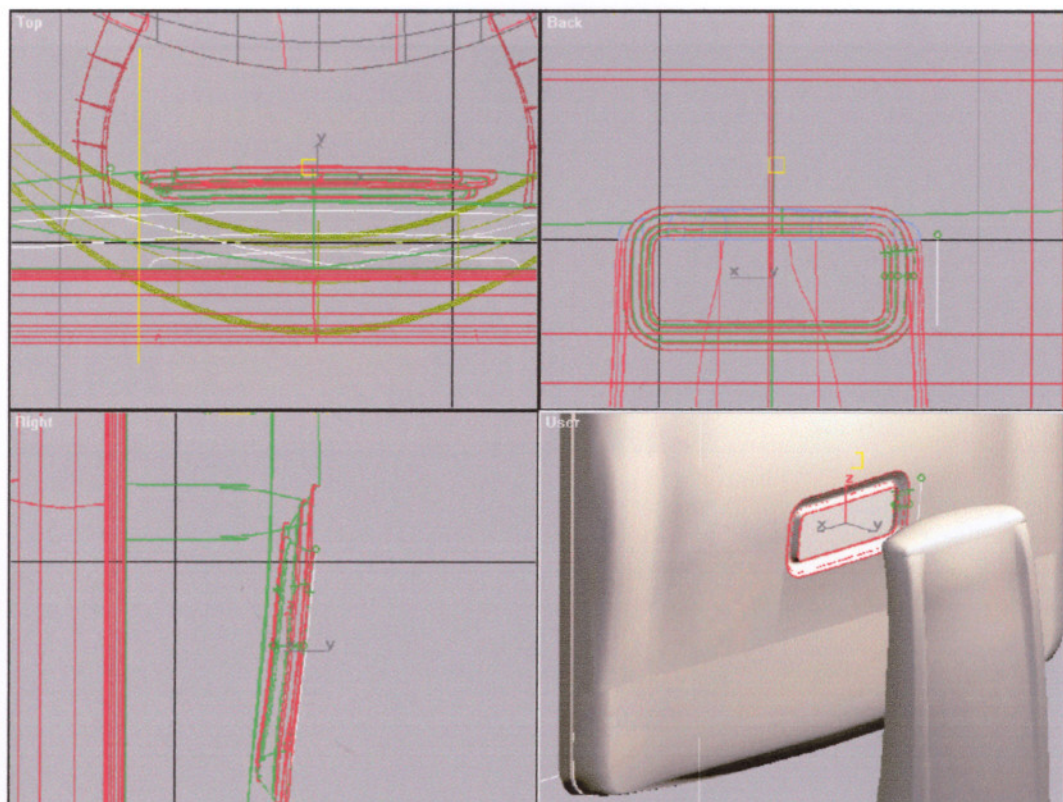
figure 3.13: The back part of the screen is trimmed to place a curved surface for the "joint" system. 3 different cross sections are used to form a *U Loft surface*, including the trimming curve.
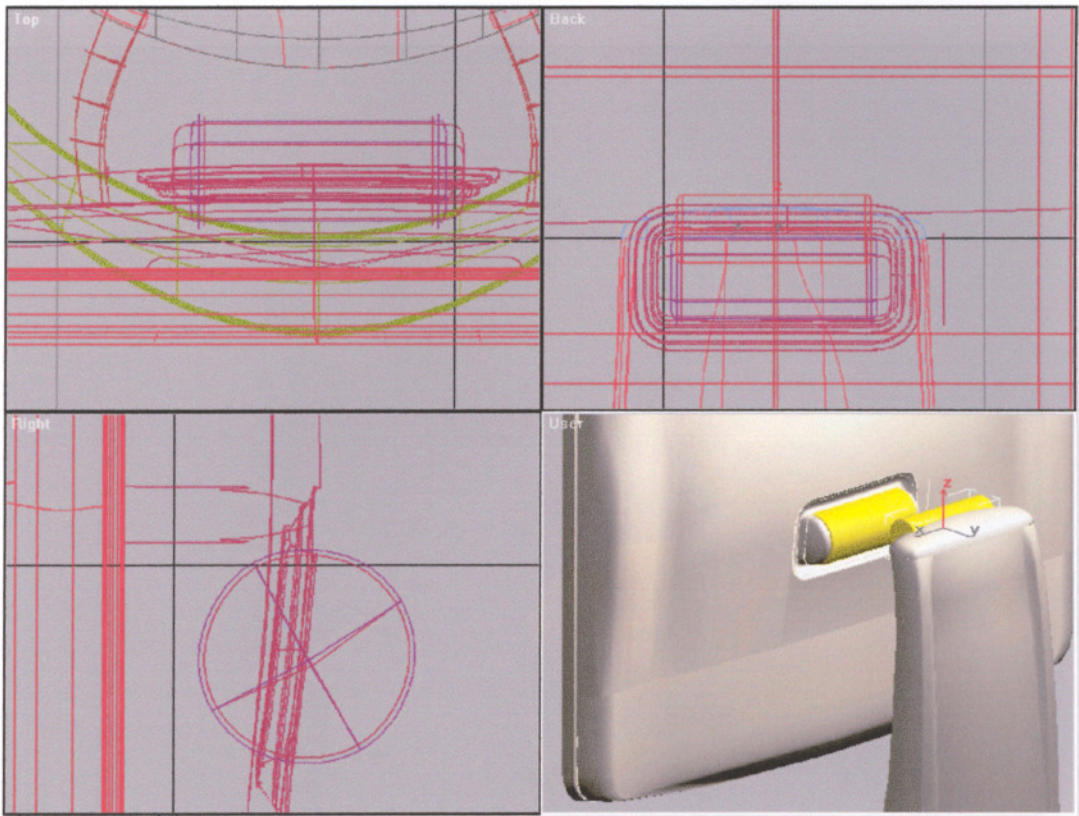
figure 3.14: The rotating parts of the hinge system are constructed *with cylinder primitives*.
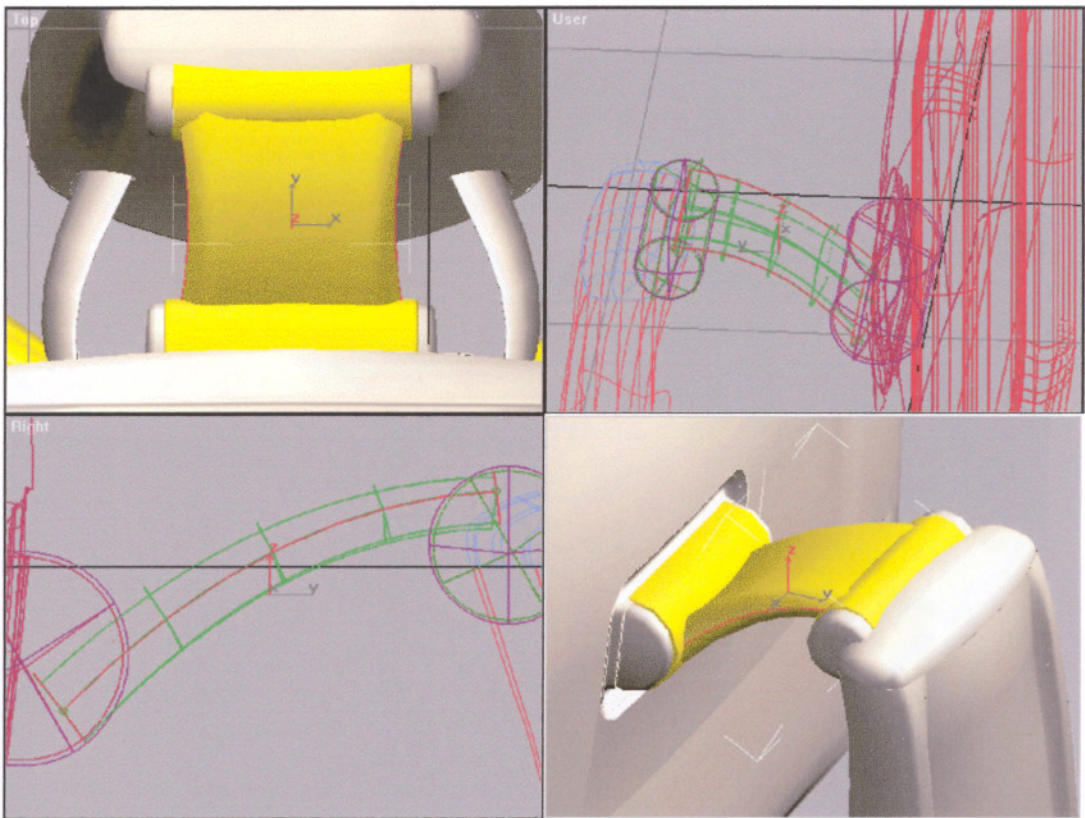
figure 3.15: The connecting part of the two cylinders is generated by a set of NURBS curves.

151
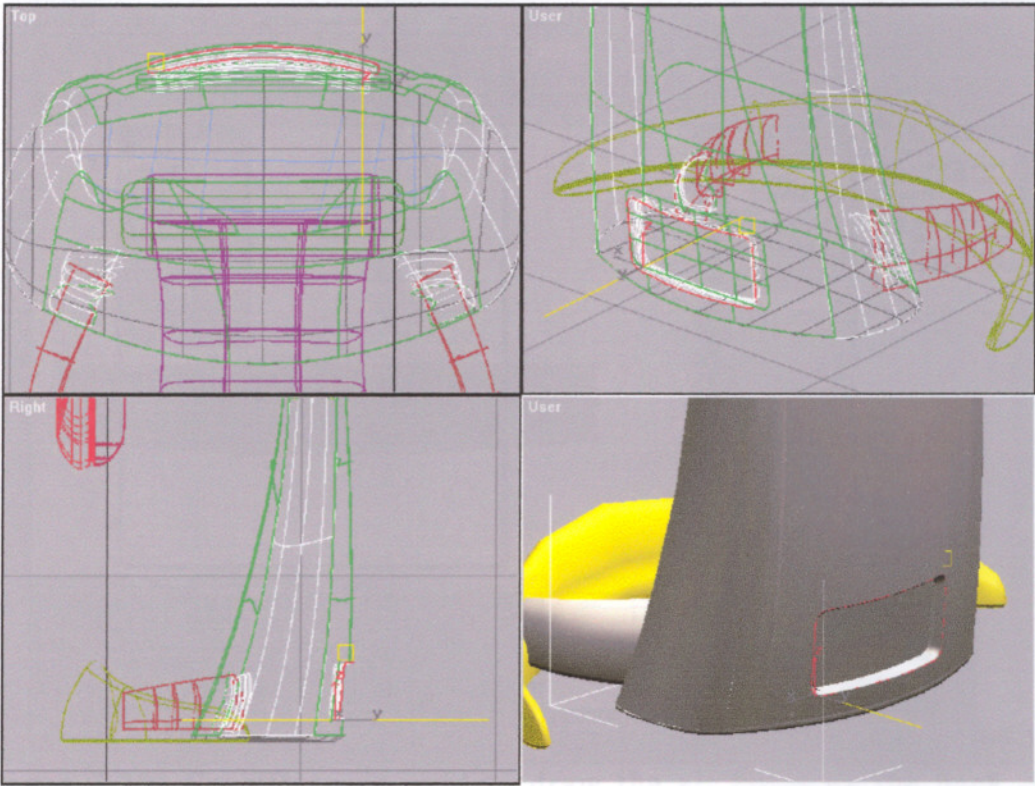
figure 3.16: The back side of the body is trimmed by projecting a NURBS curve and then a new surface is constructed to form the cable housing.
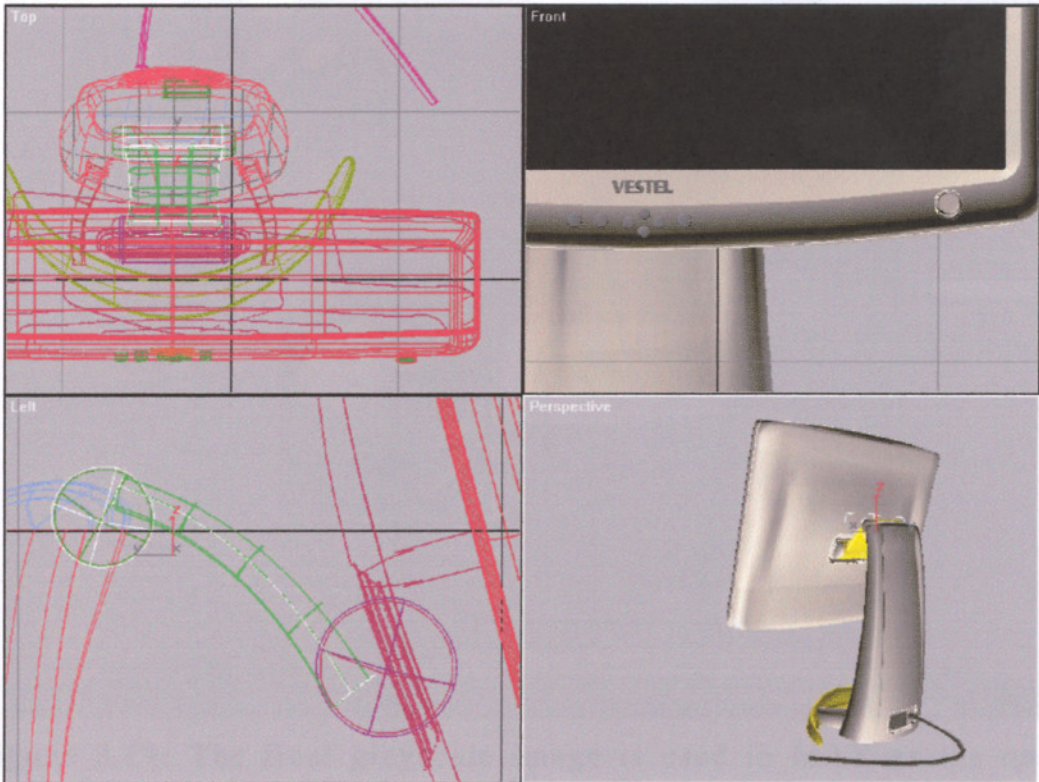
figure 3.17: Final details such as cable, power button, control panel and the logo are added. The moving parts are *linked* together.
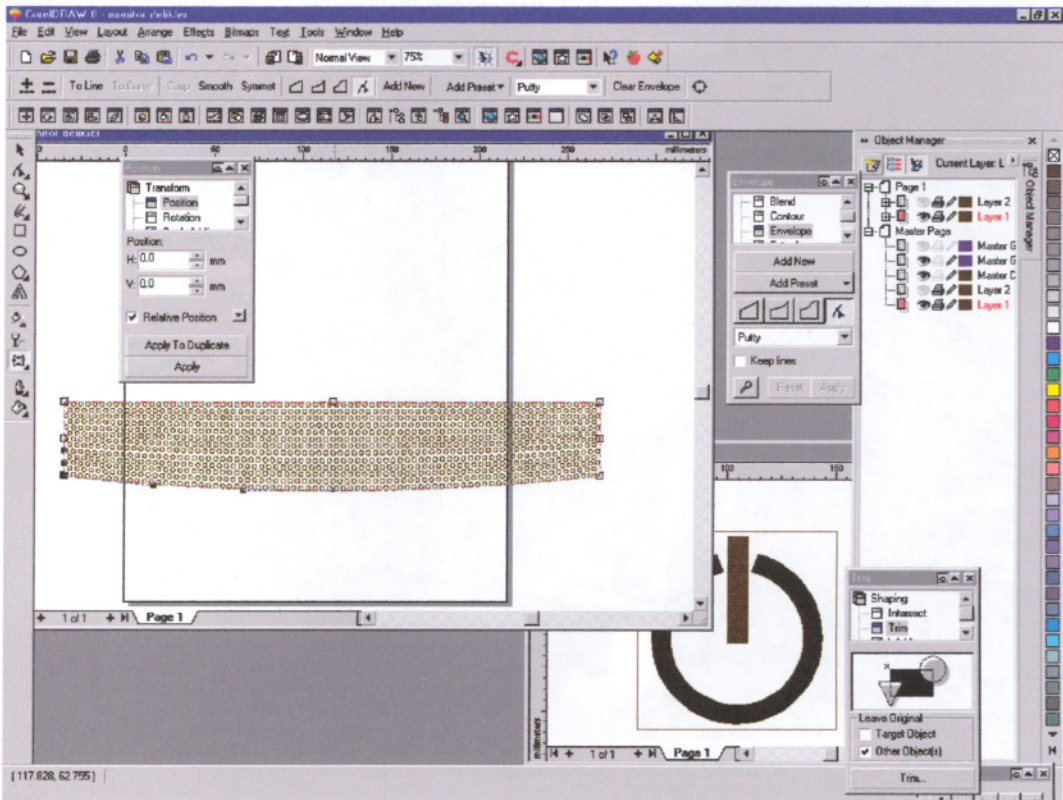
figure 3.18: CorelDraw is used to draw the air holes on the back of the screen. The image is exported as a *raster* file to MAX.
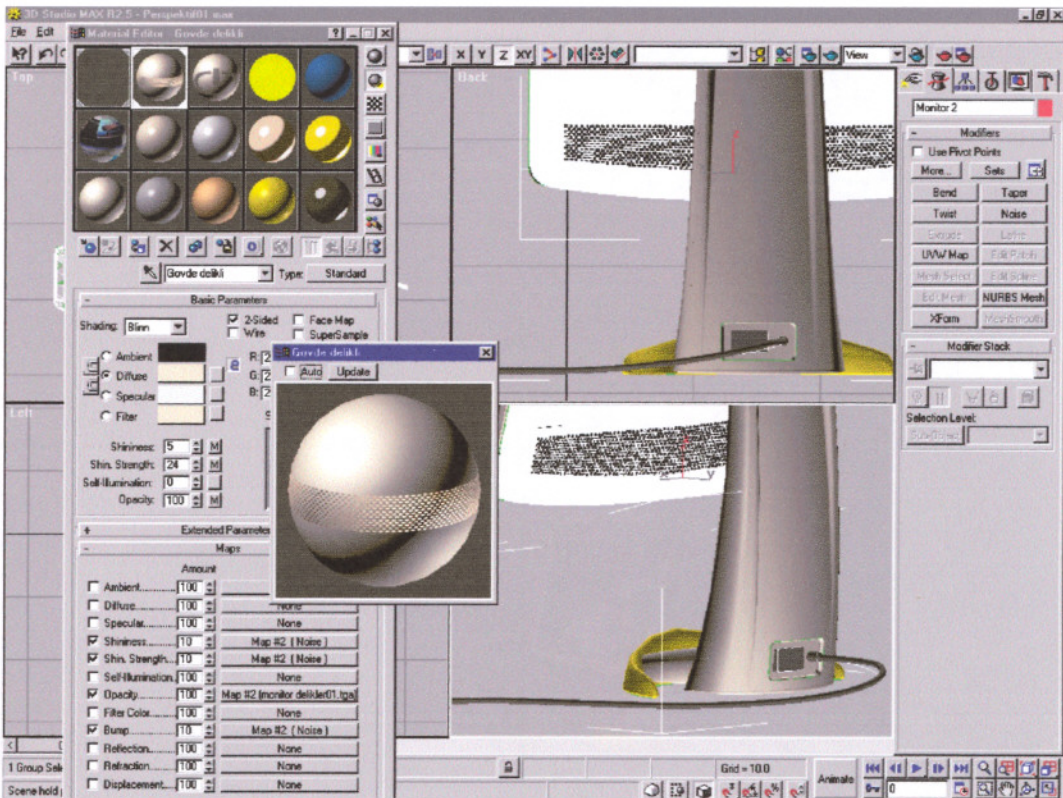
figure 3.19: The final grayscale image is used in MAX as the *opacity map* of the screen to simulate the holes. The image is properly placed by *planar mapping*.
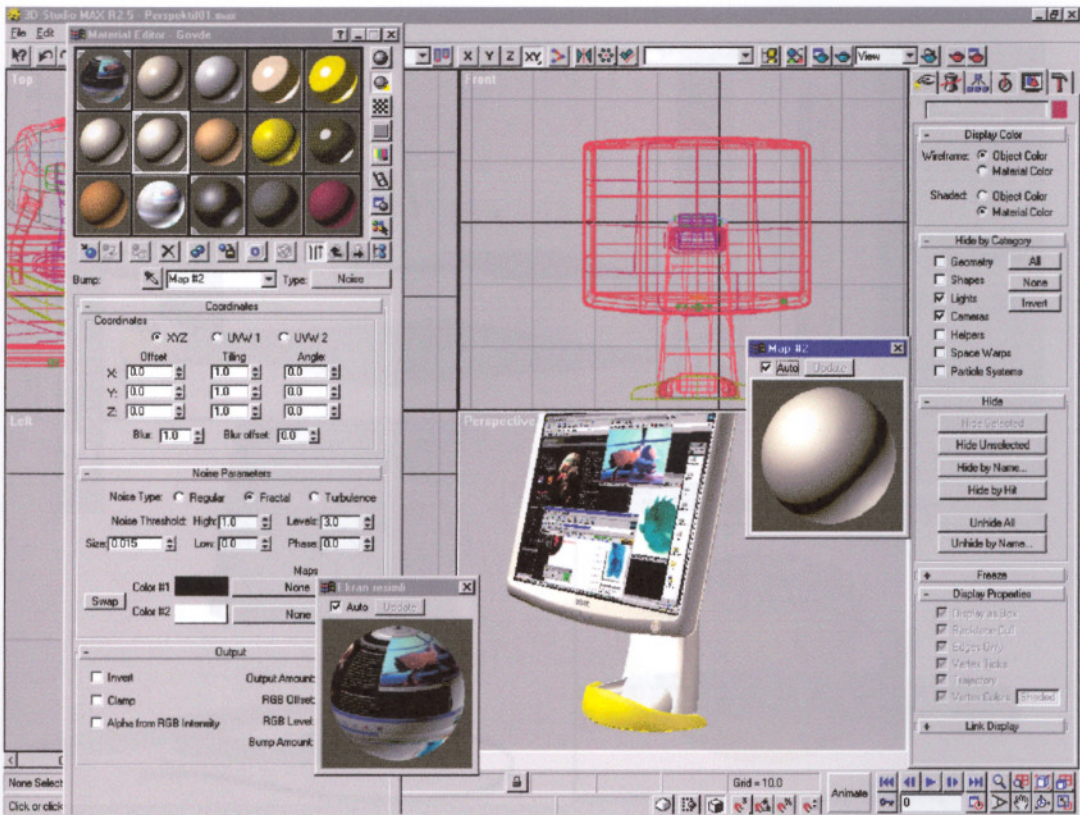
figure 3.20: *Screen capture* utility is used to obtain an image of a computer screen with several applications running. *Noise procedural texture* is applied to all plastic surfaces to simulate the graininess.
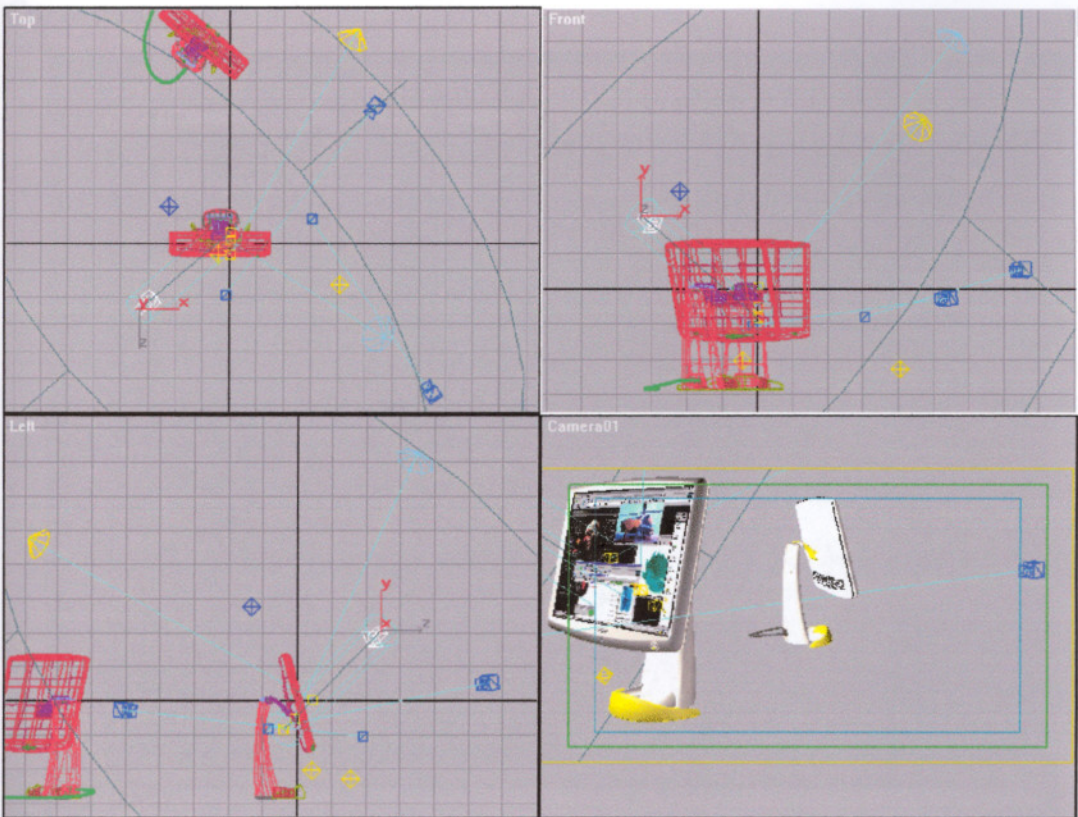
figure 3.21: For final renderings, different cameras are inserted. For every camera, different lighting setup is required.

154
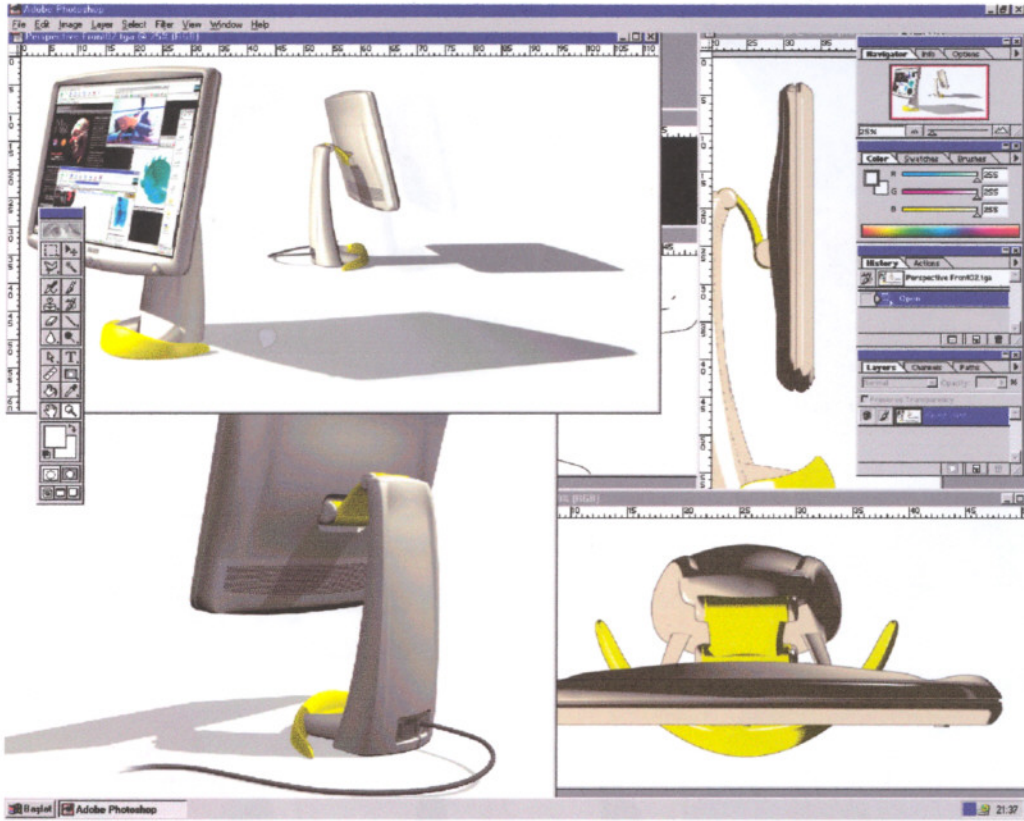
figure 3.22: Several other renderings with different camera angles, light setups, material and *shaders* are composed in PhotoShop. The outline image of the model is generated with a special plugin shader, *CartoonReyes*.
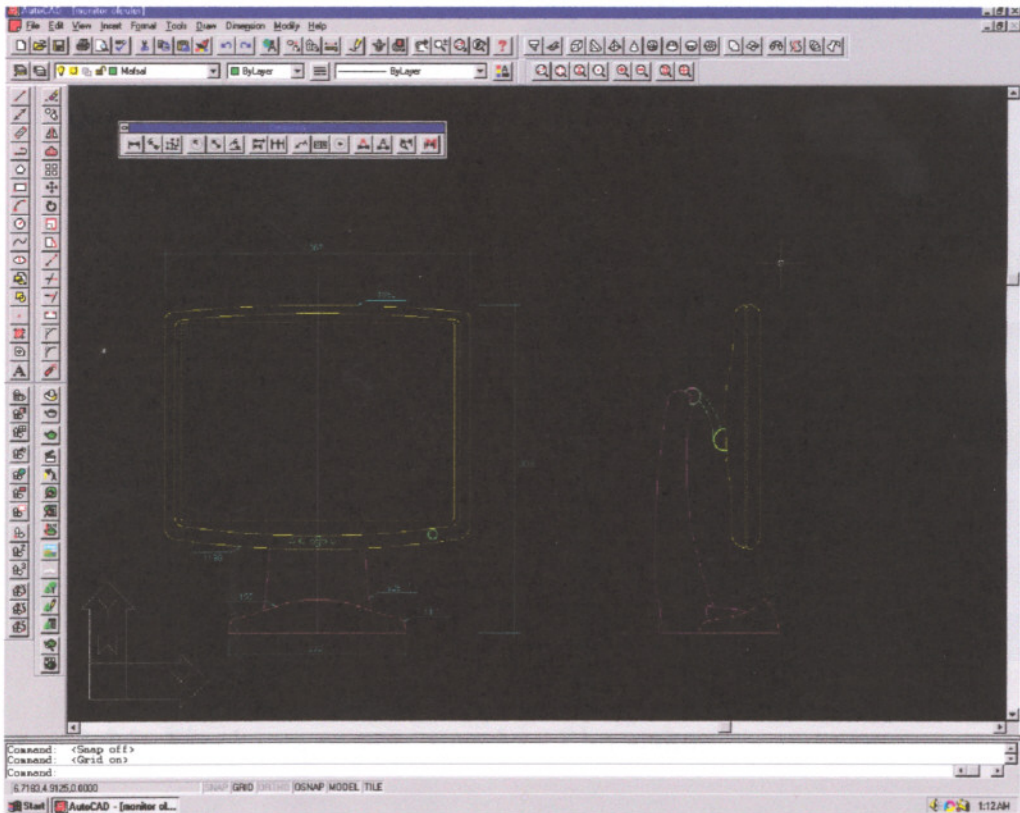
figure 3.23: Final dimensioning is done with AutoCAD.

155

figure 3.24: Final image composed in Photoshop.

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http://www.siggraph.org

Glossary

absolute coordinates The location of a point in terms of distances and/or angles from a fixed origin.

accuracy settings Refers to system tolerances. All 3D objects, whether manufactured or computer-generated, are defined within acceptable geometric tolerances.

active coordinate system Coordinate system in which key-in point coordinates and read-out coordinates are expressed.

active depth Plane in a 3D design upon which you can)lace elements and perform manipulations.

algorithm A mathematical procedure used to compute a desired result.

aliasing Refers to the jagged lines or edges that can appear in computer-drawn images. Aliasing occurs when smooth lines or edges in an image are drawn with pixels. Aliasing can be eliminated automatically through a technique called oversampling (also called *antialiasing)*, but at a cost of increasing the time required to create the image.

ambient light Background light that is defined in rendered images or animations. Examples of ambient light are starlight and hazy sunlight.

animation To give life to. In SM, animations can either be real time or simulated. A real-time animation would consist of a macro actually executing commands to modify or move geometry. A simulated animation would simply be a slide show of captured images.

annotation The text included on a drawing or model, such as notes, instructions, dimensions, etc.

API Application Programmer's Interface.

arc A curve segment defined by a start angle, end angle, and a constant radius.

array A rectangular or circular pattern of graphical objects.

ASCII American Standard Code for Information Interchange. A standard set of 128 binary numbers representing keyboard information such as letters, numerals, and punctuation.

aspect ratio The shape of the display device on which an image will be viewed. The aspect ratio of a rendered image is expressed as the width of the image divided by its height.

assembly A final gathering of piece-parts and subassemblies to make one unique assembled product.

assembly modeling The process by which individual solid models are brought together to form an assembly model.

associative geometry A system that lets you place graphic elements based on a relationship (for example, parallel to) with existing graphic elements. Elements placed associatively maintain the relationship when the existing graphic element is manipulated.

attenuation The gradual decrease of light intensity or fog thickness as it travels from its origin.

attribute Textual information associated with CAD geometry. Attributes can be assigned to objects and then later extracted. Applications include creating bills of material.

automatic mesh generation A process that uses geometry and topology of the solid model and mesh rules developed by analysts to allow computer generation of the mesh model.

axis An annotation tool that provides a model's orientation in 3D space.

B-spline curve Parametrically defined curve where each pole influences a defined range of the curve.

B-spline surface Parametrically defined surface where each pole influences a defined range of the surface.

bandwidth The difference in node numbers or degrees of freedom for a stiffness matrix stored by numerical ascending order of the nodes.

batch-oriented programs Batch implies control is passed to another solver or program for solution at a later time. The alternative is to perform the solution interactively.

Bezier curve Parametrically defined curve where each pole influences the entire curve.

Bezier surface Parametrically defined surface where each pole influences the entire surface.

bicubic patch A surface element that is defined by cubic equations in two parametric variables on its surface (e.g., *u* and *v*).

bill of materials A tabulated diagram that shows the assembly hierarchy, the number of occurrences of each part in each subassembly, and the number of occurrences of each sub-assembly in the overall assembly.

bitmap The digital representation of an image in which bits are referenced (mapped) to pixels. In color graphics, a different value is used for each red, green, and blue component of a pixel.

bit plane Hardware used as a storage medium for a bit map.

bits A binary digit (1 or 0).

blend A solid transition of variable cross section swept along an arbitrary path. Its definition consists of two or more dissimilar closed planer profiles and a trajectory curve.

boolean Boolean algebra is named after the English mathematician George Boole, 1815-1864. Also refers to three CSCi operations to construct solid objects: UNION, DIFFERENCE, and INTERSECTION. Any valid solid can be used in boolean operations, including primitives, geometric operations, or the result of previous boolean operations.

bottom-up design An approach to assembly modeling where the designer creates the part geometry as the first step. then combines parts into appropriate subassemblies and the final assembly. See also **top-down design.**

boundary A 3D outline of a data volume.

boundary evaluation An operation that generates a B-Rep solid from a CSG solid.

boundary representation (B-Rep) A database method that defines and stores a solid as a set of vertices, edges, and faces (points, lines, curves, and surfaces) which completely enclose its volume.

bounded objects In SM, an object is considered bounded if it has a complete set of bounding surfaces and is restricted to occupying a finite volume.

bounding box A box that encloses a 3D geometric object.

branch node A database tree structure in which a tree node is connected to two or more nodes below it (at a greater distance from the root node).

bump texture A texture that modifies surface normals and is used to shade an object's surface.

bytes A computer value that consists of 8 bits.

CAD Computer-Aided Design.

CAE Computer-Aided Engineering.

CAM Computer-Aided Manufacturing.

cartesian coordinate system A rectangular coordinate system consisting of three mutually perpendicular axes: the x axis, the y axis, and the z axis.

cascading windows A GUI design where the windows cascade. This is a special case of overlapping window management in which the windows are arranged automatically in a regular progression that prevents any window from being completely obscured.

CRT Cathod Ray Tube

CD-ROM Compact Disk-Read Only Memory

centroid The center of mass of an object. If the object's density is uniform, the center of mass is also the centroid of the volume. A value calculated by the mass-properties analysis of a solid model.

chamfer A beveled edge or corner between two otherwise intersecting lines or surfaces.

children (1) The components of a design instance in a product structure tree. Also referred to as *parts*. (2) Nodes in a database tree structure that have a parent.

CIM Computer-Integrated Manufacturing. Also, Corporate Information Management.

clean modeling Refers to the practice of removing geometry from a model that is not wanted or needed. Also refers to the use of proper geometry construction techniques, such as creating continuous surfaces, minimizing narrow faces, and avoiding small corner angles, that facilitates downstream processes.

click To select something by positioning the cursor and pressing a mouse button.

client A piece of software on the same network that requests and uses the capabilities provided by a server.

client-server architecture A GUI design that allows a single instance of the windowing system software to be shared across entire networks of heterogeneous machines. Response times may be limited by the communication bandwidth of the network.

clipping plane A plane parallel to the camera lens (or current view) that defines the near or far boundary of what is displayed. Objects closer than the near **clipping plane** and farther than the far **clipping plane** are removed from the display. If an object is bisected by a **clipping plane,** it appears to be cut in two.

CNC Computerized Numerical Control.

color map A range of colors associated with a range of scalar values. The scalar values can be assigned default rainbow colors or can be a custom RGB color mix.

color texture A texture that modifies the color, ambient, highlight, dissolve, or reflection of a material.

compiling The process of turning a programmer's code into a form the computer can understand.

component library A collection of frequently used, previously modeled components, often stored in an easily accessible location for access by all users.

composite imaging A process used to combine two or more 2D images to form a new image. For example, a rendered image could be composited over a scanned image to create a new image with a detailed background.

concurrent engineering Engineering teams working in parallel on different aspects of the same product; for example, design and manufacturing.

configuration A particular grouping of computer hardware as a functional unit. It may also include the allocation of hardware resources and sometimes refers to software parameter settings.

construction Any portion of a solid model that can be developed or constructed separately from and joined to the solid at a later time. Using multiple constructions saves CPU time.

Constructive Solid Geometry (CSG) A database structure which defines and stores a solid as a series of UNIONS, INTERSECTIONS, and DIFFERENCES by boolean techniques.

control panels In GUI design, control panels appear at the implicit or explicit request of the operator and provide information reflecting the current state of a number of related system parameters, any of which can be changed interactively while the panel remains on display.

controls In GUI design, any visually represented window component that can be manipulated directly with the mouse or keyboard.

coordinate system Geometric relation used to denote the location of points in 3D space. The most common is the rectangular coordinate system, whereby points are located by traversing the x, y, and z axes of 3D space. Normally, the origin of a coordinate system is defined as 0,0,0, though this is not required. Other coordinate systems are used to more easily express the coordinates of specific geometric entities. For example, a spherical coordinate system can be used to help define points on a sphere, and a cylindrical coordinate system to help define points on a cylinder.

coordinates Ordered set of absolute or relative data values that specify a location in a coordinate system.

coplanar Refers to two or more entities that lie on the same plane. Two planar surfaces, for example, that lie on the same 3D plane are considered coplanar. If these coplanar surfaces share a common edge, it is recommended that they be joined into a single surface.

CPU Central Processing Unit. It is responsible for arithmetic computations, logic operations, memory addresses, and data and control signal traffic in a computer.

CPU time curve If the Central Processing Unit (CPU) time required for a series of operations were charted, this would represent the CPU time required for later operations versus earlier ones.

cross section View of the interior of an element as it is sliced along a plane.

crosshairs A cursor usually made up of two perpendicular lines on the display screen used to select coordinate locations.

CRT Cathode Ray Tube. Denotes the video display tube used with computers.

CSG Constructive Solid Geometry.

cursor A pointer on a video display screen that can be moved around; used to place textual or graphical information.

curve A line that changes direction in a smooth, continuous fashion.

curve fitting The process of passing arc segments through a number of control points to create a curve.

curve smoothing The process of curve or surface approximation using polynomial equations to generate a curve that passes near, but not always through, a set of control points or mesh vertices.

curvilinear Refers to a path or trajectory that contains both line segments and curves (arcs or splines).

cutting plane A tool that slices through the 3D data exhibiting characteristics of a plane in the data, including scalar and vector measurements.

data Information used as a basis for reasoning or calculation.

data set A computerized collection of data items that can be processed to analyze or visualize relevant information (e.g., a 3D array of density samples from a medical scanner).

Database Related information organized and stored so that it can easily be retrieved and, typically, used by multiple applications. A noncomputer form of a database is the telephone directory.

datum Point (or plane) of reference. **DBMS** Database Management System.

debugging Act of removing flaws. In SM, the act of testing macros or programs to locate and remove sources of errors.

default A parameter or variable that remains in effect until changed. It is what a computer program assumes in the absence of specific instructions.

dependent Subordinate; relying on another item (root) for support. The position of a dependent element in a drawing file is determined by a predefined relationship with a root element.

depth cuing When calculating a computer-generated image, it is the darkening of surfaces farther from the observer to increase the illusion of depth.

design iteration The cycle in which a Solid Model design is modified and evaluated. More design iterations allow more possibilities to be explored, thus resulting in a design of usually higher quality.

dialogue boxes In a GUI, dialogue boxes provide a visual and functional context for presenting options from which to select. Any interactive exchange of information that takes place in a limited spatial context is considered a dialogue.

digitize Entering graphical location points into a computer with a tablet, puck, stylus, or scanner.

digitizing tablet A graphics input device that generates coordinate data. It is used in conjunction with a puck or stylus.

dimension (v) To form to the precise scale; to place dimensioning information on a graphic element, (n) One of a group of properties whose number is necessary and sufficient to determine uniquely each element of a system of usually mathematical entities. For example, the numeric length of an axis; the collection of annotations placed on a part to display it in either 2D or 3D representation.

dimension-driven A system in which exists the ability to modify the value of a dimension and have all affected geometry change.

dimensionally constrained Refers to a state in which a design is controlled by the dimensions associated with the geometry of the design. Thus, when the value of a dimension changes, all affected geometry also changes. Typically, but not always, dimensionally constrained systems provide for bi-directional associativity and for topological constraints.

disk Round, flat plate coated with a magnetic substance on which data is stored.

display What you see on your screen. Sometimes the display needs refreshing, which you can do manually or have set to happen automatically.

DOS Disk Operating System.

double curvature Refers to a surface entity that curves simultaneously in two directions.

downstream process All subsequent operations or processes performed on or with a solid model. Downstream processes include (but are not limited to) analysis, NC code generation, and rapid prototyping (RP).

dragging Dynamically moving the virtual image of a graphical entity across the display screen to a new location using a puck, mouse, or stylus.

DXF Drawing Interchange File.

DVD-ROM Digital Versatile Disc-Read Only Memory

dynamic analysis Determines the motion of a system due to the action of applied time-varying loads and/or restraints. Position, velocity, and acceleration are reported.

dynamics Animation that lets you see the creation or modification of elements in relation to the movement of the screen cursor.

edge A bounded line or curve that forms the intersection of two faces on the surface of an object.

element In *modeling*, the basic building block used in geometric modeling. Every modeled object created is assembled from elements. Elements include points, lines, curves, surfaces, solids, etc. In *analysis*, the lowest form of entity analyzed. In FEA this could be a mesh element. In kinematics this could be a single rigid body.

entity Anything which is being displayed on an interactive CRT which can be identified as a discrete "thing." Entities can consist of geometry (points, lines, circular arcs, conies, splines, surfaces, solids, etc.), as text items (notes, dimensions, lists, tables, etc.), or as "information-adding" things (coordinate systems, surface normal vectors, etc.). Menus, icons, prompts, tutorials, etc., are usually not considered entities.

environment variable A variable that acts upon the entire system. Environment variables may be stored with and applicable to a single model file, or they may be stored and applied globally to all model files. Also known as a *system variable*.

explicitly defined Information that is directly represented (rather than implied). In SM, for example, an edge directly defined by an equation and two endpoints is explicitly defined.

export Sending a scene or model to a file (IGES, DXF, TIFF, HPGL, etc.) so that it can be read or imported into another program.

expression Algebraic expression for numerical entities (distance, radius of circle, and so forth).

extract To separate a part from the whole, to copy part of a surface without necessarily changing the location, thus creating a new element.

extrusion A process used in geometric modeling to convert 2D shapes into 3D shapes. A 3D object is created by displacing a copy of the 2D shape, then linking the copy to the original to form a closed, solid object. Examples of extrusion are a cylinder and a prism.

face A type of element used in geometric modeling. A face can be a flat, planar polygon or a curved, bounded surface. Some systems define a face as the bounded portion of an infinite surface region.

FEA Finite Element Analysis.

feature-based modeling Performs functions that were previously performed using primitive boolean operations. *Example:* A through-hole could be defined using a boolean difference operation and a cylinder of sufficient length. However, if the design became thicker and the cylinder was not long enough, the hole would become a blind hole. In contrast, the through-hole feature understands the rule that it must pass completely through the part and will do so no matter how the part changes.

features Entities that encapsulate how geometry looks and how the geometry behaves using rules and attributes along with their defining constraints and geometry. Features impart not only geometry to a design but a set of associative, nongeometric attributes which aid in communicating the design to the manufacturing process. Features include holes, slots, ribs, webs, and user-defined features.

FEM Finite Element Modeling.

field rendering A technique used to improve the frame-to-frame continuity in a rendered animation. Field rendering combines interleaved portions of two consecutive rendered images to create a single image, which is then recorded onto video. Sequences of field-rendered images yield better continuity of motion between frames.

file Collection of logical records stored as a unit.

file name User-defined name given to an interactively created file. The name should be relevant to the contents of the file.

fillet Arc that adds material to a part by rounding a corner and blending two lines, curves, or surfaces.

Finite Element Analysis (FEA) An analysis technique that computes stress, strain, displacement, etc., using a continuum structure broken into discrete finite-sized pieces.

flat shading A display technique used to shade the surfaces of objects quickly. Flat shading is slower than wireframe display and does not show smoothed edges. Also referred to as *polygonal shading*.

floating-point operations A basic mathematical operation (e.g., addition or division) that operates on noninteger numbers (i.e., numbers with a decimal fraction such as 5.631).

floppy disk A circular plastic disk coated with magnetic material mounted in a square plastic holder. It is used by a computer to store information for later use. It can be inserted or removed from a floppy disk drive at will. It is also called a *diskette*.

font Complete set and style of the characters and symbols of a typeface used for displaying text.

form features In Solid Modeling, parts of solid objects that can be specified in familiar engineering terms (e.g., fillets, slots, and through-holes).

formula-defined shapes Shapes that are defined by using one or more equations. This includes complex shapes such as aesthetic bottles or simple shapes such hyperbolic paraboloids, oblate spheroids, prolate spheroids, or ellipsoids.

frame The basic unit of time measurement in an animation. Instead of using seconds to tell time, a frame count is used. The duration of an

animation is changed by increasing or decreasing its total number of frames. Typically, 30 frames of animation correspond to one second on NTSC videotape (25 frames for PAL videotape, 24 frames for film). Motion is created by storing object locations at every frame of an animation.

frame buffer A portion of a computer's memory that stores an image so that it can be displayed on the computer screen. The number of bit planes in a frame buffer determines the total number of colors that can be displayed on the screen simultaneously.

free-form geometry Geometry that uses curves and surfaces to define objects.

free-form surface Surfaces that are not limited to mathematically simple linear or quadric surfaces.

Fresnel reflection The reflection that results from light striking a diffuse surface at a glancing angle. Ray-tracing uses Fresnel reflection.

Fused Deposition Modeling (FDM) A patented process by Stratasys, Inc. (Eden Prairie, Minn.) for producing a physical prototype directly from a 3D surface or solid model.

gamma correction A method of adjusting pixel values so they can be properly represented on an output device.

geometric operations Refers to the group of SM operations that include but are not limited to blends, extrudes, sweeps, revolves, fillets, corner rounds, and local surface deviations.

geometric transformation Translation, rotation, and scaling.

geometry Elements that make up a model, such as points, lines, surfaces, solids, etc.

global coordinate system The coordinate system in which the geometry of the entire product is represented.

global coordinates The location of a point within the permanent coordinate system of 3D model space. Also known as *world coordinates*.

Gouraud shading A rendering process with blended colors based on light measured for each vertex in a polygon. Unlike Phong shading, the appearance of edges and the area of each polygon will remain flat.

grid An area on the graphics display covered with regularly spaced dots used as a drawing aid.

group A collection of elements. For example, the elements that form a chair might be organized into groups that make up the legs, the back, and the seat. You can perform many operations on groups, including positioning, assigning materials and texture maps. Groups can form the individual components of an assembly model. Productivity is enhanced by modeling a group or part once and referring to its definition in many assemblies. This is referred to as *part instancing*.

GUI Computer-generated Graphical User Interface consisting of windows, icons, and menus.

hard disk A rigid metal disk covered with magnetic material. Mounted permanently in a hard disk drive, it spins at high velocity, is capable of storing large amounts of data, and allows information to be accessed faster than a floppy disk drive.

hard-coded features Features which are selected from a menu (choice list), icon, or other mechanism for identifying a predetermined geometric configuration, the methods for controlling its placement, and the types of variables it can contain.

hardcopy A paper printout or plot of information stored in a computer.

hardware The portion of the SM installation that supports and facilitates the use of SM software. This includes computers, monitors, input devices, printers, and plotters.

hardware rendering The interactive display and shading performed by the system workstation independent of but in conjunction with a software application.

hidden line A wireframe display option that displays only the lines that should be visible from the current view. Lines that would be obscured by solid objects are hidden.

highlight In viewing and display applications, the color of an object where it directly reflects the light source. The size of the highlight is determined by the shininess of the material. In general modeling, elements change color when selected. This is referred to as the *highlight color*. The color used is typically a system variable.

hybrid solid modeler An SM database that actively maintains two or more substantially different representations of solid objects such as CSG and B-Rep.

I/O Input/Output, a mechanism by which a computer accepts or distributes information to peripheral devices such as plotters, printers, disk drives, and modems.

icon Symbol that graphically identifies a command. IEEE Institute of Electrical and Electronics Engineers.

IDE Integrated Drive Electronics

IGES Initial Graphics Exchange Specification. Used to represent the two- and three-dimensional drawings of objects. (An ANSI standard.)

image Information that can be displayed as an array of pixels on a video display terminal.

image file format Establishes the *x* and *y* resolution and the aspect ratio of the image file for a particular output device.

image file type Determines how the image is stored. An example of an image file type is .rla.

implicitly defined Information that is defined by a situation rather than by explicit definition. In SM, for example, an edge defined as the intersection of two surfaces is implicitly defined.

interoperability Related to the examination of the information exchange between two specific CAD systems, and the ability of each CAD system to use such information.

interface Shared boundary through which the user and software communicate.

interpolation The calculation of an estimated property value for a spatial location that is not a sample point.

intersection Boolean operator used to intersect solids and form a common volume.

intersection curve The curve computed at the intersection of two surfaces.

kernel-based architecture A GUI design in which the windowing services are provided by some portion of the operating system itself, or by a standard add-on module that resides along with the operating system

in RAM- or ROM-based libraries. This provides high levels of interactivity, but with dependents on the architecture and available resources of a single computer.

keyboard interface As an input device, the keyboard is more efficient for sequential tasks, such as text entry.

key point Point on an element, including vertices, to which you can snap.

Laminated Object Manufacturing (LOM) A patented process by Helisys, Inc. (Torrance, Calif.) of producing a physical prototype directly from a 3D surface or solid model.

LAN Local Area Network. One of several systems used to link computers together in order to share data, programs, or peripherals.

layer A logical separation of data to be viewed individually or in combination. Similar in concept to transparent acetate overlays.

leaf A part in a product structure tree that has no children.

light A simple, ambient illumination source that can be moved and colored.

line A 2D geometric entity represented by a directional vector. A line will occupy a finite section of the vector defined by two endpoints.

line segment Part of a line having two endpoints. **line string** Series of line segments joined as a single element. **line style** See **style.**

linetype Sometimes called line font. It represents the appearance of a line. For example, a continuous line has a different linetype than a dashed line.

liveware As opposed to hardware or software, liveware refers to people: designers, engineers, and managers of SM software.

local coordinate system The coordinate system in which the geometry of the components of an assembly in the product structure tree is represented. By defining the components of an assembly in the assembly's local coordinate system, the assembly can be positioned and oriented as a whole with respect to the overall product in the global coordinate system.

177

local coordinates The location of a point within a local coordinate system defined relative to the global coordinate system, to points on an entity, or to another local coordinate system.

lofting The process of fitting a surface between two or more differing control profiles.

Macintosh® OS Operating System of the Apple Macintosh computer, first introduced in 1984 as the first mass-marketed computer to feature a high-resolution, bit-mapped graphic display and a direct manipulation interaction style.

macro Generally, ASCII text files containing commands specific to an SM program. Once executed, macros are read by the SM program, and the commands are interpreted and executed one at a time.

material In viewing and display applications, a material is a predefined "color" applied to the surface of an object. It controls how an object appears when it is rendered. In addition to color, each material definition can include reflective properties such as surface shininess, dissolve (transparency), texture attributes, and reflection maps.

matte Refers to information in a rendered image that defines the transparency of each pixel. A pixel can be opaque, partly transparent, or completely transparent. The unused pixels of an image (black space) have a completely transparent matte. Other types of images, such as scanned, painted, and frame-grabbed images, can contain matte information as well.

mechanism modeling The use of assembly models to simulate a mechanism's behavior. If a product's function is kinematic or dynamic in nature, assembly modeling can simulate the relative interaction between components.

memory One of the essential components of a computer: where programs and data are stored. Memory includes both ROM (read-only memory) and RAM (random-access memory).

menus A means of command retrieval that enables an operator to see and point instead of remembering and typing. Menu systems greatly reduce problems caused by the limitations of human memory, but do so at the expense of motor performance.

merge To combine or unite graphic elements.

mesh A computational grid associated with one or more topologies.

mesh density The fineness/coarseness of a mesh.

mesh elements Simplified states of stress and displacement characterizing the behavior in each finite element.

message boxes In GUI design, message boxes provide critical information which is not requested and typically appears only when the system has entered, or is about to enter, an unrecoverable and potentially dangerous state.

microcomputer A computer principally designed for use by a single person.

microprocessor An integrated circuit "chip" (or set of chips) which acts as a CPU of a computer. Examples of microprocessors are the Motorola 68020 and the Intel 80486.

Microsoft Windows® A Graphical User Interface (GUI) created in 1985 by Microsoft Corporation as a multitasking, graphics-oriented alternative to the character-based environment provided by MS-DOS on PC-compatible systems. The bit-mapped displays and mouse-driven menus provided by Windows first opened the door to graphics-oriented software on the PC.

minicomputer A computer that is generally configured for use by a small number of people. It generally has more powerful resources and peripherals than a microcomputer.

mirror To create the reverse image of a display set through a plane or around a defined axis.

model Graphic representation or schema.

model space An electronic space defined in terms of three-dimensional coordinates where 3D modeling takes place.

model-drawing associativity The associative relationship between a 2D drawing and a 3D model. The associativity is typically one-way where the model updates the drawing or two-way where both the drawing and the model can update each other.

modeling precision The method of operational accuracy employed by the SM operator, such as making sure that arcs (fillets and rounds) are

actually tangent to adjacent straight edges and that they actually connect. Higher modeling precision means that more SM data can be utilized by downstream processes.

modem Stands for modulator/demodulator. It is the device that allows a computer to send and receive data over telephone lines.

motion The process of creating a sequence of frames in order to animate visualized data.

mouse An input device which is well suited to certain types of interaction tasks. The mouse provides an efficient means of accomplishing tasks that require spatial manipulation, such as menu navigation and window sizing and positioning.

multiuser The ability for a computer operating system to allow multiple users on different terminals to share resources such as the CPU, storage, and memory.

multitasking The ability for a computer operating system to manage concurrent tasks.

named element An element that is named and that can be placed or manipulated by specifying that name.

named view A defined view that is named and that can be recalled by specifying that name.

NC Numerical Control.

network Interconnection of host computers and workstations that enables them to share data and control. The term *network* can mean the devices that connect the system, or it can mean the connected system. Also referred to as the *process of discussion* between people.

node The basic graph element used to represent distinct items (vertices, faces, etc.). A single coordinate in a grid.

nonrational B-spline B-spline curve or surface whose poles have no weighting factor.

nonuniform B-spline B-spline curve or surface where knots occur at varying U or V increments.

normal In SM, planar profiles have a front and a back side. For example, in an extrusion operation, "normal to the profile" means that the front of the profile is facing the direction of extrusion. Normals are displayed to

indicate the orientation of faces (polygons or surfaces). A normal is displayed as an arrow originating at the center of and at right angles to each face. Normals point toward the viewer for faces drawn in counterclockwise order. Since faces are visible only when they are facing toward the viewer, it is sometimes necessary to reverse a normal to correct a face's orientation. For a solid, all surface normals should point outward. See also **surface model.**

NURBS Nonuniform Rational B-Spline. A spline and surface representation based on B-splines. Nonuniform refers to the fact that the control points of each curve segment do not have to be evenly spaced.

object-oriented A way to develop computer systems such that the basic form of the program is an "object" that includes both data and instructions for manipulating data.

octree An SM database method in which a solid is represented by a hierarchical tree generated by a recursive subdivision of a finite universe.

omnidirectional light Light that is emitted in all directions at equal intensities. The sun is an example of an omnidirectional light. Other types of lights are directional spotlights and directional infinite lights.

OODB Object-Oriented Database.

open B-spline curve B-spline curve that has start and end edges in either or both the U and V directions.

open B-spline surface B-spline surface that has start and end edges in either or both the U and V directions.

operating system Software that manages computer resources and allows user access and control.

origin The intersection point of the axes in a coordinate system. For example, the origin of a cartesian coordinate system is where the x, y, and z axes meet, at (0,0,0). Also, the center of the boundary that encloses a data volume or geometry.

paging A software operation that swaps blocks of data and/or software between memory and disk storage during program operation. It is used when the amount of data and/or the size of a program exceeds the available memory in a computer.

parameter Any piece of mathematical information used in the creation of, or extracted from, a geometric entity.

parametric CAD system A type of modern CAD system that lets you relate the geometry of different elements of a product. When you change one element, the geometry of the rest of the product changes as well.

parametric curves and surfaces Mathematically described free-form curves and surfaces.

parametric element Graphic element whose position is determined by a relationship with another element. Parametric elements are also called *associative elements*.

parametric equation Equation expressing the coordinates of either a curve as a function of one parameter or a surface as a function of two parameters.

parenting A technique used to link objects together with movable joints. An example of parenting would be rotating wheels parented to a car. When a parent is moved, all of its children (and grandchildren, and so on) move with it. A term also used in database tree structures where higher-level nodes are parents to lower-level nodes.

part A construction that cannot be further reduced. SM parts consist of axial sweeps, rotational sweeps, and solid primitives, and can contain any number of features.

pattern To fill a defined area with repetitions of a predefined geometric shape.

PC Personal Computer.

PDES Product Data Exchange using STEP

PDM Product Data Management. A technology for managing all engineering and manufacturing data for a product to control the product development cycle.

Phong shading A display process that computes lighting and color for each pixel of a displayed object. Phong shading also blends the boundaries between adjacent polygons to make faceted surfaces appear smooth and continuous.

photorealistic rendering Refers to the ability to display an object on screen with photorealistic qualities. Rendering techniques used can range

from transparency, texture mapping, specular reflection, radiosity, bump mapping, shadowing, and multiple light sources.

pixel The fundamental element of a computerized image (short for "picture element").

plane Spatial element in 3D geometry that may or may not have a boundary, but is level (having no elevations or depressions) and is 3D.

plotter A computer-controlled device that produces text and images on paper or acetate by electrostatic, thermal, or mechanical means.

point Graphic element representing a position in space.

pointing device A hand-held device (typically a mouse or puck and tablet) used to control the movement of the cursor on the display screen.

pole Vertex of a polygon. Also called a *control point.*

polygon Multisided shape.

polygonal geometry Geometry that uses points, lines, and flat faces to define objects.

polygonal representation A form of boundary representation (B-Rep) in which all enclosing surfaces are planar.

polyline A geometric entity composed of one or more connected segments which are treated as single entity.

primitive Simple or elemental. The lowest state of a solid model. A solid or surface that is not derived from other elements. A solid volume defined by simple standard geometrical shapes, such as a box, cone, and cylinder. Primitives are used by the CSG modeling method.

procedural texture A ID, 2D, or 3D texture that is calculated from a mathematical formula. If you cut open an object that has a 3D procedural texture applied to it, you will see a texture on the inside.

process plan A plan which defines the order of manufacturing operations needed to obtain a final part.

product life cycle Refers to the cycle of a product from concept to design, manufacture, use, disposal, or recycle. Can also refer to the life span of a particular product model or version.

profiles A set of curves on a plane connected end to end and forming a cross section of a blend, sweep, extrude, revolve, etc.

project To move an element or point along a straight line or vector (usually the view z axis) until meeting another element. Often a data point is moved down the z axis of the view until an element is found within a specified tolerance of the axis. The point is then calculated as the point on the element closest to the z axis.

project file A file that provides environment-variable settings, history information, and descriptions of user-defined selections for a project.

prompt A message from the computer software requesting a response from the user.

pull-down list An interface object used to select from a large set of options. A pull-down list is typically characterized by an arrow button. Clicking on the arrow, which normally displays the current selection, posts a list of available options.

quadric surface Surfaces generated by quadratic equations (spheres, cylinders, cones, ellipsoids, paraboloids, and hyper-boloids).

query boxes In Graphic User Interface (GUI), design query boxes appear in response to operator actions, but are not requested explicitly. Query boxes prompt for a single piece of information, such as a yes-or-no answer to a single question, and provide a context in which the necessary information can be provided.

radio button An interface method for setting options where you must select one of the options, but only one.

radiosity A process where certain aspects of an object's reflective characteristics can be computed; then, when the point of view is moved, these do not need to be recomputed.

RAID Redundant Array of Inexpensive Disks

RAM Random-Access Memory.

Rapid Prototyping (RP) The process of producing a physical prototype directly from CAD 3D surface or solid modeling data by a number of patented processes such as SLA, LOM, FDM, SGC, or SLS.

raster A regular array. A computerized image is composed of a raster array of pixels.

rational B-spline Curve or surface that has weighted poles.

ray-tracing A technique used to create realistic reflections and refractions on reflective surfaces. Ray-tracing is a high-quality alternative to reflection mapping.

real time The execution of time during an actual solid modeling session as opposed to simply viewing the results of an execution previously performed. Similar to a live versus a recorded event on video.

recursive subdivision The process of subdividing a shape (e.g., square or cube) into successively smaller parts, usually of the same shape.

redraw Redisplaying the display contents without recalculating the database. Also referred to as *refresh*.

reference plane Any two of the three axes in a cartesian coordinate system form a reference plane. There are three reference planes of any given cartesian coordinate system, the *X-Y* plane, the *Y-Z* plane, and the *X-Z* plane. Sketch pads for variational profiles. They provide a frame of reference for spatial location of elements.

reflection map A movable image to cast background reflections onto reflective surfaces. Reflection mapping is a faster alternative to ray-tracing, but it can only approximate simple reflections (like a windshield reflecting clouds) or enhance the reflectivity of metallic surfaces.

refraction The bending of light as it travels through a dense material such as glass or water. Refraction is simulated by ray-tracing and is typically defined as an attribute of a material.

relative coordinates Coordinates specified by differences in distances and/or angles measured from a previous set of coordinates rather than from the origin point.

relative mesh density The ratio of density of the finest and coarsest regions of a finite element mesh as measured by element edge lengths or sometimes face areas.

render Computing all information in a scene about objects, surfaces, lights, and cameras to create a photorealistic image.

revolve A process used to convert a 2D profile or silhouette into a 3D object. The 3D object is created by revolving the 2D profile around a central axis to sweep out a surface. Examples of objects created using

revolve are wine glasses, lamp shades, and vases. This is also referred to as a *surface of revolution.*

RGB A color space used to specify a color using values for Red, Green, and Blue. Values are usually specified between 0 and 1 for each color to obtain a color mix for a material definition. For example, the values 0.4, 0.4, and 0 yield a dark yellow color. RGB color space is also used to specify the colors of individual pixels in a rendered image.

rigid bodies A body on which any two points remain the same distance apart during motion. The shape of the body does not change.

RISC Reduced Instruction-Set Computing.

ROM Read-Only Memory.

root The design instance that is the top of the product structure tree. Also, element(s) upon which an associative element or macro depends.

RP Rapid Prototyping.

ruled surface A surface generated by linear interpolation between two lines or curves, or a point and a line or curve.

scan line A row of pixels in a rendered image. Stated another way, a rendered image is comprised of scan lines, which are in turn comprised of pixels.

scene An arrangement of tools, geometries, labels, and annotations in 3D space that can be rendered or animated.

screen image The current state of the CRT screen. Specially developed images of solid models can be displayed, saved for use in animations and simulations, converted to graphic files or 35mm slides, overheads, etc.

script A set of command instructions. An operator may use a script when flavoring CAD data before transfers or when creating consistent test case files for data exchange testing.

scroll bar A bar on the side of a list that lets you scroll through the list by clicking on a direction arrow.

SCSI Small Computer System Interface

sculptured solid A solid which contains sculptured surfaces.

sculptured surface A free-form surface that is curved in more than one direction, typically defined by NURBS, Bezier, or other mathematical definitions.

Selective Laser Sintering (SLS) A patented process by DTM Corporation (Austin, Tex.) for producing a physical prototype directly from a 3D surface or solid model.

server A computer-running software that provides a particular capability to an entire network of interconnected computers.

session The process of saving, recalling, or starting a new model.

SFC Shop Floor Control , the operational control of the workflow through the factory floor.

shape 2D or 3D element.

shell A solid model defined by a surface, thickness, and surface normals, such as formed sheet metal.

simulation The act of displaying a predetermined sequence of events. Simulations can be interactive or self-running. An interactive simulation prompts for input to determine a course. A self-running simulation displays images or executes commands based on a predetermined plan.

single curvature A surface entity that curves on only one direction, such as an extruded arc or spline.

smoothing A technique in which element normals are to be interpolated to give those elements a smooth, nonfaceted appearance.

snap To place the cursor using an Input Generation command, with the cursor appearing to jump or snap to the point.

software Computer code that operates and controls computer-related hardware. Software can be used for design, analysis, or manufacturing, and includes SM, FEA, and NC.

solid Geometric element, such as a cube or sphere, having three dimensions.

Solid Ground Curing (SGC) A patented process by Cubital, Incorporated (Troy, Mich.) for producing a physical prototype directly from a 3D surface or solid model.

solid model Mathematical model composed of primitives or enclosed by surfaces. Valid solid models have surface normals that point toward the exterior of the solid.

Solid Modeling (SM) A geometric technique used to build and manipulate solid objects and combine them into assemblies. Complex

solid objects are built from primitive shapes using boolean operations. Primitive shapes usually include analytic solids such as a block, cylinder, cone, sphere, and torus, linear and rotational sweeps, and parametric free-form surfaces. Solid Modeling can determine and store physical properties of objects such as weight, volume, surface area, etc.

solid modeling engine A tool kit or package of core SM functions that can be used as a basis for the development of an SM program. The provided functionality of a solid modeling engine can range from purely math-related functions to a full-featured modeling, database, and display package.

solid of revolution Solid composed of one surface that is swept about an axis and closes on itself; sometimes called a *sweep*.

solids-based NC machining A process where both the design model and the NC source code are geometrically represented as part of the solid model.

source code The instructions that make up a program in ASCII or readable text format.

specular reflection A mirrorlike reflection characteristic of metallic or glossy surfaces.

spline A mathematically defined curve through an ordered set of points.

state tree Hierarchical diagram showing the global and local modifications of a solid model.

STEP Standard for the Exchange of Product Model Data, a familiar name for the emerging international standard ISO 10303. The goal is a complete, unambiguous, computer-readable definition of the physical and functional characteristics of a product throughout its life cycle.

StereoLithography (SL) A patented process by 3D Systems, Incorporated (Valencia, Calif.) for producing a physical prototype directly from a 3D surface or solid model.

stylus An input device used like a digitizer puck, but looks like a pen.

subdivision The process of dividing a solid model into smaller constructions to be operated on separately. The subdivision of a solid models saves CPU time.

subassembly A gathering together of piece-parts into a logical unit that will eventually be added to an assembly. An example of a subassembly would be the ring and rod in our test case.

subtree A subset of a tree that consists of a node and its descendants.

surface A boundary defining an exterior face of a solid model. The surface is typically defined beyond the limits of the face. Enlarging the extent of the face still yields a valid face on the solid.

surface rendering A rendering method for creating high-quality images with antialiasing, reflections, and transparency.

sweep A solid geometric operation defined by sweeping a planar cross-section profile along an arbitrary curve.

system crash An internal conflict or error in hardware or software that causes the SM system to halt operations. A system crash can cause software to lock out any input or the hardware to shut itself down. SM data is usually lost unless automated recovery procedures were in place.

tabulated surface A special case of the ruled surface generated by a straight line as it moves parallel to itself along a curve.

tessellating Subdividing a patch element into face elements and a curve element into a line element (applied in polygonal modeling). Tessellation lines are lines which connect tessellated elements.

texture A preprocessed image that modifies surface detail. A texture is part of a material definition and can impart color, bump, and transparency effects to the surface of an object. Texture is mapped to the surface of an object to give it more detail.

thresholding Specifying a specific range of measurements you want to exhibit.

TIFF Tagged Image File Format.

tiled windows In a Graphic User Interface (GUI), design where the windows are arranged automatically by the windowing system to completely fill the available display space (which may be either the entire display screen or an entire content area of a window).

tolerances Refers to the limits of accuracy of a system. Similar to manufactured objects, computer-generated geometry can be constructed to varying tolerance levels.