COMPUTER AIDED DESIGN
CAD

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INNOREGIO: dissemination of innovation and knowledge management techniques

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Contents

1 DESCRIPTION

1.1 What is the technique

Computer Aided Design-CAD is defined the use of information technology (IT) in the Design process. A CAD system consists of IT hardware (H/W), specialised software (S/W) (depending on the particular area of application) and peripherals, which in certain applications are quite specialised. The core of a CAD system is the S/W, which makes use of graphics for product representation; databases for storing the product model and drives the peripherals for product presentation. Its use does not change the nature of the design process but as the name states it aids the product designer. The designer is the main actor in the process, in all phases from problem identification to the implementation phase. The role of the CAD is in aiding him/her by providing:

- Accurately generated and easily modifiable graphical representation of the product. The user can nearly view the actual product on screen, make any modifications to it, and present his/her ideas on screen without any prototype, especially during the early stages of the design process.
- Perform complex design analysis in short time. Implementing Finite Elements Analysis methods the user can perform:
- Static, Dynamic and Natural Frequency analysis, Heat transfer analysis, Plastic analysis, Fluid flow analysis, Motion analysis, Tolerance analysis, Design optimisation
- Record and recall information with consistency and speed. In particular the use of Product Data Management (PDM) systems can store the whole design and processing history of a certain product, for future reuse and upgrade.

The technique initiated in the MIT from Ian Sutherland, when the first system the Sketch-pad was created within the SAGE (Semi-Automatic Ground Environment) research project. The automotive and aerospace industries were the first users and the forerunners of development of CAD technology.

The first system were very expensive, the computer graphics technology was not so advanced at that time and using the system required specilised H/W and S/W which was provided mainly by the CAD vendors. The first CAD systems were mainframe computer supported systems, while today the technology is for networked but stand alone operating workstations (UNIX or WINDOWS based systems). AUTODESK was the first vendor to offer a PC based CAD system the AUTOCAD (beginning of 1980). Today WINDOWS is the main operating system for CAD systems.

The first applications were for 2D-Drafting and the systems were also capable of performing only 2D modelling. Even today 2D-drafting is still the main area of application (in terms of number of workplaces). Later, (mid-1980), following the progress in 3D modelling technology and the growth in the IT H/W, 3D modelling systems are becoming very popular. 3D modelling are at the beginning wire frame based. Aerospace and automotive industries were using surface modelling systems for exact representation of the body of the product. At the same time solid modelling was recognised as the only system, which could provide an unambiguous representation of the product, but it was lacking adequate support for complex part representations. Today we are experiencing a merge of solid and surface modelling technology. Most solid modelling systems are capable of modelling most of industrial products. Systems sold today (especially for mechanical applications, which are the majority of systems sold world-wide) are characterised as NURBS (Non Uniform Rational B-Sline) based systems, employing solid modelling technology, and they are parametric and feature based systems.

The use of CAD systems has also been expanded to all industrial sectors, such AEC, Electronics, Textiles, Packaging, Clothing, Leather and Shoe, etc. Today, numerous CAD systems are offered by several vendors, in various countries.

1.2 Objectives of the technique

Originally the technique was aiming at automating a number of tasks a designer is performing and in particular the modelling of the product. Today CAD systems are covering most of the activities in the design cycle, they are recording all product data, and they are used as a platform for collaboration between remotely placed design teams. Most of its uses are for manufacturing and the usual name of the application is CAD/CAM. The areas of application of CAD related techniques, such as CAD, CAEngineering and CAManufacturing is shown in Fig.1. On the left side of the figure we have a simplified representation of the design cycle and on the right side the use of IT systems. Each of the above functions is not accomplished by a single system and it is quite often for a company to use more that one system, especially when we have CAD and CAE applications.

CAD systems can shorten the design time of a product. Therefore the product can be introduced earlier in the market, providing many advantages to the company. In fig.2, there is a representation of the product development time and of the product useful life span. The shortest the development time, the earliest the product is introduced into the market and it may give a longer useful life span, if the built in quality is correct.

As mentioned above, the first applications of CAD were 2D drafting applications, while now most of them are 3D solid and parametric representations of the real part. Complete assemblies can be modelled and a full analysis of a virtual prototype can be performed. The 3D representation can be exported to other platforms and it can be the communication medium between groups of people from various departments of a company-organisation.

CAD systems enable the application of concurrent engineering and can have significant influence on final product cost, functionality, and quality.

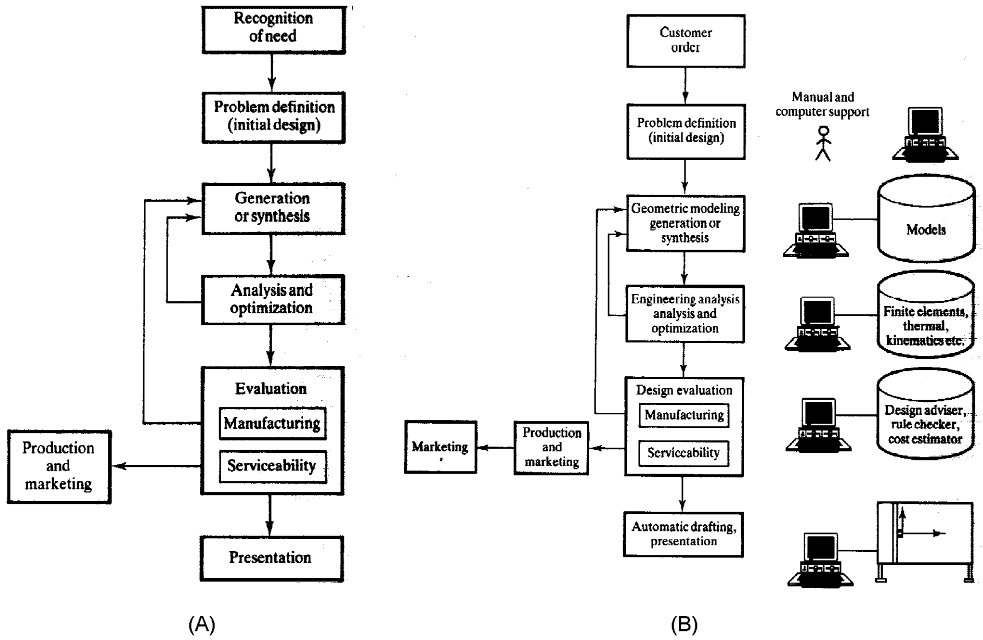


Fig.1. (A) The traditional generalised design process, and (B) IT applications in the design process.

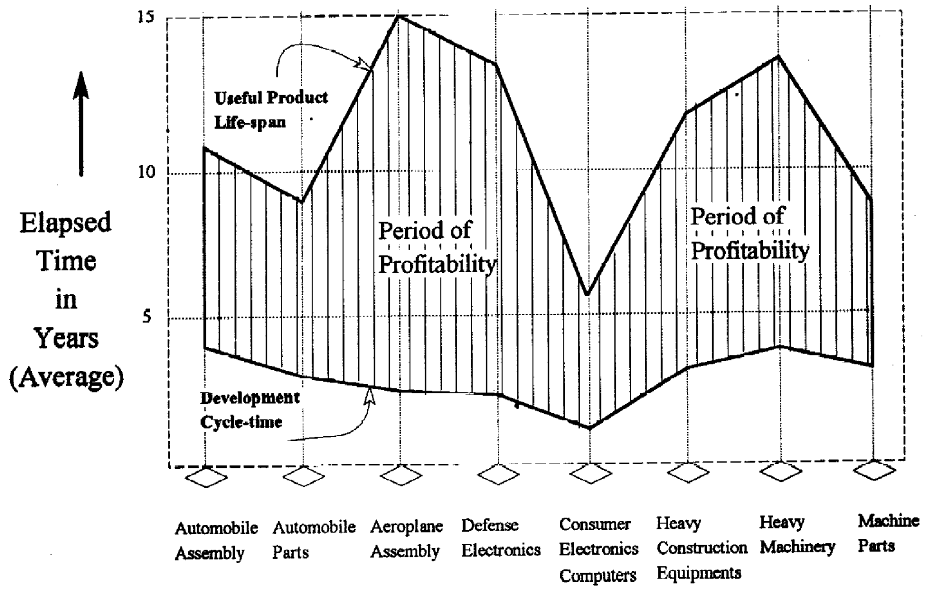


Fig. 2. Analysis of the average product development time (which indicates the start of the pay-off period) and of the product useful time (period of profitability) for various industrial products.

It has been reported in many case studies performed in several sectors, that the design process contributes by a small fraction towards the total product cost, fig. 3. The design time varies with the product and for the aerospace industry can reach up to 40%.

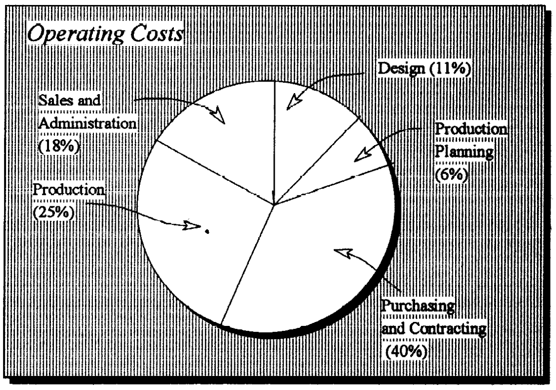


Fig. 3. Distribution of actual operating costs incurred by various departments.

However during the design stage we can forecast the final product cost, as shown in figure 4. The x-axis represents the various stages of the design process and in the y-axis the product cost. The two solid curves represent the product cost: the lower one represents the cost as they are incurring, the actual cost of the product as it follows its development. Conceptual design and detail design contributes only by 20% to the final cost, while manufacturing has the greatest influence. The other curve, the committed costs, indicates that most of product's cost is fixed early in its life cycle, before the original design cycle is complete. It is obvious that significant cost is committed during the design stage. This implies that we should consider various aspects of product life cycle at the design stage.

The dashed curve indicates the degree of easiness to incorporate changes into the product. In early stages it is very easy to test various alternatives solutions, but at later stages the modifications are very difficult.

CAD systems have the ability to provide a digital prototype of the product at early stages of the design process, which can be used, for testing and evaluation. Many people from various departments can share it, they can express their opinion for the product at early stages, in order to complete the design in less time and with the least mistakes. Most researchers accept that having the digital prototype in early stages allows more effort to be spent on the definition stage (early stage) of the design process and not in redesigning an already completed design, as shown in fig. 5.

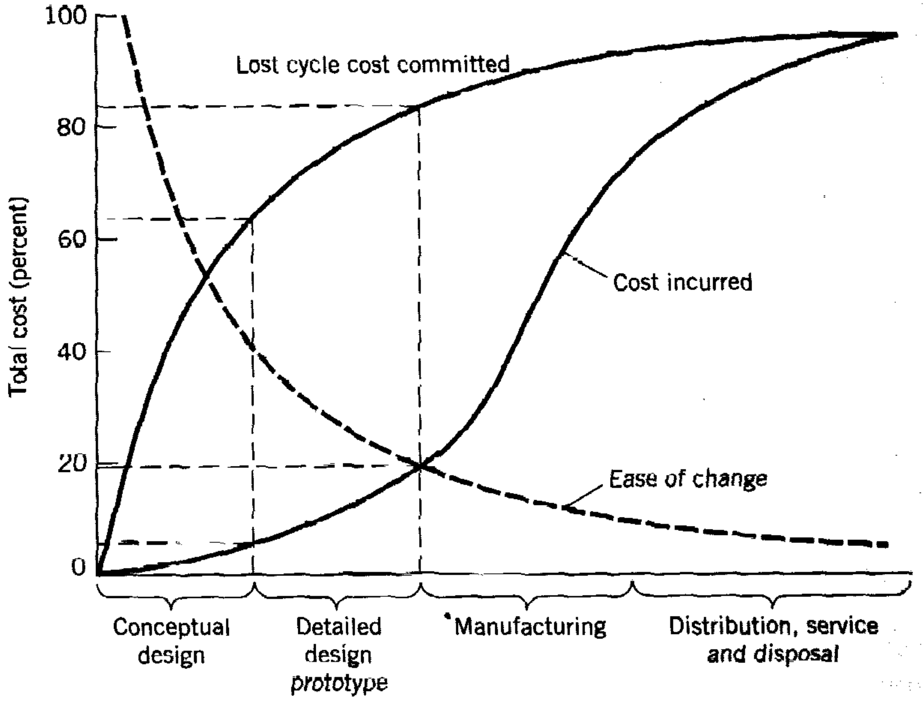


Fig. 4. Characteristic curves representing cost incurred and committed during the product life cycle.

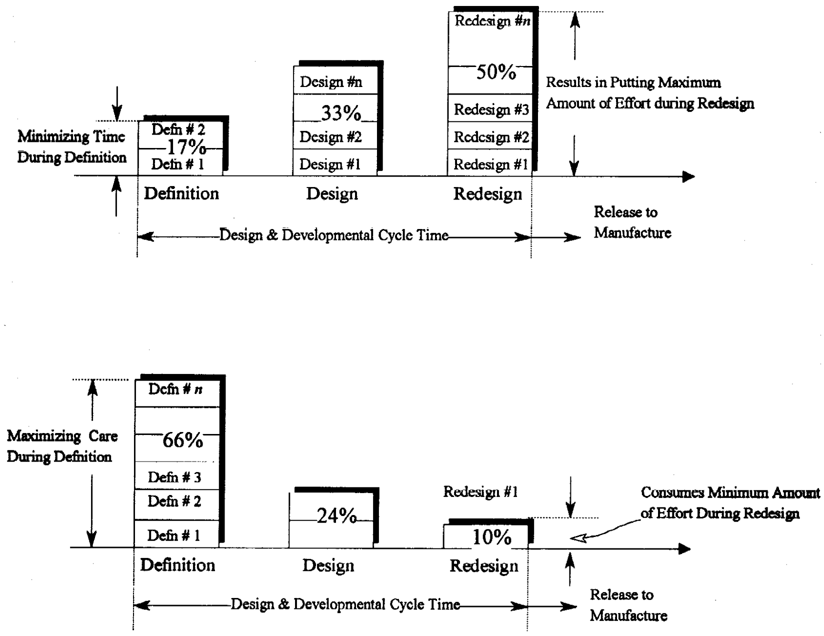


Fig. 5. Distribution of product development time. The earlier a new product definition is introduced the least redesign is required to the final design.

The earlier a design change is tried, the less time it takes to be implemented and tested, it requires less degree of control to activate a change, thus resulting in lower relative cost for introducing the change, fig. 6.

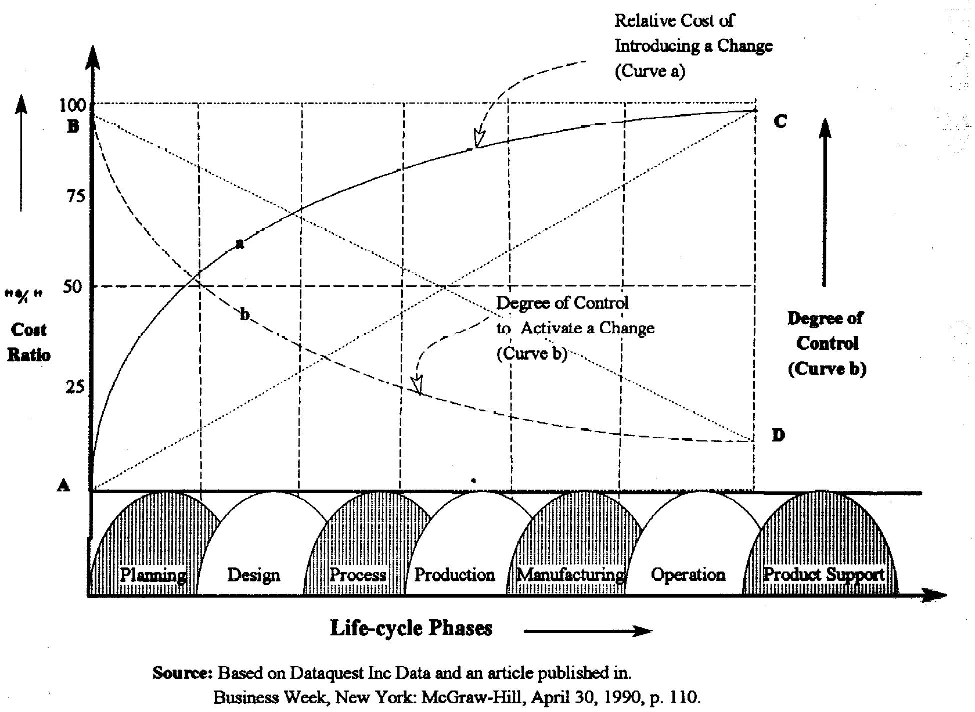


Fig. 6. (a) Relative cost of introducing a change to a product, (b) Degree of control required to activate a change.

In addition, the more time we spend on product design and on refocusing efforts in the prediction of the quality of the final product, less time will be required for fixing the mistakes. When a fault is detected during the production stage, then the effort is directed in mending the symptoms of the fault and not the cause generating it.

1.3 Description/Structure of the methodology/ alternative solutions

The range of systems related to the product development cycle is quite extensive. A typical classification is as follows:

1. Concept Development or Industrial Design Products

These are mainly surface modelling systems for mechanical products, with very good rendering capabilities. The process usually starts with a rough sketch of the product, fig. 7(a), you can apply colour and texture to it, fig.7(b), create the 3D model from the 2d sketches and then use advanced photo-realistic rendering and animation to further evaluate, present and sell the concepts, fig. 7(c).

Fig. 7. (a) Sketch the product, (b) Colour and texture mapping, (c) Rendering of the 3D Model.

Computer Aided Industrial Design systems are applied to many industrial products, ranging from every day consumer products, sports-ware, computers, equipment, and complex parts such as automobile, see fig.8.

They are usually integrated products capable of taking you from the initial concept to the creation of manufacturable objects. They combine:

- digital sketching, enabling experimentation which is not possible using traditional tools.
- free form surfaces modelling with highly flexible modelling tools.
- Unprecedented realism in visualisation for design, evaluation, review and approval.
- Quality, accuracy and precision required for integration with engineering and manufacturing processes.
- Reverse engineering tools, which transform data from digitisation to 3D digital models.
- Data transfer to CAD systems.

Some of the most popular systems for Industrial Design are:

- Alias/Wavefront and Maya from Silicon Graphics
- CDRS from Parametric Technology
- Products from CATIA, Unigraphics, SDRC, etc.

Fig. 8. Various commercial products designed with a Computer Aided Industrial Design system.

2. CAD Systems

Current systems, especially for mechanical products are 3D systems and they are spreading now their dominance to the other sectors. 3D modelling can be Wire Frame, Surface or Solid Modelling. Most of the mid-range mechanical sector CAD systems are Parametric and Feature Based Solid Modelling systems.

Wire frame modelling was the first attempt to represent the 3D object. The representation was inadequate with many drawbacks in terms of precision, adequacy of the representation, etc. In simple terms a 2D-wire frame model is built by forming the skeleton of the part, consisting only of edges. This technique is now an intermediate step for building a surface or a solid model.

With a surface model we are modelling the skin of the part. Early systems were based on Fergusson and Bezier type of curves, while current systems are using mainly NURBS, which are capable of modelling nearly every industrial part, such as aeroplane surfaces and automobile surfaces (characterised as Class A surfaces), shipbuilding, plastic parts and packaging in general, metallic parts, shoes, etc. They are the most capable types of system for representing industrial parts. Its use is not an easy task and it requires significant knowledge of the NURBS mathematics. They allow creating surfaces, which are not currently available from solid modelling systems. They are created by general sweeps along curves, proportionally developed shapes using 1, 2 or 3 rails lofted bodies, blends (fillets) with circular or conical cross sections and surfaces that smoothly bridge the gaps between two or more other bodies. Most of them have the ability to form shapes defined through a mesh of curves/points or through a cloud of points, technique suitable for reverse engineering tasks. Model editing is done by modifying the defining curves, by changing the numerical values of parameters or through using graphical or mathematical laws controlling the created shapes. The systems also include easy-to-use tools for evaluating the shape, the size and the curvature of complex models. Surfaces created through a free form surface module can be integrated into a solid model. Typical parts modelled with a surface modelling system are shown in Fig.9. These systems are not capable (or not suitable) of modelling artistic parts (such as jewellery), or organic forms such as action figures, human bodies and faces, etc. Special systems are developed for such applications, such as the Paraform, SensAble Free Form, and Simagrafi from Graphitek, etc.

Solid Modelling systems are considered to offer the most full representation of a part. They combine modelling and topology. Early systems were based on primitives for representing the space, forming the Constructive Solid Modelling (CSG) systems. Current systems are of Boundary Representation (B-Rep) type. CSG and B-Rep are used to model the topology data base of the part. During the 1990's all solid modelling systems offered are characterised as Parametric and Feature based systems. It started with Parametric Technology Corp. when it introduced the Pro/ENGINEER system.

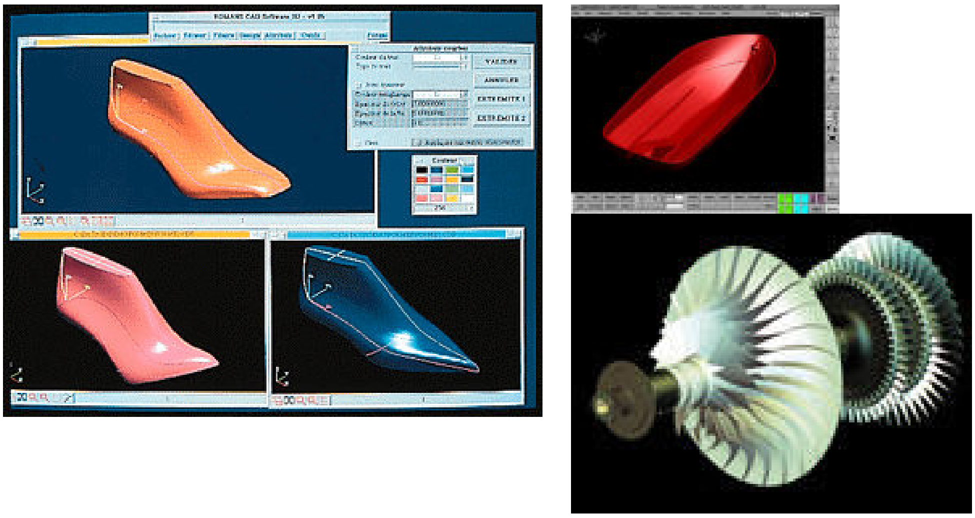


Fig. 9. Parts requiring a surface modelling system.

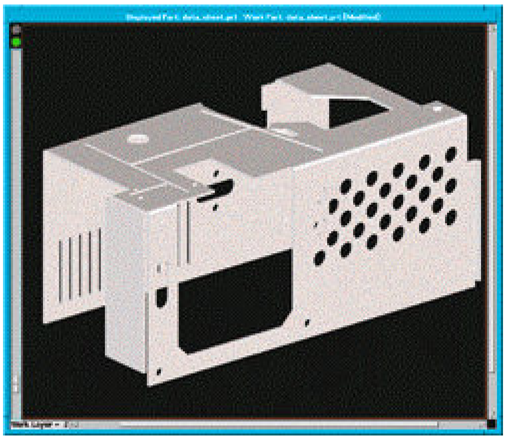
With parametric technology the user assigns parameters for defining dimensions, relations between parameters and relations between parts (in terms of position and size). Therefore, he/she can define a new part by assigning new values to the parameters or define a whole family of parts through a table of dimensions. With feature modelling the user has access to higher level of expression for modelling (or he/she can define his own features). These features have built-in a number of properties including form, dimensions and position.

Usual operations integrated inside the solid modelling systems are, 2-D and 3-D wire-frame models, swept, lofted and revolved solids, and booleans as well as parametric editing. They are employing variational sketching tools for quick and efficient conceptual design as well as tools for more general modelling and editing tasks. With feature modelling the user can create a variety of holes, slots, pockets, pads, bosses, as well as a full set of cylinders, blocks, cones, spheres, tubes, rods, blends, chamfers and more. He/she can also hollow out solid models and create thin walled objects. User defined features can be stored in a common directory and be added to design models.

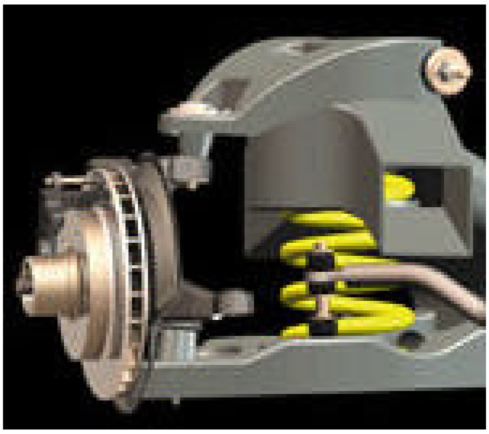
A strong characteristic of Parametric and Feature based solid modelling system concerns the assembly modelling capabilities, which provide a top-down or bottom-up, concurrent product development approach. Parts are mated or positioned and are associative. Some of them allow extremely large product structures to be created and shared by a design team. For these assemblies a number of special systems are used which take a data loading control for quick response to user commands. These systems are suitable for the digital mock-up process for layout of complex products, allowing fast clearance checking and rendering of shaded and hidden line views.

Most systems integrate a module for sheet metal design, enabling the designer to define and simulate manufacturing sequences, unfold and refold the models and generate accurate flat pattern data for downstream applications.

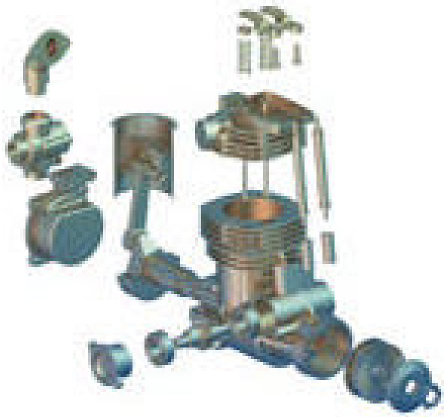
(A) A solid model of a part



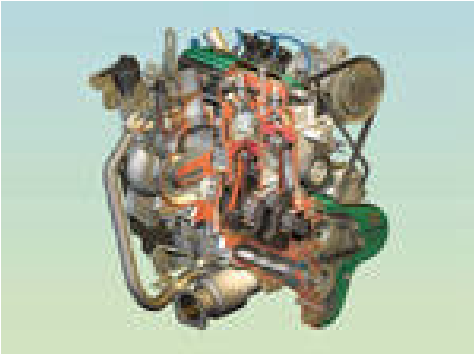
(B) A solid model of a sheet metal part



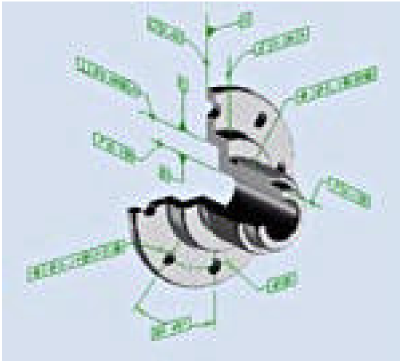
(C) A hybrid model of a mechanism



(D) An assembly model of a cylinder block



(E) A complex and large assembly of an engine requiring virtual prototype systems



(F) Geometric tolerances on a solid model.

Fig. 10. A review of parametric modelling systems

Parts created in solid modelling system can be exported to drafting systems for drawings production. This module creates dimensions that are associated to the geometric model, ensuring they are updated on a model change and reducing the time required for drawings updates. Automatic view layout capabilities provide fast drawing layout for all views, sections and projections, etc.

3. Computer Aided Engineering Tools

Engineering analysis is concerned with analysis and evaluation of engineering product designs. For this purpose, a number of computer-based techniques are used to calculate the product's operational, functional, and manufacturing parameters. Finite element analysis (FEA) is one of the most frequently used engineering analysis techniques. Besides FEA, tolerance analysis, design optimisation, mechanism analysis, and mass property analysis are some of the computer aided techniques available to engineers for the purposes of analysis and evaluation of the engineering product designs.

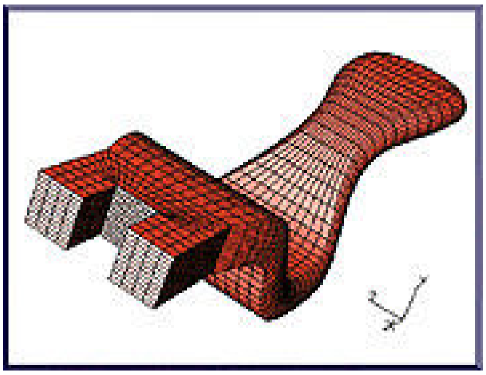
4. Finite-Element Analysis

Finite-element analysis is a powerful numerical analysis process widely used in engineering applications. FEA is used to analyse and study the functional performance of an object by dividing it into a number of small building blocks, called finite elements. For example, functional performances of an object or continuum, such as a structure's stresses and deflections, are predicted using FEA. The core of the FEA method is an idealisation of the object or continuum by a finite number of discrete variables. For this purpose, the object is first divided into a grid of elements that forms a model of the real object. This process is also called meshing. Each element is a simple shape such as a square, triangle, or cube or other standard shape for which the Finite-element Program has information to write the governing equations in the form of a stiffness matrix. The unknown parameters for each element are the displacements at the node points, which are the points at which the elements are connected. The Finite-Element Program assembles the stiffness matrices for these simple elements to form the global stiffness matrix for the entire model. This stiffness matrix is solved for the unknown displacements, given the known forces and boundary conditions. From the displacement at the nodes, the stresses in each element can then be calculated. The following steps are usually followed in applying FEA:

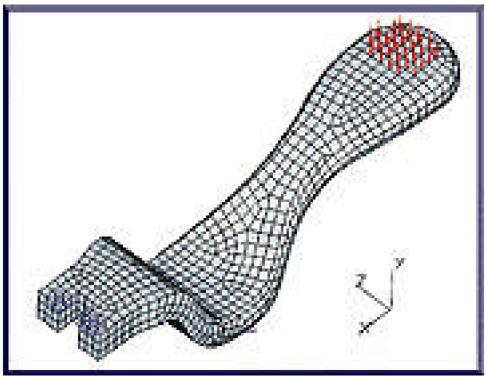
1. Discretization of the given continuum
2. Selection of the solution approximation
3. Development of element matrices and equations
4. Assembly of the element equations

5. Solution for the unknown at the nodes
6. Interpretation of the result

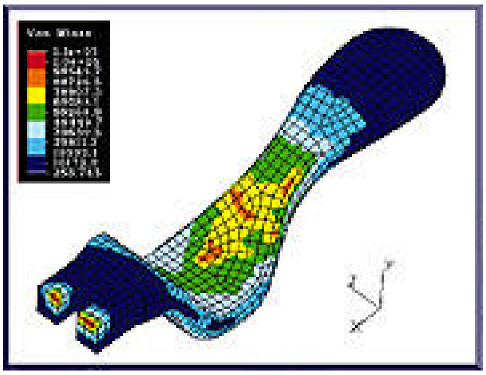
A number of software packages for engineering analysis have been developed that are capable of covering a wide range of applications. These applications include: Static analysis, Transient dynamic analysis, Natural frequency analysis, Heat transfer analysis, Plastic analysis, Fluid flow analysis, Motion analysis, Tolerance analysis.



(A) The Finite Elements Mesh



(B) Application of loading

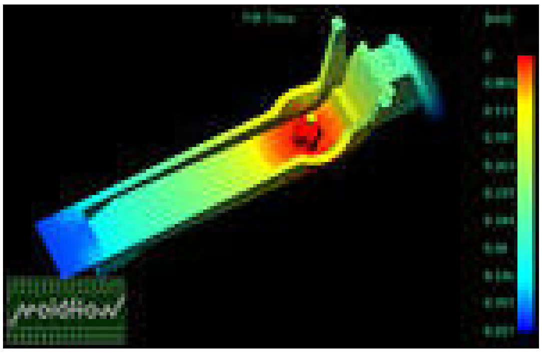


(C) Analysis and presentation of results

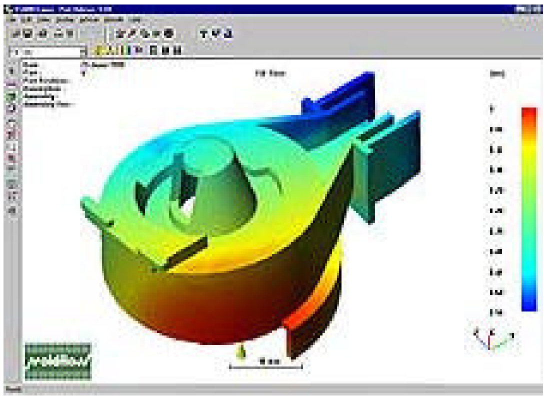
Examples of Finite Elements Analysis

(D) Kinematics Analysis of landing gear

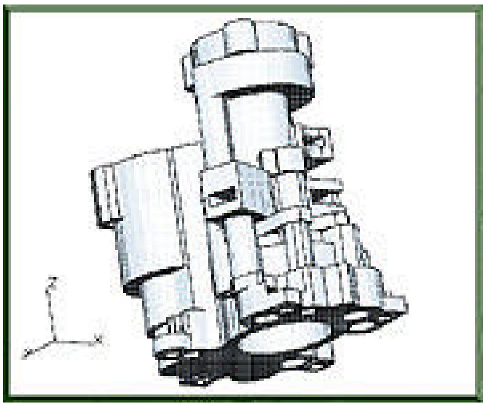
(E) Kinematics Analysis of support mechanism



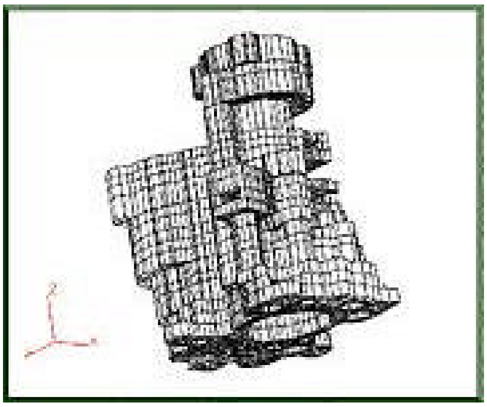
(F) Mould Filling time simulation



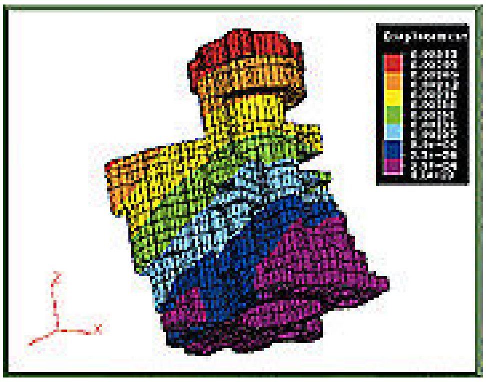
(G) Mould temperature distribution



(H) The model



(I) The Finite Elements mesh (with hidden lines removed)



(J) Presentation of analysis results

Fig. 11 Examples of Finite Elements Analysis

5. Rapid Prototyping Tools and Machines

Rapid prototype allows to "print" three-dimensional models of designs as easily as printing them on paper. It is a fast and cost-effective way to improve the way a designer communicates his/her ideas, both inside and outside the organisation. It revolutionises the development process, helping the design team to take advantage of more opportunities, more profitably than ever before. It's benefits help them win greater understanding -and faster approval- of their ideas, create superb models quickly and inexpensively, start building immediately -without training- and dramatically improve the way they do business.

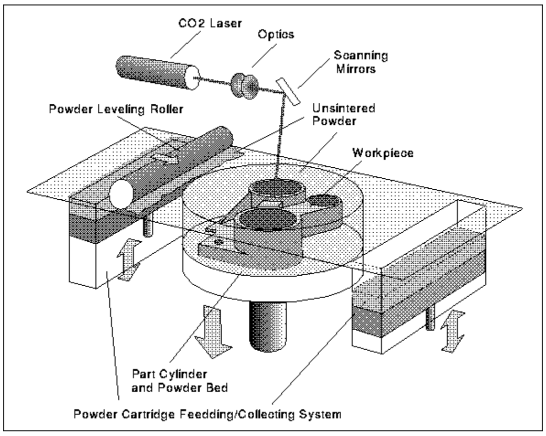
The technology is used for

- Concept validation
- Design intent communication
- Customer and vendor feedback
- Bid packages
- 3-D faxes Master
- patterns for casting

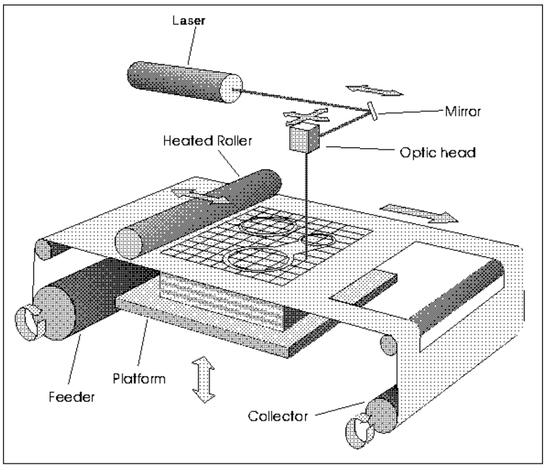
The method was first presented in 1987, and today many technologies are in the development phase. The main technologies used are:

- Stereolithography
- Solid Ground Curing
- Selective Laser Sintering
- Laminated Object Manufacturing
- Fused Deposition Modelling
- Three dimensional Printing

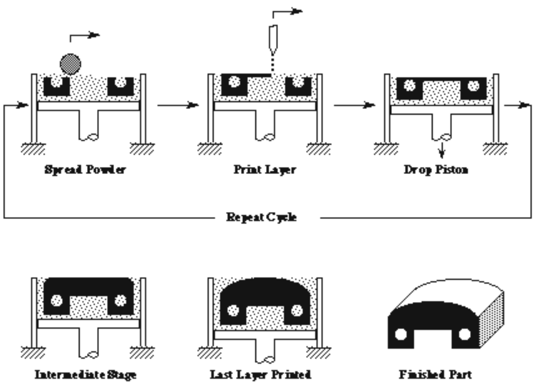
Most CAD system can provide output for Rapid Prototyping machines in the STL format.Some of the above technologies are shown in the following figures



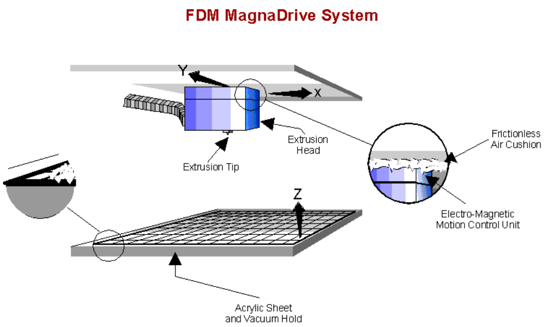
(A) The Selective Laser Sintering method



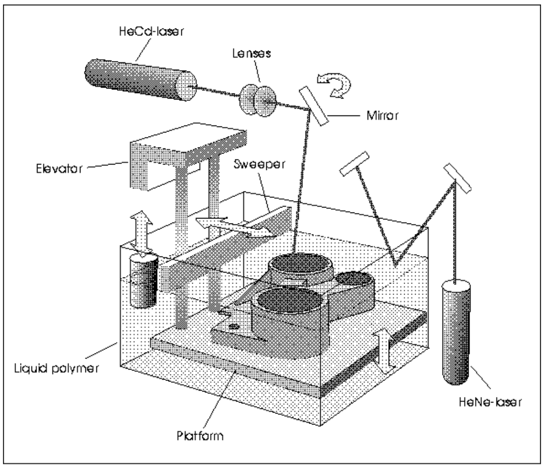
(B) The Laminated Object Manufacturing method



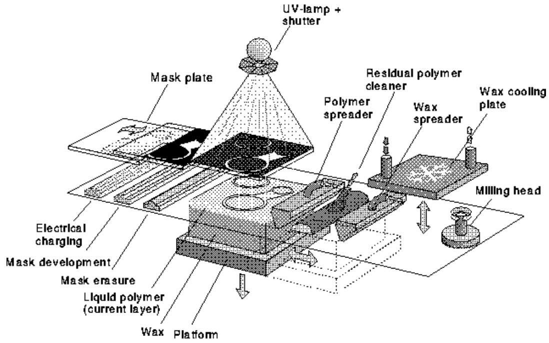
(C) The 3D printer



(D) The Fused Deposition Method



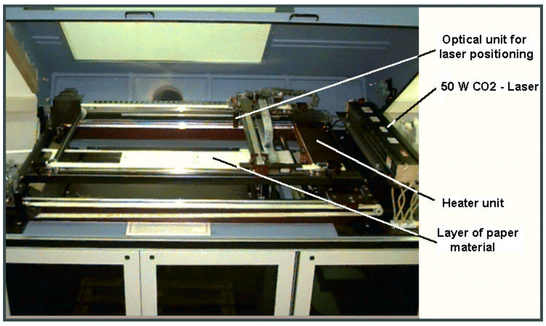
(E) The Stereolithography method



(F) The Solid Ground Curing Method

(G) Parts produced with Rapid Prototyping

(H) The 3D Printer by Stratasys



(I) The LOM machine

(J) The SLA5000 machine.

Fig. 12. The Rapid Prototyping method: (A) – (F) Schematic presentation of the main technologies, (G) –(J) Parts produced with Rapid Prototyping

6. Product Data Management Tools

Product Data Management (PDM) is a tool that can be used to support the entire product life cycle including product or plant definition, production and business operations support.

PDM technology provides a way for systems to work together and exchange information at multiple points of continuous integration, from design through manufacturing and support. In extended enterprises, PDM can be effective in managing the product definition supply chain by serving as an information bridge connecting OEMs, subcontractors, vendors, consultants, partners, and customers.

PDM systems manage the full configuration of a product, including all mechanical, electronic, software, and documentation components. The technology is applicable to any discrete manufactured products such as automobiles, aircraft and defence systems, machine tools, and telecommunications equipment.

Whether it relates to design concepts, prototypes, fabrication, operations, or maintenance, PDM assures that people and systems will have access to accurate information throughout the life cycle of a product.

PDM systems provide a structure in which all types of product information are stored, managed, and controlled. That includes electronic documents, digital files, and database records pertaining to:

- Product configuration
- Project plans
- Part definition and other design data
- Audio/visual annotations
- Specifications
- Hardcopy documents
- CAD drawings
- Maintenance and service records
- Geometric models
- Electronically stored documents, notes, correspondence
- Scanned images
- Safety and regulatory requirements
- Engineering analysis models and results
- Manufacturing process plans and routings
- NC part programs

PDM systems are currently used by many industries, such as:

- Aerospace
- Automotive: assembly and components
- General mechanical manufacturing
- Electrical and electronic components
- Computer manufacturing
- Defence industries
- Oil and gas exploration and production
- Chemical and process engineering
- Design and management consulting
- Food and beverage manufacturing
- Pharmaceuticals
- Power generation
- Construction companies

- Transport operators: road, rail, sea, air
- Utilities: electricity, water, telecommunications
- Central and local governments

1.4 Characteristics of firms/ organisations and service providers

There are many CAD vendors for the various applications. The following table summarises some of them but it is not by any means explicit.

Mechanical CAD Vendors • Alias/Wavefront Surface Studio • Applicon Bravo • Autodesk AutoCAD • Autodesk Mechanical Desktop • Baystate Technologies Cadkey • Bentley Systems MicroStation • CoCreate SolidDesigner • CoCreate ME10 • Dassault Systemes CATIA • IBM CATIA • Matra Datavision Euclid3 • MCS Anvil Express • MicroCADAM Helix • PTC Pro/DESKTOP • PTC Pro/ENGINEER • SDRC Artisan Series • SDRC I-DEAS Master Series • SDRC Imageware Surfacer • SofTech (Adra) CADRA • SolidWorks SolidWorks • Think3 (CAD.LAB) Eureka Gold • Unigraphics Solutions Solid Edge • Unigraphics Solutions Unigraphics • Varimetrix VX Modeling • Visio IntelliCAD • Visionary Design IronCAD	**Mechanical CAE (Analysis) Vendors** • Algor Algor • ANSYS DesignSpace • MacNeal Schwendler (MSC) NASTRAN, Etc. • MARC Mentat & MARC • Mechanical Dynamics ADAMS • LMS CADSI DADS • PTC Mechanica • SRAC COSMOS/M
AEC CAD Vendors • Autodesk Architectural Desktop • Cadcentre PEGS • IBM CATIA/CADAM • Intelligent Computer Solutions OpenPlant • Intergraph Imagineer	**CAD Kernels** • Matra Datavision CAS.CADE • Ricoh Designbase • Spatial Technology ACIS • Unigraphics Solutions Parasolid • XOX Shapes
CAD Verification Tools • ITI CAD/IQ • Prescient DesignQA	**Electrical CAD Vendors** • Cadence Alta • Mentor Graphics Inter-Connectix
Clothing and Shoes Industry • Lectra Systemes - Lectra (clothing & shoes)	**Rapid Prototype** • 3d Systems - SLA • Cubital - Solider

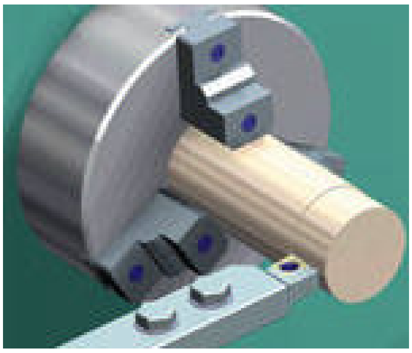
• Gerber - Gerber (clothing & shoes) • Innova - Innova (clothing) • Csm3d - Shoe Master (shoes)	• DTM corp. - SLS • Helisys - Lom • Stratasys - FDM

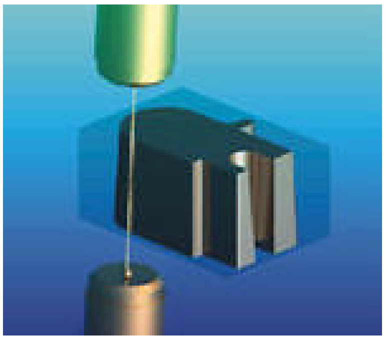
2 APPLICATION

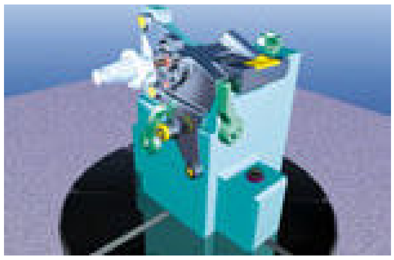
2.1 Where the technique has been applied

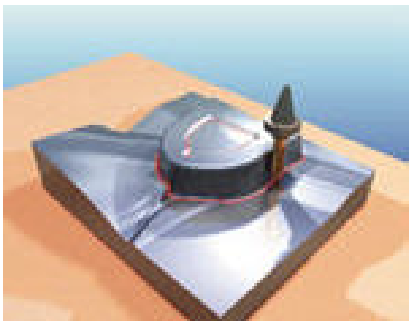
CAD has been applied to many industrial sectors.

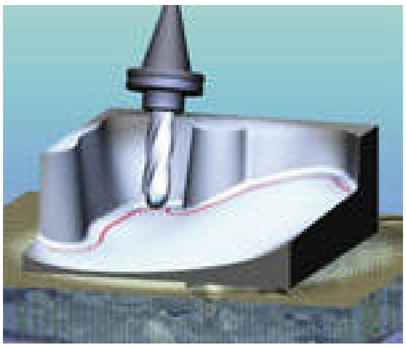
■ The mechanical sector is the largest user of CAD systems. Applications are usually coupled with manufacturing, forming a CAD/CAM system. The applications cover all types of manufacturing operations, such as milling (2 ½, 3 – 5 axis of control), turning, wire EDM, punching, etc. The user can test the part programme on screen prior to the transfer to the machine tool and accomplish collision detection, undercuts, etc. Most of the systems have a post processor integrated to communicate with the machine tools. Figure 12 presents a number of such examples.


(A) Turning

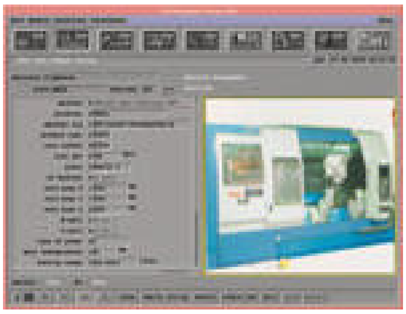

(B) EDM


(C) Milling a part and his fixture

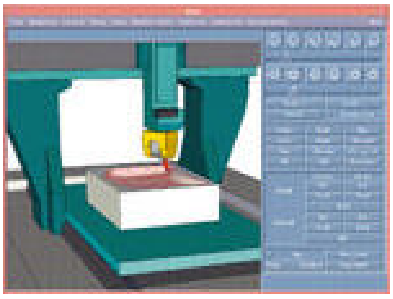

(D) Multi axis and multi spindle milling


(E) Multi axis and multi spindle milling


(F) Multi axis and multi spindle milling



(G) Library of machine tools



(H) Graphical simulation including the machine tool

Fig. 13. Examples of CAM applications

- The AEC sector is the second largest application areas of CAD systems. Applications range from single a simple building design, to large scale projects, interior design, static and dynamic analysis, etc. These applications are beyond the scope of this report. A number of large projects examples are shown in Figure 14.

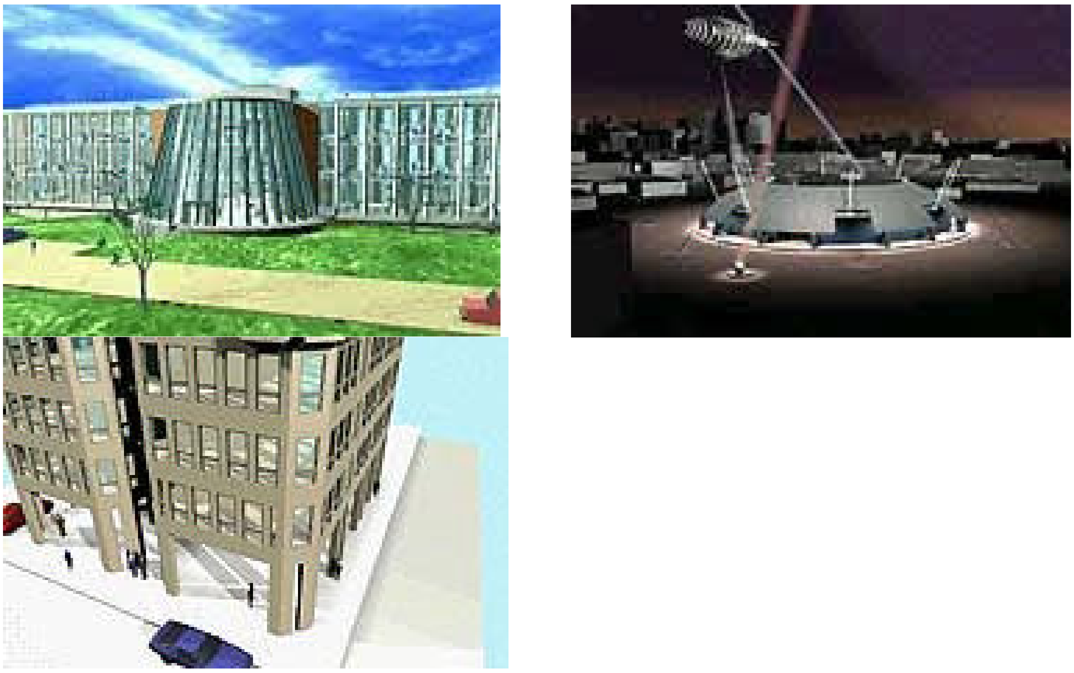
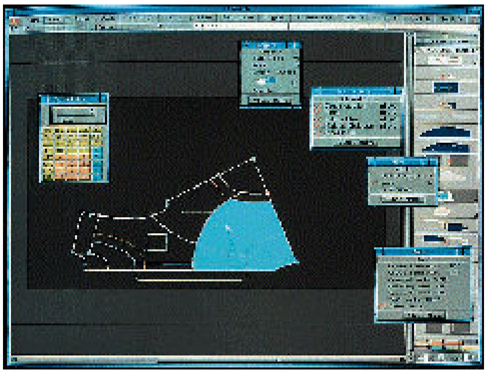
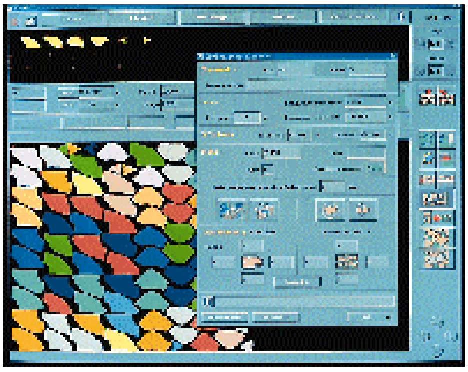


Fig. 14. Various large projects where AEC CAD has been applied.

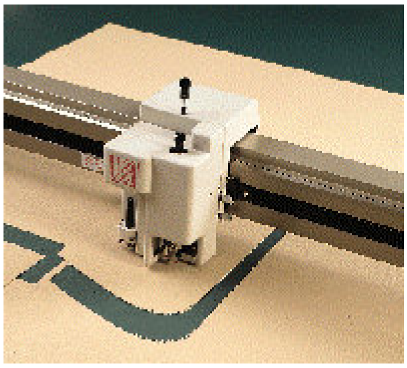
- The electronics engineering is the third largest application. The computer performs all IC designs. It is the complexity of the designs that imposes the usage of CAD systems. Current systems also include in their software a number of designs in order to offer some assistance to the users for their new designs.
- The apparel industry is also a large user. The number of systems on offer is limited. A small number of companies are offering systems for the apparel sector worldwide, while on a national base there is a number of companies offering such systems. Systems for clothing are rather expensive, because they are using specialised equipment, such as large plotters, cutters for patterns, and automatic machines for

cutting the fabric. Their application ranges from fashion design to manufacturing. The largest usage of the systems is for pattern design and lay planning, where most of the savings are achieved. It is absolutely necessary today for all companies subcontracting a large supplier to be able to handle electronic data (pattern designs). Lay planning can save on material and it can justify the investment in CAD. Today the application of fashion design systems is becoming quite popular. These systems can produce a whole collection on paper, saving a lot of money on sampling and quite often are connected to special ink-jet printers capable of printing on fabric for quick sampling. Similar to the CNC machines used in metal manufacturing, computer controlled machines exist in the apparel industry. These machines perform fabric laying and cutting automatically and they are controlled directly from the CAD systems. In addition, they can be combined with storage system in front of them forming a kind of Flexible Manufacturing Cell. A number of equipment used for the apparel CAD are shown in the following figures.


(A) Pattern design


(B) Lay Planning


(C) Cutter Plotter for stencil design


(D) Cutting the patterns


(E) Fabric Laying in Cutting Machines


(F) The Cutting process

(G) An automatic machine for cutting the fabric

Fig. 14. Applications of CAD in the Apparel industry and equipment used

2.2 Implementation cost

Implementation cost consists of equipment and software acquisition, training and support cost. None of these costs should be underestimated. System prices are continuously dropping (Hardware and Software) but the cost of training is increasing. The training process is explained in the following sections.

The cost is higher for specialised systems, such as sheet metal manufacturing, analysis programmes, etc. Regarding supporting systems, such as PDM, RP, etc. the costs of support and consultancy are very high. The implementation process is a lengthy one and it takes a long time to set up the system and use it efficiently.

2.3 Conditions for implementation

In a survey conducted by the CAD Report magazine within a number of its readers and CAD users, regarding the causes of lost productivity in CAD/CAM and CAE operations, the following results were obtained:

- Operator error – 28%
- Application bugs – 26%
- Inadequate data management – 18%
- Network server or system failures – 12%
- Operating system failures – 4%
- Hardware breakage – 2%
- Other – 10%

In order to take full advantage of the system, the CAD managers, especially for large installations, must handle these causes of failure. We will explain more the first two causes of failure.

Application bugs. Most CAD software is less reliable than general business software, because:

- they are performing more difficult functions
- there are more logical branches in a CAD programme than in a typical business application
- the small size of the user community, and the beta testers are limited
- most CAD software developers have only a hazy idea of what designers do with their systems
- CAD software developers rarely meet with real CAD users

CAD users should contribute to programme debugging. They must collect their own data about system crashes or failures on performing a certain task. This will also help them identify incompatibilities with Hardware, lost productivity, not properly installed software, etc.

Operator Ignorance. This is due to the fact that many users fail in following procedures, which are usually complicated. It is due to the:

- Inefficient software
- Systems are not smart at all
- Procedures such as numbering, layering, file-naming conventions, standard parts-libraries, etc. need to be updated with every new release

The best way to update the procedures is not through paper work but through an internal WEB site.

3 IMPLEMENTATION PROCEDURE

3.1 Steps/ phases

The successful introduction of a full range CAD/CAM system is a lengthy procedure. It starts, as with every IT application, with the evaluation of needs, the technical specifications of the system, the selection of the most suitable system and the implementation.

During the evaluation of needs there must be a phased implementation of the full system. Certain steps must be followed prior to the implementation of several modules. Existing IT systems or equipment, which require data exchange with the CAD system must be taken into consideration in drawing the specifications. Also, current trends in CAD development must also be considered.

The technical specification of the system should cover most of user needs. In certain applications these should not be independent from the vendor. In developing countries, like Greece, where the number of sophisticated systems users is limited, the local support is very important. Existing customer base must be taken into consideration and a number of local visits must be undertaken.

The evaluation of alternative solutions and the selection of the most suitable system should not be based only on desk evaluation. Benchmarking of three to four candidate systems must be made, based on one or two parts, representative of the product spectrum a company is producing. Desk evaluation of the various systems is not easy to be performed, unless the company is already a CAD user, has a very good knowledge of CAD systems and follows developments within the CAD systems.

Sometimes the type of work a company is performing directs the selection of a CAD system. Large manufacturers with many subcontractors are forcing them to acquire the same CAD system as the one they are using. They aim at avoiding data translation problems from one CAD system to another.

The implementation is the most difficult phase. It requires a strong support from the management, time to pay back and it should not be a temporary task for some designers. The problems that must be addressed include, training, organisation of the CAD team, operation of the system and procedures that must exist. Each of them will be presented next.

Training

Training is the most important step for the successful implementation of a CAD system. For new installations, personnel selection and training success is critical because setbacks may be very hard to overcome. Emphasis should be placed on building a solid level of user expertise and confidence rather than production goals that will be difficult to achieve.

After initial system set-up and training, productivity should pick up and will probably approximate the production levels existing before CAD was introduced. However, many times setbacks caused by loss of data, operator errors or lack of proficiency will clobber productivity and frustrate management and the users. Causes of these setbacks must be determined and corrected. Each problem encountered should be used to represent a self-teaching opportunity.

Operators have the tendency to use familiar commands instead of trying to learn new and faster ways to do their work. The task will usually fall on the manager to identify operations that can be accomplished more productively and to research and develop new methods to be used.

Training should include:

- Initial training for new operators as well as on-going training for experienced users
- Cross-training within the group. It is particularly important that all CAD personnel help new members of the group learn efficient techniques and procedures
- Regular meetings for the purpose of demonstrating new commands, programs, menus, or other time-saving techniques
- Documentation of specific programs and procedures to enable the personnel to find and use them easily
- Personnel must develop their own problem-solving abilities. Therefore they must be assigned challenging responsibilities.

As training is not just a one-time activity, we provide the following checklist of training activities:

- Every new user must be given a regular course of instruction in how to use CAD software. A user moving from 2D to 3D must also receive a course. Courses can be bought from the vendors or, in case of large companies, they can take place in-house.
- Training must be provided with new releases. Usually this is a short training (one day the most)
- The team must hold productivity meetings at least every two weeks, where new procedures, bugs, etc. can be discussed
- Develop WEB site for each CAD SW brand. On it post
    - Company procedures
    - Answers to frequently asked questions
    - Ways to overcome known software bugs
    - Bug reporting form
- Attend user group meeting and have a report from them
- One person must be assigned to develop and document design-automation tools specific to company procedures
- Budget for training and productivity-building activities.

Organisation
It is important to make CAD work on the first attempt. This can be done by selecting people who have the best chance of making the system work, and by clearly defining their authority and responsibilities. If the department is properly organised, the manager will be allowed to dedicate more time on production and technical problems. On the other hand, if the department is disorganised, or if too many people or disinterested operators are on the system or operators don't know what is expected of them, no work will get done and the CAD program will be a disaster.

Co-operation between departments is crucial to the future development of CAD/CAM within the company. By anticipating future applications of the CAD/CAM equipment, the group will be better prepared to handle this growth in an organised manner. Future expansion plans should be considered before making substantial investments in facility layout or design. In large installations, forming a graphics committee will help to determine the direction of CAD/CAM within the company, and identify areas where new equipment can be applied. Problems with incompatible computer systems can be avoided with proper planning and communication between the departments that will use the CAD/CAM database.

Organisational matters are crucial to the effective management and development of the system. CAD managers can benefit from properly organising their departments so that they can dedicate more time to technical and operational matters.

Operations
At the beginning, the CAD system should be used for simple projects in order to check out the system and to gain confidence. If the system is for drawings generation, then drawings that may have a lot of revisions are ideal because revising data in a CAD system is faster and neater than changing paper drawings. Even if it first takes longer to create the job or the drawings on the CAD system than with manual methods, the time saved on the repetition or revision cycle should provide a net savings over traditional method or manual drafting. Furthermore, inserting “pre-checked” parts, details, notes or other data into a product or a drawing can also save some checking time.

The success of CAD is not automatic. A lot of study, training, and perseverance are required to make the system work successfully. Attempts to automate will certainly fail if operators are not capable in programming the system, or if planning is insufficient. A company must learn how to use library parts, menus, and basic system commands fluently before attempting to program the system. In case a user is selecting projects to automate, he/she must be sure that there is enough work to offset both training costs and software development costs, especially if extensive programming is required.

It is recommended to first automate tasks which will save the largest amounts of money and which have the best probability of successful completion on the system. Remember that no work will be done if assignments are beyond the abilities of the operators.

Schedules must include time for system development or capabilities will level off quickly. Development should be applied to areas that will most benefit the bulk of group responsibilities. All members of the CAD team should participate in analysing work in order to find "the better way to do it" on the CAD system.

The CAD manager must be versatile enough to make CAD work in the department and to direct its evolution within the company.

Procedures

Written procedures are important because they provide clear, indisputable instructions to CAD personnel and CAD users know what is expected of them in specific terms. If users become confused concerning task requirements, they can communicate their complaints more clearly by referring to parts of the procedure that need embellishment or revision. Procedures should be updated as needed to simplify and streamline operations, and provide the best integration with other departments using the CAD database.

Procedures are also valuable because once they are finalised they can be reused. They help train new users and refresh casual users, and information is not lost when key people leave the company. Good procedures will provide a sound basis for productive CAD development in the company.

3.2 Related software (existing or being prepared)

Within the framework of the INNOVATION programme, the SELECT-IT project has developed a structured methodology for selecting CAD systems.

The methodology works on three levels. On the first level it has the indicators, each indicator is composed of a number of Items and each Item of a number of Components. Each component is valued and desired values are given. The system iterates through all three levels and when finished it produces desired specifications. These specifications are distributed to the suppliers who can report back by filling their compliance with the required specifications. The system automatically evaluates all responses, and, by performing a pair-wise comparison, ranks all systems.

The SELECT-IT provides a checklist not only for CAD systems but also for other IT applications, including Accountancy, Shop-Floor data collection systems, Quality control, Finite Scheduling, and it is within its plan to expand the range of applications. The provided checklists can be modified according to the user needs. The software is supported through the WEB and the user can easily get a strong support from the consortium either locally in several countries or through mail worldwide.

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