1. CAD software history, 1960s

Euclid to SDRC...

CAD software, also referred to as **Computer Aided Design software** and in the past as computer aided drafting software, refers to software programs that assist engineers and designers in a wide variety of industries to design and manufacture physical products ranging from buildings, bridges, roads, aircraft, ships and cars to digital cameras, mobile phones, TVs, clothes and of course computers! CAD software is often referred to as **CAD CAM software** ('CAM' is the acronym for Computer Aided Machining).

While he could never have foreseen today's CAD software, no **CAD software history** would be complete unless it started with the mathematician Euclid of Alexandria, who, in his 350 B.C. treatise on mathematics "***The Elements***" expounded many of the postulates and axioms that are the foundations of the Euclidian geometry upon which today's CAD software systems are built.

It was more than 2,300 years after Euclid that the first true CAD software, a very innovative system (although of course primitive compared to today's CAD software) called "**Sketchpad**" was developed by Ivan Sutherland as part oh his PhD thesis at MIT in the early 1960s. Sketchpad was especially innovative CAD software because the designer interacted with the computer graphically by using a light pen to draw on the computer's monitor. It is a tribute to Ivan Sutherland's ingenuity that even in 2004, when operations which took hours on 1960s computer technology can be executed in less than a millionth of a second and touch-sensitive TFT combination display/input devices are readily available, there is no leading CAD software that has yet incorporated such directness into its user interface.

Sketchpad was the world's first CAD software but the first commercial CAM software system, a numerical control programming tool named PRONTO, had already been developed in 1957 by Dr. Patrick J. Hanratty. For that reason it is Dr. Hanratty who is most often referred to as "the father of CAD CAM".

Due to the very high cost of early computers and to the unique mechanical engineering requirements of aircraft and automobiles, large aerospace and automotive companies were the earliest commercial users of CAD software. First-generation CAD software systems were typically 2D drafting applications

developed by a manufacturer's internal IT group (often collaborating with university researchers) and primarily intended to automate repetitive drafting chores. Dr. Hanratty co-designed one such CAD system, named DAC (Design Automated by Computer) at General Motors Research Laboratories in the mid 1960s. Proprietary CAD software programs were also developed by McDonnell-Douglas (CADD released in 1966), Ford (PDGS released in 1967), Lockheed (CADAM released in 1967) and many others.

Also in the mid 1960s, the Digigraphics division of Control Data Corporation released the first commercially available CAD software system. The system was a successor to ITEK's earlier CAD software research system (which was named "The Electronic Drafting Machine" and ran on a Digital Equipment Corp. PDP-1 mainframe computer) and as with the Sketchpad CAD software, input was made using a light pen. Digigraphics was priced at $500,000 per unit and only a very few units were ever sold.

Much of the early pioneering research in 2D CAD software was performed at what was then MIT's Mathematical Laboratory (now the Department of Computer Science). European researchers were also becoming active though and in 1965, Charles Lang's team. including Donald Welbourn and A.R.Forrest, at Cambridge University's Computing Laboratory began serious research into 3D modeling CAD software. The commercial benefits of Cambridge University's 3D CAD software research did not begin to appear until the 1970 however, elsewhere in mid 1960s Europe, French researchers were doing pioneering work into complex 3D curve and surface geometry computation. Citroen's de Casteljau made fundamental strides in computing complex 3D curve geometry and Bezier (at Renault) published his breakthrough research, incorporating some of de Casteljau's algorithms, in the late 1960s. The work of both de Casteljau and Bezier continues to be one of the foundations of 3D CAD software to the present time. Both MIT (S.A.Coons in 1967) and Cambridge University (A.R.Forrest, one of Charles Lang's team, in 1968) were also very active in furthering research into the implementation of complex 3D curve and surface modeling in CAD software.

Toward the end of the 1960s, interest in the commercial applications of CAD software was growing and by the end of the decade many CAD software companies, including, Applicon, Auto-trol, Computervision (which sold its first commercial CAD software license to Xerox in 1969), Evans & Sutherland, the McAuto division of McDonnell-Douglas (actually established in 1960), SDRC (Structural Dynamics Research Corp.) and United Computing had been established.

Despite later waves of technology change, rapid growth and inevitable mergers and acquisitions, many of those early CAD software companies continue to be successful; some under their original name (for example Auto-trol) and some under changed names (for example United Computing which is now UGS). Early pioneering researchers such as Dr. Hanratty, still the active President of MCS (Manufacturing and Consulting Services), Dr. Sutherland, Charles Lang and others continue to be very influential.

2. CAD software history, 1970s

Internal to international standard.

CAD software started its migration out of research and into commercial use in the 1970s. Just as in the late 1960s most CAD software continued to be developed by internal groups at large automotive and aerospace manufacturers, often working in conjunction with university research groups. Throughout the decade automotive manufacturers such as: Ford (PDGS), General Motors (CADANCE), Mercedes-Benz (SYRCO), Nissan (CAD-I released in 1977) and Toyota (TINCA released in 1973 by Hiromi Araki's team, CADETT in 1979 also by Hiromi Araki) and aerospace manufacturers such as: Lockheed (CADAM), McDonnell-Douglas (CADD) and Northrop (NCAD, which is still in limited use today), all had large internal CAD software development groups working on proprietary programs.

Most CAD software programs were still 2D replacements for drafting, with the main benefits to manufacturers being: i) reduced drawing errors, and, ii) increased reusability of drawings. One of the most famous of those 2D CAD software programs, and one which still exists (in name only) more than 30 years later, was the CADAM (Computer Augmented Drafting and Manufacturing) system originally developed by the Lockheed aircraft company. In 1975 the French aerospace company, Avions Marcel Dassault, purchased a source-code license of CADAM from Lockheed and in 1977 began developing a 3D CAD software program named CATIA (Computer Aided Three Dimensional Interactive Application) which survives to this day as the most commercially successful CAD software program in current use.

The 1970s started with simple 2D CAD software programs such as CADAM but research and commercial interest in 3D CAD software was rapidly gaining momentum and one of the most influential pieces of research of the decade was in complex 3D surface modeling for CAD software. K. Vesprille's (at Syracuse

University) 1975 PhD dissertation "*Computer-Aided Design Applications of the B-Spline Approximation Form*", built on the 1960s research of de Casteljau, Bezier, Coons and Forrest and earlier (1973) work by R.F.Risenfeld (also at Syracuse University) and continues to be one of the foundations of complex 3D curve and surface modeling in 3D CAD software to this day.

The first 3D solid modeling program, SynthaVision from MAGI (Mathematics Application Group, Inc.) was released in 1972, not as CAD software but as a program for performing 3D analysis of nuclear radiation exposure. SynthaVision's 3D models were solid models similar to the CSG (constructive solid geometry) models used by later 3D CAD software. In general though, and despite steadily increasing computer performance, solid modeling was still too compute intensive for most practical applications. Extensive solid modeling research was done by Charles Lang's group (at Cambridge University) and by Herb Voelcker and his team (at the University of Rochester's Production Automation Project) throughout the decade and the approaches taken throughout the 1970s by the two groups were fundamentally different, as were the CAD software products ultimately based on their research.

Herb Voelcker's efforts focused on CSG solid modeling and resulted in the 1978 release of the PADL (Part and Assembly Description Language) solid modeler, which was subsequently used in several commercial 3D solid modeling CAD software programs in the early 1980s.

B-rep (boundary representation) data structures had been proposed by B. Baumgart (at Stanford University) in the early 1970s for their advantages in finte-element meshing applications but it was Ian Braid, working in Charles Lang's group at Cambridge University, who released prolific research on the applications of b-rep in solid modeling throughout the mid 1970s to culminate in the 1978 release of the BUILD solid modeler, the first true boundary representation solid modeler implementation. Shortly after that release, Ian Braid moved into Shape Data Ltd. a CAD software consulting company which had been established by Charles Lang, Ian Braid and others in Cambridge in 1974.

The increasing power of computers, and especially the introduction of lower cost minicomputers with optimized Fortran compilers and graphics capable terminals, were beginning to make CAD software more accessible to engineers. The commercial CAD software market was emerging and by the end of the decade was to be very strong and profitable. The increasingly widespread development and use

of CAD software was prompting calls for some form of standardization and in late 1979, Boeing, General Electric and the NBS (then the National Bureau of Standards, now NIST, the National Institute of Standards) agreed to commence the first implementation of IGES (Initial Graphic Exchange Standard), which was published the following year. IGES facilitated the transfer of complex 3D curves and surfaces between different 3D CAD software programs and despite other initiatives continues to be the most widely used data-transfer format in CAD software to the present time.

Many CAD software vendors were founded in the 1970s and many new commercially available CAD software programs were released. In 1970 M&S Computing (later to become Intergraph) was established while in the following year Dr. Hanratty founded MCS. In 1972 MCS released the ADAM CAD software which was rapidly licensed as an OEM product by other CAD software companies, including Computervision, Gerber Scientific and United Computing and was used as the core (or kernel) of their commercial CAD software systems.

By the end of the decade, the first wave of true commercial CAD software vendors had formed and many automotive, aerospace and consumer electrical/electronics companies were using some amount of commercially available CAD software in conjunction with their proprietary, internally specified and developed CAD software programs. Commercial CAD software included: Auto-trol's Auto-Draft, Calma, Computervision's CADDS, IBM's CADAM (marketed on behalf of Lockheed), M&S Computing's IGDS (Interactive Graphics Design Software) and McAuto's Unigraphics (the result of McAuto's 1976 acquisition of United Computing) all contending to capture share in the new and dynamic CAD software market. The CAD software and hardware market had grown from under $25M in 1970 to just under $1B in 1979, with investor interest in CAD software vendors mirroring that trend. Not surprisingly, in 1979 Auto-trol became the first CAD software vendor to successfully complete a public offering.

The 1970s then was a decade which saw major advances in CAD software, especially in the fundamental geometric algorithms that CAD software was built on. Equally important, the power of computer hardware was steadily increasing while the new VAX minicomputers launched by DEC, by 1979 second only to IBM in market share, and minicomputers from Data-General, HP and Prime were continuing to reduce computer prices and operating costs and making CAD software accessible to smaller companies. In the late 1970s new high-level programming languages such as C and simpler operating systems such as UNIX were emerging

into more wide-scale use and the first generation of graphics capable desktop computers (such as Hewlett-Packard's HP9845 series in 1978) was encouraging engineers to experiment with programming and heralding the dawn of workstation computing.

3. CAD software history, 1980-85

Mainframes to UNIX workstations...

CAD software began the 1980s as a research topic that had just blossomed into commercial profit but the CAD software industry was to end the decade facing the stark reality of harsh commercial competition driven by frenetically commercial product development schedules and unprecedented change in both hardware and CAD software technology.

In the early 1980s DEC's new VAX range of minicomputers seemed set to dominate engineering computing and CAD software for the decade. In many ways, DEC's MicroVAX paradoxically marked the company's apparent technology lead and yet foreshadowed the impending workstation era (which would ultimately be DEC's demise) by setting new standards in price, performance and accessibility and becoming the first performance computer capable of running CAD software but not requiring special power supplies or cooling.

In the CAD software market, M&S Computing renamed itself to Intergraph in 1980 and had a successful IPO in 1981. In 1983 Intergraph released the InterAct and InterPro range of 3D complex surface modeling CAD software based on DEC's VAX and MicroVAX processors. At that time most successful CAD software was sold as a turnkey hardware/software package and realizing the apparent commercial potential of CAD software to help sell its computers, HP set up its commercial CAD software group in 1980 to develop the its PE CAD software. Avions Marcel Dassault created its Dassault Systemes subsidiary in 1981 and signed a sales and marketing agreement allowing IBM to resell the CATIA CAD software. CATIA Version 1 (which was an add-on for CADAM providing 3D surface modeling and NC functions) was released in 1982 and the IBM-Dassault partnership continues to the present time. GE also moved into the CAD market in 1981 with its acquisition of CALMA which at the time was earning over $100M annually.

DEC was the undisputed #1 vendor in the crowded engineering minicomputer market of the early 1980s but a new challenge, the UNIX workstation, was emerging to revolutionize the computing and CAD software markets far more rapidly than anyone, most especially DEC, anticipated. UNIX's open architecture opened the performance computer market to a new wave of low-cost, low-maintenance, high-performance workstations with hardware optimized specifically for science, engineering and of course CAD software applications. Apollo Computer started the trend in 1980, then Sun Microsystems in 1981 and Silicon Graphics in 1982. The mainframe and minicomputer makers (IBM, DEC, Burroughs, Unisys, Data-General, Wang etc.) suddenly began to find themselves undercut and outflanked as the newcomers used their UNIX open-architecture advantage to focus on rapidly improving hardware and growing market share while the traditional vendors were forced to maintain expensive proprietary operating-systems supporting legacy hardware.

PCs also first appeared in the early 1980s. IBM shipped its first PC in 1981 and Autodesk, founded in 1982, demonstrated the first CAD software for PCs, "AutoCAD Release 1", in November 1982. Adra Systems was founded in 1983 and soon after began shipping its CADRA 2D CAD software. In 1984 Bentley Systems was founded and released MicroStation, a PC implementation of Intergraph's IGDS CAD software and the following year Micro-Control Systems was founded and released the first 3D wire-frame CAD software for PCs "CADKEY". Apple had released the first Macintosh 128 in 1984 and in 1985 Diehl Graphsoft was founded and released MiniCAD which rapidly became the best selling CAD software on the Mac. Although PCs and Macs steadily increased in power throughout the 1980s and AutoCAD continued to gain substantial market share in the 2D CAD software market (despite being ridiculed by the leading CAD software vendors) the general lack of processor power and especially the poor graphics performance compared to UNIX workstations meant that it was not to be until the next decade that PCs would have their revolutionary effect on the CAD software industry.

Throughout the 1980s, the new generation of powerful UNIX workstations and emerging 3D rendering was inevitably shifting the CAD software market to 3D and solid modeling. In 1981 Unigraphics released its UniSolids CAD software based on Voelcker's PADL-2 CSG solid modeling kernel and then in 1982, Ian Braid, Charles Lang and the Shape Data team in Cambridge, England, released the Romulus b-rep solid modeler; the first commercial solid modeling kernel designed for straightforward integration into CAD software. Romulus incorporated the CAM-I AIS (Computer Aided Manufacturers International's Application Interface Specification)

and was the only solid modeler (other than its successor Parasolid) ever to offer a third-party standard API to facilitate high-level integration into a host CAD software program. Romulus was quickly licensed by Siemens, HP and several other CAD software vendors. The first version of IGES had been published in 1980 but already the emerging shift to 3D CAD software using solid models, and the need for such CAD software to manage product data such as material properties, surface finish, engineering tolerances etc., was creating a need for a new data exchange standard. In 1984 the PDES (Product Data Exchange Specification) initiative was started in Europe to address the new needs.

In 1985, CATIA Version 2 was released as a CAD software program independent of CADAM and another French CAD software vendor, Matra Datavision (founded in 1980), released its Euclid-IS solid modeling 3D CAD software which used a unique hybrid mix of planar faceted models (for speed) with CSG data-structures. The Romulus solid modeling kernel went through several upgrades to add assembly management, instancing, improved blending and b-spline surfaces before being retired in 1986. Also in 1985, Evans & Sutherland, who had maintained close relations with Charles Lang and Ian Braid for several years and was interested in developing CAD software to supplement its graphics terminals and simulator business, acquired Shape Data. E&S soon commissioned Bernard Solomon and his team at Shape Data to begin developing the Romulus-D 3D CAD software. Romulus-D was an innovative 3D CAD software program built on the Romulus solid modeling kernel. Romulus-D ran on Apollo workstations and used Apollo's DOMAIN networking to provide the CAD software industry's first network-enabled 3D CAD software, including assembly modeling, fully distributed product configuration management and change control functions.

By 1985 the CAD software industry seemed to have settled into a comfortable trend, with incremental improvements in software functionality taking advantage of continuing advances in computer hardware performance. Profit margins were high as CAD software prices stayed high despite falling hardware prices and sales growth was strong. Computervision, with annual revenues exceeding $350M, was the market leader ahead of GE/CALMA, Applicon and Intergraph followed by McDonnell-Douglas/Unigraphics and IBM/CATIA. Then, in 1985, a new and very aggressive 3D solid modeling CAD software vendor, Parametric Technology Corp. (now PTC), appeared in the market - commercial reality was arriving and in many ways the industry would not be the same again.

4. CAD software history, 1986-89

Complacency to reality as the world goes Parametric...

CAD software vendors had begun the 1980s as a collection of fast growing companies benefiting from rapid advances in computer hardware and a potential market that was expanding as falling computer prices and maintenance costs made CAD software available to more users. CAD software prices stayed profitably high and in 1981, as CAD market revenues exceeded $1B, an expectation of perpetually continuing growth permeated the CAD software industry. A sense that the major CAD software brands had been decided, and that new competitors, such as Matra Datavision, would be limited simply to niches was contributing to the leading CAD software vendors' complacency in just the same way as IBM and DEC had become complacent in the computer hardware market. GE's acquisition of CALMA in 1981 and Dassault's acquisition of CADAM in 1986 further reinforced the sense of complacency as the CAD software market began a trend of consolidation through acquisition which has continued to this time.

A further trend was contributing to the CAD software industry's complacence; aerospace and automotive manufacturers had begun to retreat from proprietary internally developed CAD software and were starting to buy larger quantities of CAD software from the commercial vendors. Boeing had started its TIGER 3D CAD software project in 1980 but by 1988 announced that CATIA would be used to design and draft the new 777 aircraft, creating a staggering $1B revenue for IBM-Dassault. Following on from its CADANCE CAD software, GM had started development of the GDS CAD software in the early 1980s but by 1988 had already instigated its C4 (CAD CAM CAE CIM) program to consolidate and rationalize the unwieldy number of different CAD software programs it was using. Similarly, McDonnell-Douglas' aerospace division was then establishing its C3 (CAD CAM CALS) initiative for similar reasons. The 1980s emerging shift from internally developed CAD software to commercial solutions promised to more than double the total CAD software market size to the benefit of the commercial CAD software vendors.

When Parametric Technology Corp. launched the first UNIX workstation 3D CAD software, Pro/Engineer, in 1987, the leading CAD software vendors were: Computervision (CADDS), Intergraph (IGDS and InterAct), McDonnell-Douglas (Unigraphics), GE/CALMA, IBM/Dassault (CADAM and CATIA) and SDRC (I-DEAS,

which had been launched in 1982). Those vendors initially dismissed Pro/Engineer as irrelevant, immature and unstable, yet within 18 months of Pro/Engineer's release, the CAD software market and the sales, marketing and development groups of the major CAD software vendors were in various stages of turmoil as Parametric Technology sold new licenses of 3D CAD software at a record pace.

Pro/Engineer irrevocably changed users' expectations of CAD software's user interface functionality, ease-of-use and most especially of the speed of solid modeling. Pro/Engineer was the first mainstream 3D CAD system to fully implement the concepts first demonstrated over 20 years before in Ivan Sutherland's **Sketchpad** (except the light pen) but did so with the first 3D CAD software to be entirely based on solid models and history-based features and constraints. Literally overnight Pro/Engineer made the user-interfaces of the other vendors' CAD software programs obsolete. Pro/Engineer made extensive use of UNIX's X-Windows to provide a user-interface with drop-down menus, context-sensitive menus, pop-up option and input boxes, icons and other user-friendly features. Compared to Pro/Engineer, the established vendors' CAD software programs, which were all based on proprietary operating-systems and written in Fortran and assembler, were slow, ungainly and seemingly uncompetitive. If it had not been for Pro/Engineer's initially weak 3D curve and surface modeling functions and the investments in training and especially legacy data (which would have been very expensive to convert into Pro/Engineer's proprietary data format) that manufacturers had already made in the established CAD software vendors' systems, Parametric Technology's advance would have been even more dramatic than it anyway was.

MDM&E/Unigraphics (McDonnell-Douglas Manufacturing & Engineering) had been the first major CAD software vendor to fully comprehend the rapid emergence of UNIX workstations and one of the few with a history of supporting multiple hardware platforms (having supported various Data-General models since 1976 and DEC models since 1977). In 1987 John Mazzola, Tom Curry and Jerry Maryniak had adopted an "open hardware platform" strategy under which Unigraphics was to be ported to UNIX workstations from Apollo, HP and Sun with the HP version released first (in early 1988). Dassault Systemes had also ported CATIA to IBM's new UNIX RISC workstation (the RS6000) under pressure of the close marketing relationship with IBM and the RS6000 being supported with CATIA Version 3, also released in 1988.

Dassault, with their aerospace heritage, had already earned a very strong reputation for complex 3D surface modeling CAD software when Pro/Engineer was released. Dassault was also preoccupied with their massive commitment to Boeing and felt less initial threat from Parametric Technology. MDM&E/Unigraphics was far more threatened by Pro/Engineer and was forced to react more quickly, and so, in late 1988, the Unigraphics business acquired Shape Data (which was about to release Parasolid) from Evans & Sutherland. The Unigraphics team quickly retired the PADL-2 based UniSolids solid-modeling CAD software and in late 1989 introduced a more integrated and competitive solid-modeling CAD software program named UG/Solids based on Parasolid.

Parasolid had been designed by John Owen and his team at Shape Data to be upward compatible with the previous Romulus solid modeling kernel and retained the CAM-I AIS API. Ron Davidson launched Parasolid as a "de-facto standard" solid modeling kernel business in 1989 and very quickly licensed Parasolid to Siemens-Nixdorf, General Dynamics, Fujitsu and others for integration into their CAD software programs. Independently, Charles Lang and Ian Braid had formed Three-Space Ltd. in Cambridge, England in 1985 and had been retained by Dick Sowar's Spatial Technology (which had been founded by Sowar and John Rowley in 1986) to develop the ACIS solid modeling kernel for Spatial Technology's Strata CAM software. The first version of ACIS was released in 1989 and was quickly licensed by HP for integration into its ME CAD software.

Japanese researchers were also very active in the 1980s and Professor Fumihiko Kimura and his team at the University of Tokyo had been researching solid modeling since the start of the decade. One of Professor Kimura's researchers, Dr. Hiroaki Chiyokura, had moved into Ricoh in the mid 1980s and in 1987 Ricoh released the DesignBase boundary representation solid modeling kernel which was unique in using Gregory surfaces (as opposed to NURBS) as its primary geometry. Designbase was quickly adopted by many Japanese CAD software vendors and Ricoh began to sell Designbase through their US office in 1989. That marked the beginning of the "kernel modeler wars" between ACIS, DesignBase and Parasolid which was to continue throughout the following decade.

In the computer hardware market, the "workstation wars" fought between Apollo Computer, Sun Microsystems, SGI, HP, DEC and IBM reached boiling point in 1987 when Apollo Computer achieved the #3 position after IBM and DEC. In 1989 HP acquired Apollo Computer to take the #2 position from DEC and by the end of the 1980s, first-generation RISC processors and high-performance real-time 3D

full-color rendering were setting the benchmark in the hardware market. HP and Sun emerged as the strongest general purpose workstation vendors with SGI dominating the 3D graphics workstation market. DEC was by then desperately searching for ways to regain its early 1980s dominance and IBM was shortly to face some of the biggest losses in US corporate history.

In the CAD software market, Parametric Technology's Pro/Engineer CAD software continued to dominate the news with 3D solid modeling and rendering performance an order (sometimes orders) of magnitude faster than its competitors. Major CAD software vendors were training their salespeople to spread the message that "Pro/Engineer is just a faster way to get to the bugs" but were simultaneously developing "Pro/E killer" products. 3D CAD software developers were working late nights and weekends trying to replicate Pro/Engineer's user interface and match its solid modeling benchmark performance.

The industry had started the decade complacently but events, and their toll on CAD software vendors, had been substantial. The potential market for CAD software was expanding significantly but the recessions in Europe and the US were at last driving down average prices of CAD software and reducing the previously fat margins. By the end of the decade the leading CAD software vendors had become: Dassault Systemes (CATIA), Parametric Technology (Pro/Engineer), MDC (Unigraphics) and SDRC (I-DEAS). Both Computervision and CALMA (divested by GE) had been acquired by Prime Computer (which itself was on the verge of bankruptcy) in 1988 and together with Intergraph were losing momentum which they were never to regain.

5. CAD software history, 1990-94

UNIX to Windows NT...

The CAD software market entered the 1990s in conflicted turmoil: Parametric Technology's Pro/Engineer 3D CAD software continued to influence users' expectations and sold 3D CAD software licenses to more customers more quickly than had ever been done before, yet simultaneously, some of the largest contracts in CAD software's brief history were being competed for and won by the other CAD software vendors. User expectations for 3D CAD software had been fundamentally changed by Pro/Engineer's UNIX X-Windows based user interface and especially by its 3D solid modeling speed. The other CAD software vendors were hastily

developing their "Pro/E killer" upgrades while their sales and marketing groups were busy convincing existing customers and new prospects to wait for those new upgrades to be released. Although Autodesk was not directly threatened by Parametric Technology's success, it had its own new set of challenges as the PC CAD software market rapidly expanded and John Walker, Founder of Autodesk, summed up the mood of the day perfectly in his **Information Letter 14**; "Whenever I read something written between 1982 and 1988, or reflect upon those years, they seem increasingly distant, foreign, almost *quaint*."

Fortunately for the longer established CAD software vendors, the market for CAD software was growing strongly as manufacturers were increasingly driven by cost and 'time to market' pressures to utilize more automation, including of course more seats of CAD software. By 1990 it was apparent that Boeing was succeeding with its 'all CATIA no paper' design strategy and that it would achieve substantial reductions in time to market by safely eliminating many of the physical mockups traditionally required to verify paper designs. Boeing's success was motivating other aerospace and automotive manufacturers to consider standardizing on a single 'corporate CAD software vendor' for the bulk of their work and so, in the period 1990 - 1993, some of the largest contracts in CAD software history were competed for and won. Pratt & Whitney standardized on Unigraphics, as did GE Aircraft Engines. Mercedes-Benz, Chrysler, Renault and Honda standardized on CATIA. Caterpillar standardized on Pro/Engineer. GM also decided that it was going to use substantial amounts of Unigraphics and, as a result, MDM&E/Unigraphics was acquired by EDS (Electronic Data Systems Corp.) in late 1991.

By 1992 UNIX workstations had redefined CAD and no new CAD software was being sold for use on mainframe or minicomputer terminals. Those vendors (most notably Computervision and Intergraph) who had traditionally focused on proprietary hardware plus software turnkey solutions were particularly hard hit as it became clear (as IBM's shock $5billion 1992 loss helped illustrate) that customers increasingly wanted lower cost "open" systems and were no longer prepared to pay the huge costs of maintaining proprietary hardware and operating-systems. By 1993 the CAD software market had clearly polarized with IBM-Dassault Systemes (CATIA), EDS-Unigraphics (Unigraphics) and Parametric Technology (Pro/Engineer) the clear leaders in the UNIX workstation 3D CAD software arena followed closely by SDRC (I-DEAS). The giants of the previous two decades; Computervision (CADDS), which separated from Prime Computer when Prime shutdown in 1992, and Intergraph (I/EMS); were trailing and unable to regain their former momentum.

Despite the rush of big "corporate standard" CAD software contracts in the early 1990s, it was becoming increasingly difficult for the leading CAD software vendors to differentiate their products. Pro/Engineer's influence had been so strong; and the 3D CAD software vendors' rush to counter Parametric Technology's advance so rapid; that by 1994 the 3D CAD software programs offered by each of the leading vendors were becoming very similar: each had sketching, constraints management, feature-based solid modeling, history trees, NURBS surfaces and X-Windows user interfaces etc.

A further problem for the leading vendors was resulting from the "3D solid modeler kernel wars" being waged by Spatial Technology (ACIS), EDS-Unigraphics (Parasolid) and Ricoh (Designbase). Those 3 companies were licensing increasingly sophisticated 3D b-rep solid modeling libraries which licensees could integrate into existing CAD software to provide strong solid modeling functions. Because of the very aggressive pricing of the kernels, even the smallest CAD software vendor could afford to integrate 3D solid modeling into their products. The ACIS modeler, although then less functional than Parasolid, was being very aggressively sold by Spatial which already had a customer list of more than 70 3D CAD software vendors worldwide using ACIS by 1993: the most famous of which was Autodesk.

Autodesk had steadily ridden the PC wave to become the #1 2D CAD software company with 1992 revenues of $285million (by comparison EDS-Unigraphics CAD software revenues in 1992 were less than half at ~$130million). Autodesk had originally licensed the ACIS kernel from Spatial in 1990 and in 1994, Autodesk announced that it had sold the 1,000,000th license of its AutoCAD 2D CAD software and that it was releasing AutoCAD Release 13, including 3D solid modeling functions based on the ACIS 3D kernel.

So, in late 1994, just as the CAD software industry had acclimatized to the shock of UNIX workstations, and even DEC seemed to be about to regain its former glory with the release of its new 'Alpha' processor, two further events combined with Autodesk's release of 3D CAD software which were to totally revolutionize the CAD software industry: Microsoft released its first 32-bit operating system for PCs, Windows NT, and Intel released the first 32-bit Pentium Pro chips. At the same time the "3D solid modeler kernel wars" were intensified as EDS/Unigraphics officially released Parasolid for Windows NT, Spatial Technology released its 3D Toolkit extensions for ACIS on Windows NT and Ricoh released Designbase on Windows NT. 3D CAD software had previously taken years and millions of dollars to develop but in principle could now be developed and released on start-up budgets in less than a

year; in 1993 a small CAD software company called SolidWorks started to do exactly that.

6. CAD software history, 1995-97

SolidWorks and PDM...

The CAD software market was marked by two great changes in the mid 1990s, the PC 3D CAD software explosion and the unrelated explosion in PDM systems.

Just as word-processors had created an explosion in the number of documents produced, so had CAD software resulted in an explosion in the number of drawings created and, as CAD software proliferated, so PDM software (such as SherpaWorks from Sherpa, founded in 1984) had begun to emerge to streamline the management of those drawings. Boeing's success with the 777 paperless design was driving interest in using PDM software to manage not only drawings, but to enable configuration management and change control of the huge databases of parts being created by CAD software.

In the early 1990s the number of new PDM vendors had grown dramatically. EDS/Unigraphics released its first PDM software, InfoManager (later renamed to iMAN to avoid a possible trade-name conflict) in 1991 and in 1992 Metaphase was founded as a joint-venture between SDRC and Control Data; Workgroup Technology Corp. was also founded that year. The move towards PDM was so strong that by 1994 Adra Systems, which had produced the CADRA 2D PC CAD software since the mid 1980s and the CADRA Solids 3D PC CAD software since 1992, was earning almost as much revenue from its MatrixOne PDM software as from its CD software products.

While developments in PDM were accelerating, by 1995 it was clear that 3D CAD software based on b-rep solid modeling and NURBS surface modeling was beginning to plateau and vendors were focusing less on fundamental technology breakthroughs and more on incremental improvements as the breakneck "catch PTC" development pace of the early 1990s receded. When SolidWorks suddenly released the SolidWorks 95 3D CAD software as an "80% of Pro/Engineer's functionality at 20% of the price" product in late 1995, the other CAD vendors' reaction was very different from the reaction to Parametric Technology's release of Pro/Engineer back in 1987.

The original release of Pro/Engineer had created turmoil as CAD vendors were forced to totally reevaluate and rewrite their fundamental architectures; SolidWorks 95 forced them simply to decide whether to port a subset of their existing product. or the entire product, to Windows NT. While there were substantial differences between the UNIX and Windows NT operating-systems and porting was not totally straightforward, Windows benefited from extremely good development tools (MFC, Visual C++ etc.) and "leveling the technology playing-field" was generally perceived to be simply a matter of time. In fact all of the leading UNIX 3D CAD software vendors had released Windows NT versions by the end of 1995.

The advent of serious, aggressively marketed sub-$10,000 3D CAD software on Windows created a business dilemma for the UNIX workstation CAD software vendors. While it was clear that many 3D CAD software users needed the CPU power and especially the graphics power provided by UNIX workstations, it was equally obvious that there was a large market of users that were satisfied with the performance offered by PCs. By 1997 it was also clear that UNIX's performance advantage was being rapidly eroded as Intel rolled-out increasingly powerful Pentium processors and multiple Taiwanese manufacturers competed to produce ever more powerful 3D graphics boards for PCs.

Suddenly the UNIX 3D CAD software vendors found themselves coming under intense pricing pressure as customers with lower performance sensitivity began to buy SolidWorks 95 in preference to higher performance much more expensive UNIX 3D CAD software (or the less expensive but more complex Windows offerings from the leading CAD software vendors). Conversely, Autodesk found itself under pressure to improve its 3D CAD software offering as AutoCAD customers with higher 3D performance requirements bought SolidWorks 95 in preference to AutoCAD's lower priced ACIS based 3D CAD software. The mid-range CAD market had been born and SolidWorks' perceived success was such that after just 2 years they were acquired by Dassault Systemes in 1997 for $320million!

In 1996 Intergraph also released a 3D CAD software product on Windows similar to SolidWorks. Intergraph's SolidEdge product was based on Spatial Technology's ACIS kernel modeler (in fact the very first prototype of SolidWorks had also been based on ACIS but Spatial refused SolidWorks' licensing proposal) and was launched in a bid to enhance sales of Intergraph's high-performance "TD" 3D graphics PCs. After some successful sales and reviews the SolidEdge business was acquired by EDS-Unigraphics in 1997 shortly after Dassault-Systemes acquired SolidWorks.

Meanwhile Autodesk had become increasingly concerned at the prospect of their much vaunted million-plus 2D CAD software users being wooed by SolidWorks, SolidEdge and other full-function 3D CAD software programs on Windows from Bentley Systems, CADKEY and numerous others. In 1996 Autodesk released Mechanical Desktop which was their first full-function 3D solid modeling CAD software product and which rapidly became the #1 selling 3D CAD software product in the world.

In 1997 Computervision, which had been steadily declining throughout the decade, also attempted to gain a position in the PC 3D CAD software market with the release of its DesignWave PC 3D CAD software based on EDS-Unigraphics' Parasolid kernel modeler.

General Motors' 1996 decision to standardize on Unigraphics followed by Ford Motor's 1997 decision to replace its internally developed PDGS CAD software with SDRC's I-DEAS 3D CAD software were the last of the "great American corporate CAD software deals" and the end of the era of internally developed CAD systems started back in the 1960s. It also marked a new phase for the CAD software industry as it was clear that:

1. the boom years of relatively easy and fast growth were over,
2. the increasing lack of differentiation at the CAD software technology level were making competition more difficult and expensive,
3. the downward pressure on 3D CAD software revenues caused by fierce price/function competition from the Windows 3D CAD vendors was reducing the value of pure CAD software sales.

The leading CAD software vendors needed to diversify and PDM provided them with the opportunity. Throughout the mid 1990s the PDM market had been growing at >20% per year to ~$1.1billion revenues in 1997. The market was predicted to more than double in the next 5 years and the leading CAD software vendors only held single digit shares of it; it was inevitable that they would turn to PDM systems for future growth.

7. CAD software history, 1998-99

PDM, the Internet and PLM...

1998 was the year in which DEC, after a decade of struggling to regain its glory of the 1980s, was acquired by the "PC clone" maker Compaq. The message that DEC's acquisition sent across all software markets, including the CAD software market, was in a sense confirmation of what was already a well established fact: if it did not run on Windows then it probably did not run. The market had come a very long way in just two decades.

The CAD software market in the late 1990s was marked by three main developments, each of which was driven by the basic premise that it was no longer possible for the leading CAD software vendors to compete and grow simply on 3D CAD software revenues. The three developments were:

1. acquisitions and consolidation,
2. the rush to gain share in the PDM market,
3. the stampede to become "Internet enabled".

Dassault Systemes started the run of acquisitions when it bought SolidWorks in 1997. In the same year EDS-Unigraphics acquired SolidEdge from Intergraph and Dassault also acquired Deneb Robotics (founded in 1985) the leader in the manufacturing visualization market. The biggest shake-up of the CAD software market since its inception then occurred in 1999 when Parametric Technology, then market leader, acquired former market leader Computervision. Also in 1999 Dassault acquired Matra Datavision, another well established CAD software vendor.

Meanwhile the dot-com bubble had been triggered in May 1997 when Amazon.com had completed its successfully IPO. By the end of 1998, Amazon.com's market cap had soared to $17billion and showed no signs of slowing its rate of ascent. In all industries, including the CAD software industry, vendors were devising strategies to become "Internet-enabled", benefit from the enormous B2B revenues that were then being predicted and of course have their share price benefit from the stock market's craze for Internet stocks.

Although a few companies (such as Alibre founded in 1997) were soon announcing client-server Internet enabled 3D CAD software which would allow full 3D modeling across the Web, the main focus was to enable viewing of 3D models in Web browsers and building Internet/intranet browser interfaces to PDM systems. One of the leaders was Dassault Systemes, which benefiting from its experience of integrating CAD software across networks for the Boeing 777 project, had already

made its first move toward Internet enabled CAD software in 1996 with its CATIA Conferencing Groupware, which enabled review and annotation of CATIA models across the Internet. In 1997 Dassault released its CATWeb Navigator which provided enhanced Web based viewing of CATIA 3D models and assemblies and then in early 1998 created its ENOVIA subsidiary to develop the PDM II system (which could use the CATWeb Navigator module to provide Internet enabled PDM).

In 1998 EDS spun-off the Unigraphics and iMAN division as Unigraphics Solutions and sold 14% of the new company in an IPO. In 1999 Unigraphics Solution's President John Mazzola announced that the company was realigning itself to focus more intently on Web-enabled PDM and desktop visualization and the iMAN Web Author extension to its iMAN PDM software was launched. Also in 1999, Parametric Technology announced its alliance with SupplierMarket.com to add an ecommerce aspect to Parametric's newly launched Windchill PDM software, Dassault announced that it was acquiring Smart Solutions and its SmarTeam Web enabled PDM software and CoCreate, formerly the CAD software division of Hewlett-Packard, announced its OpenSpace Web enabled 3D portal.

Compared to the rush of acquisitions, new PDM software releases and "Internet-enabled" upgrades, the changes in 3D CAD software were few and far between in the late 1990s. Once Dassault Systemes released its long awaited CATIA Version 5; the first version of CATIA to be fully implemented on Windows; in 1999, all the leading vendors had fully implemented Windows look-and-feel CAD software with large assembly viewing capabilities, sketching and constraints management, feature-based history, etc. To upgrade its 3D CAD software offering to compete bead-on with the traditional (and newer such as SolidWorks and SolidEdge) 3D CAD software vendors, Autodesk released its new Inventor 3D CAD software based on Spatial Technology's ACIS kernel in 1999. Inventor was the first Autodesk mechanical CAD software not to be based on its AutoCAD architecture. Also in 1999 the Italian CAD software company CADLab changed its name to think3 and renamed its EurekaGold 3D CAD software to thinkdesign.

While the dominating news of the year was Parametric Technology's acquisition of Computervision and how that would affect the CAD software industry, the less obvious news was that there were no longer any fundamental technology breakthroughs being made in 3D CAD software. There were a number of new small niche 3D CAD software vendors appearing with various low-cost products based on the two major 3D modeling kernels (Parasolid from Unigraphics Solutions and ACIS from Spatial Technology; Ricoh's Designbase had effectively disappeared from the

commercial 3D kernel modeler wars in 1997) but no new major technology breakthrough had appeared in over a decade since Pro/Engineer had been launched back in 1987.

37 years after Ivan Sutherland published his SketchPad thesis, the CAD software industry had clearly entered what Clayton Christensen would term its period of "sustaining technologies".

8. CAD software history, 2000-04

PDM, the Internet and PLM...

The clocks ticked into 2000 and the IT industry, CAD software vendors included, breathed a sigh of relief as it became evident that fears of Y2K problems were not to materialize.

In the CAD software industry, attention swung back to Web enabled CAD as Alibre released Alibre Design, based on Spatial Technology's ACIS, which was the first 3D CAD software able to perform client-server 3D modeling over the Internet (although in Japan, Toyota Caelum's TeamCAD had been capable of 3D modeling across LANs since the mid 1990s, even before the term 'client-server' became popular!).

Autodesk released AutoCAD 2000i in mid 2000 which was their first Web enabled CAD software and provided the ability to output drawings that could be viewed with a Web browser and also enabled some online simple collaboration using Microsoft Net Meeting.

The pressure on manufacturers to reduce new product concept>design>detail>manufacture>shelf time had increased relentlessly throughout the previous decade and in late 2000 Ford showed how much could be achieved with fully integrated 3D CAD software and Internet enabled PDM when it released the Ford Mondeo which had been designed entirely over the Internet using Ford's C3P (CAD CAM CAE PDM) platform in about 1/3rd of the time traditionally required. Ford's success proved that the integration of CAD software, PDM software and the Internet to give engineers and designers the ability to view and collaborate on a single digital "master", not only saved in time and travel expense, but almost eliminated the traditional misfit, mismatch and "nocando" problems inherent in the

design and production of a complex product by a globally dispersed manufacturer working with an equally dispersed group of suppliers.

Using "virtual product development" with a digital master 3D assembly of 3D component models replacing clay prototypes, Boeing had succeeded in reducing product development times in the aerospace industry and now Ford had done the same in the automotive industry. At least at the enterprise manufacturing level, the competition had shifted away from the function to function comparisons typical of the major 3D CAD software deals of the late 1980s and early 1990s and had now become a test of how well the vendor could manage the flow of design and engineering data; of which the 3D CAD model was an increasingly smaller percentage.

Picking up on the term PLM "Product Life-cycle Management", which had started as university research into manufacturing databases in the early 1990s and had begun to gain popularity in the industry in the late 1990s, the leading CAD software companies were quick to redefine themselves to the emerging market trend. Suddenly "3D CAD software vendor" was out and "PLM solution provider" was in. The four leading vendors (Dassault Systemes, Parametric Technology, Unigraphics Solutions and SDRC) began the task of realigning their corporate images, marketing and sales processes; "blistering 3D modeling speed", "faster than lightening rendering" and "graphics so real you can feel it" were out and "value propositions", "portfolio management" and "life cycle analysis" were in.

Ford was using SDRC's Metaphase PDM software in its C3P platform and in late 2000 SDRC acquired Metaphase's long-time PDM competitor, Sherpa, to consolidate its PLM image. In addition to strong database and network management, the ability to rapidly view large assemblies of 3D data is a key component of modern PLM solutions and in late 2000 Unigraphics Solutions acquired the leading 3D viewer vendor EAI.

One of the few 3D CAD software events (other than mostly routine upgrades, updates and extensions to the leading vendors traditional 3D software products) was Dassault Systemes' acquisition of Spatial Technology's ACIS 3D solid modeling kernel in late 2000. Despite its 1996 IPO, which proved that a component technology vendor could achieve commercial success, Spatial had lost its way; partly because it had never managed to license ACIS to a leading 3D CAD software vendor and partly because like many other vendors it had over-invested in non-essential Internet ASP development. To this date neither Dassault Systemes

nor its SolidWorks subsidiary use ACIS and the reasons for the acquisition remain obscure.

Early in 2001, Unigraphics Solutions changed its name to UGS and acquired SDRC. At the same time EDS bought back the 14% of UGS stock that it had publicly sold in the late 1990s (UGS was recently acquired from EDS by a consortium of venture capital funds). Ford were relying on SDRC for the core of the C3P platform but were prompted to consider a multi-vendor strategy for their future PLM software needs. That strategy began to be implemented in early 2003 when Ford announced that they were implementing IBM-Dassault Systemes' CATIA and ENOVIA software.

While there have been no fundamental technology breakthroughs (what Professor Clayton Christensen would term "disruptive technological changes") since Pro/Engineer's release in 1987, the early part of this decade did see one or two interesting developments in making it simpler and more intuitive to create 3D CAD models. In late 2001 think3 introduced its GSM "Global Shape Modeling" into its thinkDesign software to make it possible to "push and pull" NURBS surfaces. Early in 2003, PTC (which is how Parametric Technology now likes to be known) released its new WildFire 3D CAD software which also attempted to make it simpler to create 3D geometry.

The only new 3D CAD software vendor (at least that I am legally allowed to mention) that emerged to upset the industry's status quo was ImpactXoft, which in 1999-2000 jointly developed the IX/Speed and XXen CAD software with Japan's Toyota Caelum. Initial releases of IX/Speed and XXen were made early in 2001. Dassault Systemes made a substantial investment in ImpactXoft at the end of 2002 and IX, having now broken away from the joint development agreement with Toyota Caelum, has joined a long list of companies that have become partners of Dassault Systemes developing on the CATIA Component Application Architecture.

So today, in July 2004, the CAD software industry is dominated by 3 PLM solution vendors (IBM-Dassault Systemes with CATIA & ENOVIA, UGS with Unigraphics & iMAN, and PTC with Pro/Engineer & WindChill) and Autodesk, whose market value is typically slightly below Dassault Systemes' and more than 3x that of PTC. SolidWorks and SolidEdge (owned by Dassault Systemes and UGS respectively) continue to battle with Autodesk's Inventor in the mid-price CAD software market and there are many small CAD software vendors, some of which are listed on CADAZZ's **free CAD software** pages who survive by being excellent in niche

markets and by being data compatible with the CAD software programs offered by the four leading vendors.

True innovation of the kind that drove the industry forward in the 70s and 80s seems to have died though, if only temporarily, and as Clayton Christensen might say, "This is one market just waiting for a big bang to happen!".