# Early Computer Graphics Developments in the Architecture, Engineering, and Construction Industry

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*Despite 30 years' experimentation and 20 years' availability of commercial products, the architecture, engineering, and construction industry in the mid-1990s had yet to achieve an effective integration of computer-based techniques into its business processes. Business processes in all industries are resistant to change, and people tend to use new tools in the same way they used their old ones: computers as pencils. In the architecture, engineering, and construction industry within the United States, this tendency has been aggravated by the segmentation of the work process into myriad specialties, frequently performed by separate companies, with the information flow obstructed by professional licensing, regulation, contracts, the profit motive, and even the training of design professionals. However, a number of developments—the emergence of object technology; industry standardization initiatives; widespread adoption of Internet technologies; and competitive pressures—are converging to create both the feasibility of and the necessity for rethinking and restructuring the industry. This article focuses on computer graphics precedents related to the architecture, engineering, and construction industry.*

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## Introduction

Considering the current ubiquity of and myriad uses for the computer, it seems astonishing that it was not until the mid-1960s that computers were used for anything besides number crunching and numerical output, at least in the commercial market. The specification for Cobol, the first user-friendly programming language, was not finalized until 1959. The first IBM word processor was introduced in 1964. By that time, computers had enough computing power to begin to interpret and process text in addition to numbers. But if a picture is worth a thousand words, what kind of computer was required to process computer *graphics*?

Much of the basic technology that would make computer graphics possible was developed at MIT's Lincoln Laboratory and at Harvard between the 1940s and 1960s. It is clear that this work had neither precedent nor road map. It constituted a very pure form of creativity. It was primarily government-funded, defense-related, and classified. Much of the available information about this period is found only in transcripts of the SIGGRAPH 1989 special panel sessions entitled *Retrospectives: The Early Years in Computer Graphics at MIT, Lincoln Lab, and Harvard.*

## Pioneering Efforts in Computer Graphics

The first real-time computer—the Whirlwind, developed at MIT in the late 1940s—had a five-inch Tektronix display. It also occupied a quarter acre of space and had 5,000 vacuum tubes. The team developed a diagnostic program that output to the Tektronix display. Called "Waves of One," the test ran through each storage tube and lit up a corresponding spot on the screen if all was well. If it encountered a failure, the program stopped. The trick was to determine exactly where it had stopped. Robert Everett invented a "light gun" to read the position of the last dot on the screen. This was the precursor of the light pen.

The next step was the development of an air defense computer. SAGE, a multiuser, interactive system developed in 1956, converted radar information into computer-generated pictures. The system used two consoles per operator—one for graphics and one for messaging. On the graphics terminal, the light gun was used to identify the aircraft of interest. The prototype was turned over to IBM for production. Real-time computing became the hallmark of MIT's Lincoln Laboratory's efforts.

The next computer developed at MIT's Lincoln Laboratory was the TX-0, originally built to test the practicality of transistor computer circuits and large-scale magnetic core memory. Another innovation was the TX-0's Direct Input Utility System, a precursor of the modern operating system. It consisted of a set of utility programs that made it possible to:

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- communicate directly with the computer via an online typewriter,
- look at or change program instructions,
- insert parameters,
- search for specified addresses, and
- perform a number of other programming tasks.

In 1957, Ben Gurley, who would later develop Digital Equipment Corporation's first computer, the PDP-1 (see Fig. 1), invented the light pen, a miniaturized light gun measuring 5 1/2 inches in length and 3/8 inch in diameter. It weighed only one ounce. The PDP-1 eventually replaced the TX-0 at Lincoln Laboratory.

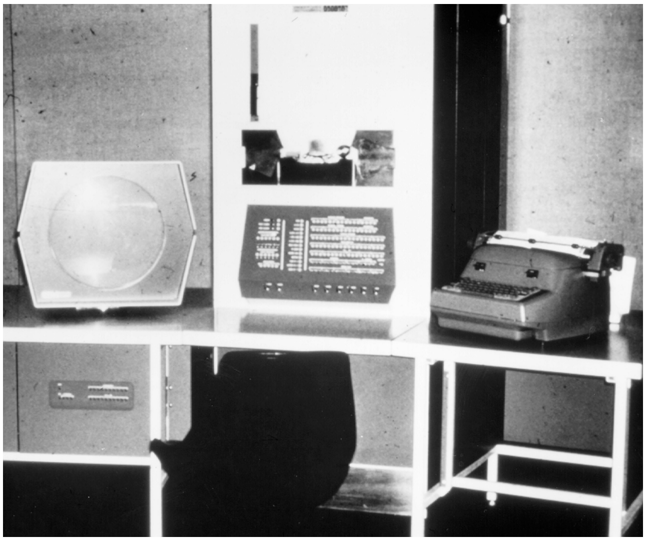

**Fig. 1. DEC PDP-1.**
**(Photograph supplied by Digital Equipment Corporation; Corporate Photo Library)**

The TX-2 came online in late 1958. It was a leap forward in terms of computational power and supported some extraordinary work in computer graphics.

One of the big hardware issues in the early 1960s was how to generate characters and lines on a tube. Character (text) generators cost $2,000 to $10,000 and were not standardized. The first storage tube screens began to appear in the mid-1960s.[1] The great advantage of storage tubes was that they did not require that the image be constantly refreshed. Instead, the phosphor in the storage tube was continuously illuminated by a low-level spray of electrons. One could write once with an electron beam, and there was no need to refresh until an image update was required. This allowed for high resolution and reduced machine overhead, permitting time-sharing: Multiple graphics terminals, even remotely connected, could be run from the same computer. The Tektronix 4010 storage tube display, at $4,000, was the breakthrough that made computer graphics "affordable." The cost per console hour dropped from between $50 and $250 to between $10 and $50. The Tektronix 4014 (see Fig. 2) provided a 19-inch display and was widely used in early commercial CAD systems.

To this point, the impediment to computer graphics development had been hardware: getting enough computational power and an adequate display device. In the 1960s, the issues of software and data structures gained prominence. Computer graphics demanded data structures of greater complexity than the arrays and link lists that had been implemented up to that point. Steven Coons developed the computer graphics techniques for describing surfaces. His published notes on the topic first appeared around 1960. The initial work described a nonparametric method that produced a surface that interpolated given boundary curves. Further work defined "blending" functions and introduced the parametric methods that are still used. Coons originally conceived of these ideas while working for Grumman Aircraft during World War II. It took 20 years for the technology—namely, computer power and displays—to catch up to what he envisioned.

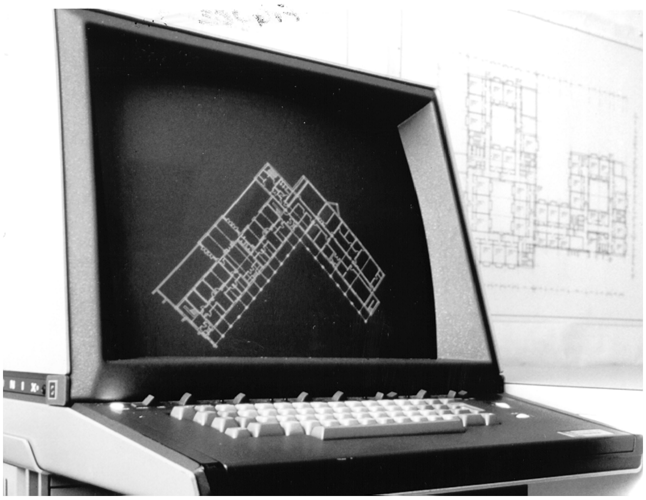

**Fig. 2. The Tektronix 4014 display.**

In 1963, a series of papers was published by MIT. Coons's paper, "Outline of the Requirements for a Computer-Aided Design System," articulated a philosophy that had a wide-ranging influence on the early work in CAD. He wrote:

> Starting in 1959 we outlined a system that would, in effect, join man and machine in an intimate cooperative complex. A combination that would use the creative and imaginative powers of man and the analytical and computational powers of the machine, each with the greatest possible economy and efficiency. We envisaged even then the designer seated at the console drawing a sketch of his proposed device on the screen of an oscilloscope tube with a light pen, modifying his sketch at will, and commanding a computer slave to refine the sketch into a perfect drawing, to perform various numerical analyses having to do with structural strength, clearances of adjacent parts, and other analyses as well.[11]

Lawrence Roberts originated a number of computer graphics techniques. In the early 1960s, he scanned photographs into the computer using an early facsimile machine as the scanner. He worked on image compression to reduce the bandwidth required to transmit photographic information. The techniques he developed were used to send back images of the Moon and Mars in some of the earliest space explorations.

From there, Roberts moved on to attempting to process photographs into 3D objects. This procedure involved trailblazing work in feature and edge detection and solids modeling. Roberts was able to create 3D objects from scanned photographs and display them, in line representation, from various points of view. He is credited with inventing the first hidden line algorithm as well as combining the mathematical techniques of perspective geometry and matrices for perspective transformations.

Generally, however, computer graphics programming is considered to be the brainchild of Ivan Sutherland, whose 1963 MIT doctoral dissertation in electrical engineering[2] laid the software foundation for computer graphics programming. Sutherland's goal was to improve the human/machine interface. He suggested several areas where computer graphics could be useful:

- for creating highly repetitive drawings;
- for making small changes to existing drawings;
- for gaining scientific or engineering understanding of operations that could be described graphically; and
- as graphical input to computational programs requiring topological data, such as circuit simulators or structural analysis programs.

Sketchpad was developed at MIT's Lincoln Laboratory on the TX-2 computer, contemporaneously with both Roberts's and Coons's efforts. Graphic input was accomplished by positioning drawing elements on the display screen with a light pen and using push-button controls to enter commands; there was no keyboard. Rotation and magnification were effected by turning knobs. Sketchpad supported only two graphic primitives: straight line segments and circular arcs. However, it permitted the grouping and establishment of relationships between graphic elements. Sketchpad allowed the grouping of elements into *subpictures*. These subpictures were instanced, so that changing the definition would change all occurrences. And they could be nested—a subpicture could include other subpictures. Sketchpad also stored topology—if the user moved a point, the lines connected to the point stretched or became shorter accordingly.

Sutherland also programmed a number of computer graphics construction techniques that are still familiar:

1) *Rubberbanding* showed a line or arc stretching, shrinking, or repositioning as it was being defined.
2) *Snap to End Point* allowed the user to attach a line, arc, or subpicture to the exact end point of an existing graphic element.
3) *Copy Definition* facilitated information reuse.
4) *Geometric constraints* permitted the precise creation of:
   - verticals,
   - horizontals,
   - perpendiculars,
   - parallels,
   - lines-on-circles, and
   - lines of equal length.

Sutherland validated the Sketchpad concept by using it to create a variety of drawing types: electrical, mechanical, scientific, mathematical, and animation. For output, he used a plotter from Electronic Associates Inc. Sutherland's dissertation indicates a strong emphasis on the development and optimization of the graphic data structure. In his Acknowledgments, he includes Claude Shannon, Marvin Minsky, Coons, Leonard Hantman, and Roberts.

The earliest commercial applications of computer graphics were launched at about the same time. ITEK contracted Adams Associates to develop the first electronic drafting machine, based on the PDP-1 (see Fig. 1). The developers were John Gilmore and David Weisberg, both from MIT. The system had two modes of operation. In sketch mode, the light pen was used like a pencil. With a set of controls on the CRT drawing board, the operator could constrain the motion of the drawing point horizontally, vertically, or to some selected angle or arc, thereby creating the illusion of drawing on the CRT with straight-edge tools.

In construct mode, the light pen, used like a pointer, activated controls that defined numerical end points of lines, centers of circles, and other boundary conditions of interest. ITEK marketed this system as the EDM machine. ITEK later sold it to Control Data Corporation, where it became the Digigraphics system. Lockheed Aircraft and Martin Marietta were among its first users.

Another early commercial use of computer graphics was General Motors's Design Augmented by Computer, or DAC-1. [Ed.: see *Annals of the History of Computing,* vol. 16, no. 3, pp. 40–56 for an article on this topic by Fred Krull.] Krull developed it with Patrick Hanratty. The DAC-1 used an IBM Alpine Display, a precursor to the IBM 2250 graphics console, which was introduced with the IBM System/360 computer in 1964 (see Fig. 3).


**Fig. 3. IBM System 360 Model 40 with the IBM 2250 CRT.**
**(Courtesy of IBM)**

It was the IBM System/360 with the 2250 graphics console that supported Nicholas Negroponte's very interesting work in the application of machine intelligence, as well as graphics, in an architectural (i.e., building design) context. Negroponte's premise, articulated in his 1970 book *The Architecture Machine,* was that the failure of modern architecture, particularly urban planning, had resulted from architects' need to generalize programmatic requirements because they were unable to keep in mind all the necessary detail simultaneously. Very early in the Information Revolution, Negroponte identified the need to process information in new ways:

> Because of this, an environmental humanism might only be attainable in cooperation with machines that have been thought to be inhuman devices but in fact are devices that can respond intelligently to the tiny, individual, constantly

changing bits of information that reflect the identity of each urbanite as well as the coherence of the city.[3]

Negroponte also foresaw that computers would not become fully acceptable until they became personal, and he understood that some way, somehow, personal computers would permit access to a vast information store:

> You need not look too far, maybe ten years: . . . such omnipresent machines, through cable television (potentially a two-way device), or through picture phones, could act as twenty-four-hour social workers that would be available to ask when asked, receive when given.[4]

Actually, it was more than 20 years, but by the mid-1990s, there were Internet-based support groups like the *Walkers in Darkness*, a mailing list for people with chronic depression, processing more than 300 messages weekly from around the globe.[5]

**Negroponte ... understood that some way, somehow, personal computers would permit access to a vast information store.**

In the early days, the human/machine interface was a pressing issue. Most of the early MIT work involved special push-button input devices, like the one configured with the 2250 graphics console (see Fig. 3) or programming on-screen buttons activated by the light pen. In the Civil Engineering Department at MIT, a second approach was undertaken in the mid-1960s: the use of Problem-Oriented Languages (POLs). These provided an English-language, engineering-oriented, command-structured syntax for the solution of civil engineering problems. The approach was closer to that taken in the development of business-oriented languages like Cobol. The Integrated Civil Engineering System (ICES) appeared in 1967. Two of its modules, Coordinate Geometry Language (COGO) and Structural Design Language (STRUDL), have been continuously updated and are still used by engineers. From the 1960s through the popularization of the graphical user interface 20 years later, a debate continued about whether command-driven or menu-driven user interfaces were preferable in CAD applications.

## Computers in Architecture, Engineering, and Construction Practice

Ellerbe Associates is credited with being the first building design firm to computerize. In 1958, it purchased a Bendix G-15. This Bendix computer was the size of a refrigerator, and communication was by electric typewriter: Output was printed one letter at a time on an electric typewriter. The machine was equipped with a paper tape punch and reader, and programs were stored externally on paper tapes. Ellerbe's first applications were in structural engineering: moment distribution calculations for concrete frames. These programs replaced the slide rule and pencil.

Rust Engineering was another early adopter of computers, first buying an IBM 610, then upgrading to an IBM 1620. David Sides and Lavette Teaque developed a critical path method routine for the 1620 in machine language. Sides and Teaque were also responsible for some of Skidmore, Owings and Merrill's (SOM) early efforts in CAD.

Caudill Rowlett Scott (CRS) acquired its first in-house computer capability in 1965. This capability was soon focused on the rapid processing of large quantities of project data. At CRS, the computer applications were developed not in design, but in project support, management, and accounting. In 1969, CRS established a separate corporation, Computing Research Systems 2 (CRS2). This organization handled all CRS computing functions and, in addition, offered computing services to other architectural/engineering firms, government facilities groups, health and educational institutions, and developers. These services included software development, consulting, and data processing services. Over time, the software development efforts created a library of applications that CRS2 then sold to others or used in its service bureau. These applications included:

- an accounting system;
- university facilities analysis, projection, and management;
- cost estimating;
- energy analysis;
- specifications;
- project scheduling;
- space inventory analysis; and
- health facilities equipment projection and specification.

In 1966, Eric Teicholz, then a student at Harvard's Graduate School of Design, founded Design Systems and began offering computerized perspectives to the Boston architectural community. Later that year, he was joined by Tom Follett, and together they started developing programs for the architectural firm of Perry, Dean and Stewart (PD&S). Comprograph generated schematic floor plans based on the building envelope, room sizes, and functional relationships. PD&S was probably the first firm to use computer graphics and certainly was the first to attempt to produce and market its system through a spin-off company, Decision Graphics. Kaiman Lee and John Nilson, as well as Teicholz and Follett, contributed to the development of PD&S's ARK-2 system, which ran on a DEC PDP-15. The program modules included:

- space programming,
- plan optimization,
- drafting,
- perspective and simulation,
- specifications, and
- office management.

By the mid-1970s, there were a half dozen ARK-2 systems in use in firms in the United States, Canada, England, Switzerland, and Australia.

SOM began developing structural engineering programs in 1962. In 1967, Neil Harper and Sides implemented the firm's first architectural application, the Building Optimization Program (BOP). BOP ran on the IBM 1130 and took a linear programming approach to create the ideal building. Given the desired square footage and the dimensions of a site, the system used rules of thumb:

- to determine the number of floors and number of elevators,
- to design the core,
- to optimize the structural bay size, and
- to generate a preliminary cost estimate.

Initially, BOP output a floor plan on a printer; later, it did so on a plotter. SOM also developed a hospital programming application that generated detailed space programs for hospitals on a department-by-department basis and developed the Storage and Retrieval of Architectural Programming Information (SARAPI) program to store and analyze facility requirements information gathered in client interviews.

In 1969, SOM held what was probably the architecture, engineering, and construction (AEC) industry's first strategic technology planning session. SOM decided to develop modular software and to use small in-house machines augmented by larger machines at service bureaus. At that time, service bureaus purchased large, expensive computers, typically IBM 360s, and then sold computer time to design firms. Because the client design firms paid for both connect time and run time, they benefited by preparing and checking their input decks of punched cards offline, on smaller in-house systems. In the early 1970s, Douglas Stoker in SOM's Chicago office was faced with the daunting task of preparing the structural analysis deck for the Sears Tower. SOM then had an IBM 1130 it used for preparing the input, but the firm ran the analysis at the University Computing Center at the Illinois Institute of Technology. Because the Sears Tower structure was regular, Stoker was able to develop a program on the IBM 1130 that would automatically generate the node coordinates and punch cards. This was the beginning of the Structural Generating System (SGS). Stoker later generalized the program so that it could create input to any structural analysis program for any building. The system was further developed within the SOM Chicago computer group into the Structural Data Management System (SDMS). SDMS used a problem-oriented language and graphic feedback to permit engineers to define structural geometry and graphically review analysis results.

**Fig. 4. William Kovacs and Douglas Stoker in SOM Chicago's computer room, circa 1977. The computer is a DEC PDP 11/70.**

By the mid-1970s, the larger AEC firms were beginning to acquire in-house minicomputer systems. These systems were sufficiently powerful to handle computer graphics. Digital Equipment Corporation became the dominant hardware vendor, first with the PDP-11 series of computers (see Fig. 4) and then with the VAX. For nearly a decade, the VAX remained the workhorse of the CAD industry.

Once firms had computers in house, 3D mass modeling became extremely popular, particularly for positioning a proposed structure within a cityscape. The 3D models were also used to study solar shading and shadow effects, by projecting views from the sun's position (see Figs. 5a and 5b). Some extraordinary architectural visualization work was done in the early 1970s by Donald P. Greenburg at the Cornell University College of Art, Architecture, and Planning in cooperation with the Visual Simulation Laboratory of General Electric. Greenburg's group created a movie of a walk through Cornell's Art Quadrangle, modeling a proposed museum among the existing structures. These images were not wireframe, but rather opaque colored surfaces. Greenburg's work influenced design firms' use of computer graphics and development directions among commercial CAD companies. Nevertheless, most of the 3D modeling work done during the 1970s consisted of wireframe rather than surfaced models. It was not until the 1980s that opaque color image output became widely available.

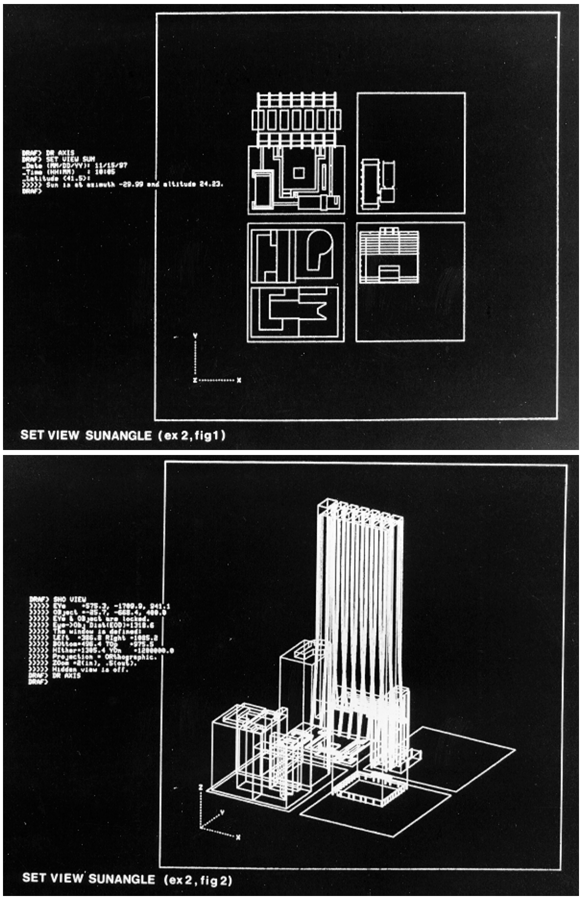


**Fig. 5. The 3D wireframe model created with SOM's DRAFT software, a precursor to AES. Note that the user communicated with the system through a POL.**

There were two possible approaches to computer graphics—buy or build. In the mid-1970s, William Kovacs began developing SOM's 3D computer graphics system to run on SOM's PDP 11/45 and PDP 11/70 computers (see Fig. 4). Kovacs soon left SOM for Hollywood, where he cofounded Wavefront Technologies. At SOM, Nicholas Weingarten and many others continued graphics development. Architectural firms building, and eventually marketing, their own software included Hellmuth Obata Kassabaum (HOK), Jung/Brannen, and Albert C. Martin & Associates, as well as SOM.

Early commercial CAD products took a very different turn from the work undertaken at MIT and Cornell, focusing on 2D drafting. Turnkey CAD providers to the AEC industry in the 1970s included Applicon, Auto-trol, Computervision, and M&S Computing (later Intergraph). The large engineering firms tended to take a mixed approach to CAD implementation, buying turnkey systems and using them as platforms for their own software development efforts. Companies that used this approach include Bechtel, Black & Veatch, and Sargent & Lundy. It is interesting to note that although 2D drafting systems were commercially available in the 1970s, the development of design software was being done by architects and engineers (see Fig. 6).

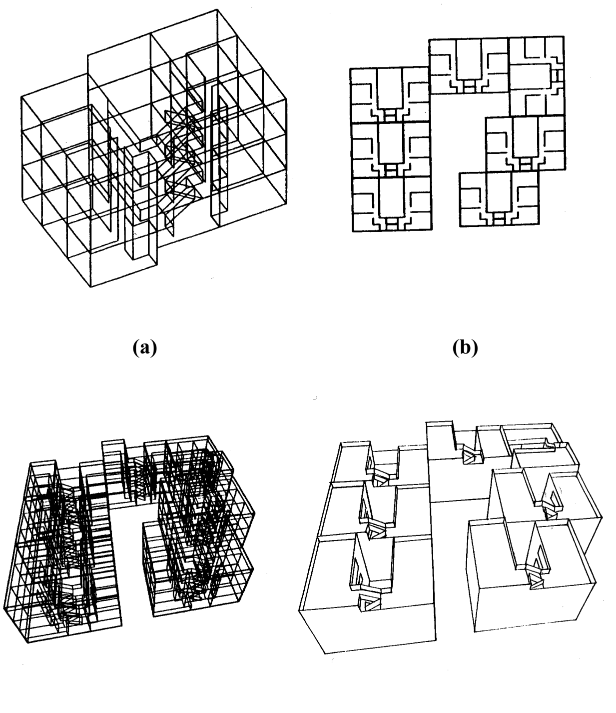


**Fig. 6. The 3D computer graphics work for the 1970s. A rough 3D model (a) was generated and repeated (b), then viewed in perspective projection (c). Hidden lines removal (d) took several hours on the PDP 11/70. (Design study of student housing clusters for a university in Saudi Arabia presented by the author at the 1979 conference of the International Union of Women Architects.)**

## The PC Revolution

By the mid-1970s, the precursors of the personal computer began to appear. The Altair 8800, based on the Intel 8080 processor, is considered to be the first true "personal computer." It was introduced in 1975. The first PC-based CAD system was T-Square, developed for T&W Systems for its TERAK computer in 1978. The TERAK was an LSI-11 machine with a 240 × 320 monochrome monitor, 64 kilobytes of main memory, and 300-kilobyte drives. It ran the UCSD Pascal operating system, later known simply as the P-system. Tom Lazear of T&W Systems had been MIS director at Fluor Daniel: The initial release of T-Square did piping isometrics and bills of materials. In 1979, the University of Arizona was looking for low-cost CAD systems for instruction. T&W rewrote T-Square for more generalized 2D drafting functions, and the University of Arizona bought eight systems.

The Apple II (see Fig. 7), the first personal computer to be a major commercial success, was introduced in 1977, and it was widely adopted in schools. There was a demand in the educational market for a graphics program. In 1981, T&W Systems ported T-Square to the Apple II, where it became CADApple. The IBM PC (see Fig. 8) was introduced in 1981. The original PC had no hard drive but booted from floppy disks. DOS was not the only operating system available for the PC; the P-system was also an option. Because T&W's CAD system had been developed under P-system, the company chose to port to the IBM PC under the P-system. VersaCAD for the IBM PC appeared in 1983. It was a capable and comparatively mature product, but it was under the wrong operating system. To quote Bill Gates:

> Few remember this now, but the original IBM PC actually shipped with a choice of three operating systems—our PC-DOS, CP/M-86, and the UCSD Pascal P-system. We knew that only one of the three could succeed and become the standard. We wanted the same kinds of forces that were putting VHS cassettes into every video store to push MS-DOS to become a standard. We saw three ways to get MS-DOS out in front. First was to make MS-DOS the best product. Second was to help other software companies to write MS-DOS-based software. Third was to ensure MS-DOS was inexpensive.
>
> We gave IBM a fabulous deal—a low, one-time fee that granted the company the right to use Microsoft's operating system on as many computers as it could sell. This offered IBM an incentive to push MS-DOS, and to sell it inexpensively. Our strategy worked. IBM sold the UCSD Pascal P-system for about $450, CP/M-86 for about $175, and MS-DOS for about $60.
>
> . . . Eventually IBM abandoned the UCSD Pascal P-system and CP/M-86 enhancements.[6]

VersaCAD was ported to DOS, but in the interim it lost momentum to a new PC CAD contender: AutoCAD.

The history of Autodesk is well-documented in *The Autodesk File,* available in both book and browser. AutoCAD began as a port of a computer graphics package originally written by Mike Riddle for the Marinchip Systems M9900. It was first released for the PC platform in December 1992. *The Autodesk File* indicates the following competitive assessment of the product, before it was ported:

> Installed on a desktop computer configuration in the $10K to $15K range, it is competitive in performance and features to Computervision CAD systems in the $70K range. There are no known competitive products on microcomputers today (although there are some very simpleminded screen drawing programs for the Apple, and we must be careful to explain how we differ).
>
> We can probably obtain substantial free publicity by issuing press releases and writing articles stressing the tie-in with computer aided design and the IBM robot controlled by the

IBM personal computer. We can also aim the ads to sell the product as a “word processor for drawings.” Potential customers are anybody who currently produces drawings. Small architectural offices are ideal prospects.[7]

**Fig. 7. The Apple IIe. The Apple II series was the first commercially successful personal computer.**

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**Fig. 8. The IBM PC.**

**(Courtesy of IBM)**

In 1984, AutoCAD and one other PC CAD system for electronics, P-CAD, appeared at the National Computer Graphics Association show; 1984 was the year PC CAD took off. *Architectural Technology* organized its first CAD shoot-out and asked me to review a package called Drawing Processor. As it turned out, I needed an electrical engineer (Charlie Pocius) and a soldering gun to get it to plot. Despite the output problems, I liked the Drawing Processor approach—the system had only eight commands and could be mastered in a couple of hours by anyone who understood scaled drawings. The Drawing Processor evaluation included a comparison to the current “best practice” of using a reprographics approach to produce plans of repetitive facilities, in this case an apartment complex, and showed that such drawings could be produced more quickly on the computer (see Table 1). Note that the steps and sequence of the work process were quite different.[8]

By 1986, the PC-AT was on the market, and there was lively competition in the PC-based CAD market. In its January/February issue, *Architectural Technology* published a detailed evaluation of no fewer than 11 PC-based CAD packages. With the advent of low-cost graphics-capable hardware, there was a sea change in the approach to computer graphics development. From the first computer graphics explorations in the 1950s through the 1970s, there had been a very open-ended exploration of how computers might be used in design practice, with architects and engineers involved in building software tools in a very hands-on fashion. In the 1980s, the baton was passed to the vendor community, and design professionals became consumers of software products.

During the same period, another approach to CAD emerged—the Unix workstation, based primarily on the Motorola 68000 family of processors. By 1984, the Sigma ARRIS system was available on Unix workstations from Sun and Auto-trol software was available on Apollo workstations (see Fig. 9). The Unix workstation shared one major advantage with the PC: It was a dedicated machine, versus the time-sharing approach of the PDP and VAX platforms. Unix workstations were considerably more powerful than the early PCs and were readily networkable for data-sharing. However, they were also about 10 times more expensive. Over the next 10 years, the price and performance of these two classes of products converged. Table 2 shows a comparison of what $15,000 bought in the PC and the workstation markets in 1988. By that time, the distinctions between the two classes of products were already blurring.

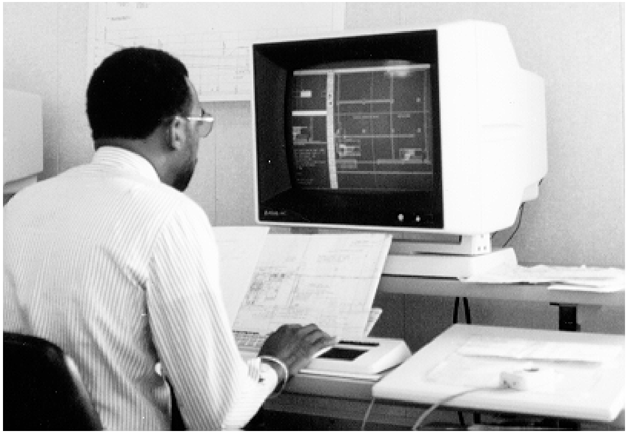


**Fig. 9. An Apollo workstation.**

By the mid-1980s, there was a great variety of commercial CAD products at a broad range of prices. Intergraph was still on the VAX, but in 1986, Bentley Systems, Inc., released a CAD product—MicroStation—that emulated Intergraph’s core graphics system (IGDS) and ran on a PC; a number of products (including ARRIS, Auto-trol, Calcomp, and GDS) were available on workstations; and there was intense competition in the PC market.

TABLE 1
REPROGRAPHIC VERSUS CAD PRODUCTION OF DRAWINGS 1984

| Reprographic Process | | CAD Process | |
|---|---|---|---|
| **Activity** | **Number of Hours Required** | **Activity** | **Number of Hours Required** |
| Draw plans at 1/4" = 1'0" | 20.0 | Develop symbol library | 3.0 |
| | | Develop apartment plans | 11.0 |
| | | Plot 1/4" drawings | 1.0 |
| Make photocopy reductions | 1.0 | Reduce/assemble plans | 5.5 |
| Draw plans at 1/8" = 1'0" | 12.0 | Plot 1/8" drawings | 2.25 |
| Matte film positive | 4.5 | | |
| Total | 37.5 | | 22.75 |

TABLE 2
HOW MUCH HARDWARE COULD BE BOUGHT FOR $15,000 IN FEBRUARY 1988

| Feature | Apollo DN3000 | PS/2 Model 80 |
|---|---|---|
| Processor | 68020 | 80386 |
| Coprocessor | 68881 | 80387 |
| RAM | 4 Mbytes | 4 Mbytes |
| Floppy drive | 1.2 Mbytes; 5.25" | 1.4 Mbytes; 3.5" |
| Hard disk | 155 Mbytes | 115 Mbytes |
| Display resolution | 1024 × 800 | 480 × 640 |
| Operating system | Aegis or UNIX | OS/2 or AIX |
| Window manager | Included | Included |
| Network | Included | Extra |
| Network manager | Included | Extra |
| Network diagnostics | Included | Extra |
| Access security | Included | Extra |
| Print queue manager | Included | Extra |

One of the emerging realizations was that the cost of CAD training was at least equal to the cost of hardware. In the coverage of the second *Architectural Technology* CAD shoot-out, it was suggested that CAD users be allowed one to two weeks of off-site training and two to six months to get up to productive speed. Another new idea was that of a multipurpose single-user workstation: The PC—with spreadsheet, word processing, and CAD software—could be used for a variety of purposes. Islands of automation were beginning to merge.

Into this turbulent mix of technologies came the Apple Macintosh (see Fig. 10), introduced in January 1984. Actually, most of the slick technology incorporated into the Macintosh—a bit-mapped video display, a graphical user interface, and a mouse—had been developed at Xerox PARC but never marketed. Apple had first introduced these features with the Lisa computer (see Fig. 11) in 1983. At $10,000, however, the Lisa fell somewhere between the personal computer and Unix workstation classifications. Despite its sophistication, the Lisa was never a successful product. The Macintosh came into the market at the right price. The market acceptance of the Mac, and the fact that its user interface clearly improved ease of use, made a clear case for a graphical user interface. In addition, its native ability to handle graphics encouraged the development of a wealth of graphics applications that had nothing to do with CAD. These included desktop publishing and image manipulation systems. The Macintosh firmly established itself, particularly within the graphic design industry.

Over the next decade, prices fell and products came and went. But more CAD products went away than came along. As prices dropped, design firms and their clients moved more and more of their project documentation into the electronic environment. As they did so, it became abundantly clear that it is much more effective to transfer information electronically than to output it onto paper, transfer it, and then reenter it into the destination system. CAD data translation and data-exchange techniques became pressing technical and business issues.

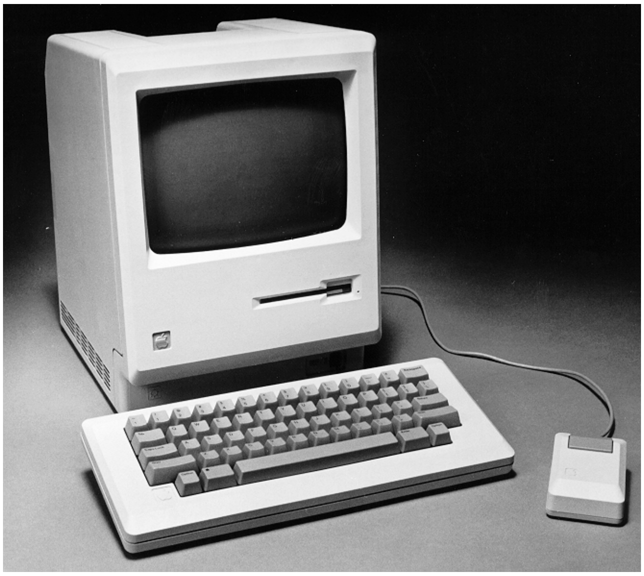


**Fig. 10. The Macintosh.**


Autodesk, in the initial development of AutoCAD, had made the right strategic decisions: to develop an open system with "hooks" for third-party developers and a data-exchange capability. Notes from the AutoCAD development log included in *The Autodesk File* indicate that the decision to implement something like DXF was made in the summer of 1982:

> All versions of MicroCAD [the first name chosen for AutoCAD] should be able to write an "entity interchange format" file. The utility which does this may not be actually in the main package, or may be called as an overlay. All versions of MicroCAD, regardless of internal file representation, will be able to interchange drawings this way. Installed in MicroCAD-80.[9]

In their 1993 book, *Computer Wars,* Charles H. Ferguson and Charles R. Morris contended that market dominance and corporate profitability in the global information technology industry of the 1990s would depend on technology companies' ability to convert superior technology into a proprietary industry standard. They commented on Autodesk:

**Fig. 11. The Apple Lisa.**


> Autodesk sells desktop computer CAD software that has a particularly strong following among the (real) architectural community—that is, the people who design houses and buildings. Autodesk protects its core software from imitators, but has provided independent software developers with tool kits to facilitate add-on special-purpose packages—a kitchen design package, for example, that runs inside of Autodesk's basic CAD programs. The availability of add-on software for Autodesk products is now many times greater than for its competitors. At the same time, Autodesk has made substantial investments to assure that it will run on as many different platforms and operating systems as possible. Therefore, it has achieved a certain architectural control over a relatively small but very lucrative competitive space, within other people's overall operating software environments. As the infrastructure of Autodesk-compatible software products steadily increases, so do customer switching costs. And as the product becomes more pervasive and customers routinely exchange Autodesk files, the lock-in can become very strong.[10]

By the mid-1990s, a number of surveys showed that more than 85 percent of design firms had AutoCAD licenses, even if AutoCAD was not their only or their primary CAD system.

The use of CAD systems, however, continued to be focused on automated drafting, primarily in the construction documents phase of the design process. A separate class of products was used to create sales-oriented visualizations and animations. These models tended to be too imprecise and information-poor to be utilized in the development of technical documentation. What had happened to Steve Coons's 1959 visions?

> the designer seated at the console drawing a sketch of his proposed device on the screen of an oscilloscope tube with a light pen, modifying his sketch at will, and commanding a computer slave to refine the sketch into a perfect drawing, to perform various numerical analyses having to do with structural strength, clearances of adjacent parts, and other analyses as well.

By 1995, indications appeared that these visions might, indeed, be fulfilled:

- A number of CAD products supported "intelligent" wall types and provided libraries of predefined wall assemblies.
- Many CAD systems incorporated parameterized routines, and at least one retail product permitted the development of a floor plan through the sizing and placement of parameterized building components—the overall footprint, rooms, and so on.
- Many CAD systems had incorporated automated, rules-based generation routines for building elements, such as stairs and ramps.
- Construction product data were widely available on CD-ROM.
- The Construction Criteria Database provided standard codes and government specifications in machine-usable form.
- CAD products, especially those from Germany like Allplan (Nemetschek Systems) and speedikon (IEZ), provided detailed quantity takeoffs.

As the 21st century nears, the Internet has emerged as the new communication backbone for project communication. Where the rubber meets the road, early adopters such as Bechtel are beginning to field tightly linked systems—built on object technology and incorporating business rules that comprehend much more than CAD—and to transform the processes of design and construction. The International Alliance for Interoperability has convened an astonishing number of participants from a broad spectrum of the AEC industry worldwide to agree on a 21st-century object-oriented information structure (the Industry Foundation Classes) for design and construction.

These developments suggest a radical departure from traditional drawing-oriented CAD systems. The question is whether the AEC industry as a whole is ready to change to a very different way of designing and documenting facilities.

## References

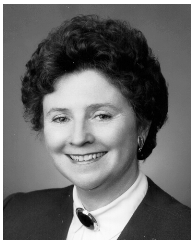

[1] C. Machover, "A Brief, Personal History of Computer Graphics," *Computer*, Nov. 1978. Reprinted in K.S. Booth, ed., *Tutorial: Computer Graphics.* New York: Institute of Electrical and Electronics Engineers, 1979, pp. 21–28.

[2] I.R. Sutherland, "Sketchpad, a Man–Machine Graphical Communication System," unpublished doctoral dissertation, MIT, 1963.

[3] N. Negroponte, *The Architectural Machine: Toward a More Human Environment.* Cambridge, Mass.: MIT Press, 1970, p. 5.

[4] Ibid., p. 55.

[5] D.H. Rothman, *NetWorld: What People Are Really Doing on the Internet and What It Means to You*. Prima Publishing, 1996, pp. 4–5.
[6] B. Gates, *The Road Ahead.* New York: Viking Penquin, 1995, pp. 48–49.
[7] J. Walker, "MicroCAD," The Autodesk File (http://fourmilab.ch/autofile/www/subsection2_9_12_1.html#SECTION 0091210000000000000000).
[8] K. Fallon and R. Robicsek, "Drawing Processor Is Easy to Learn," *Architectural Technology*, vol. 2, no. 2, 1984.
[9] J. Walker, "AutoCAD-80 Development Log," The Autodesk File (http://fourmilab.ch/autofile/www/subsection2_14.html#SECTION001 40000000000000000).
[10] C.H. Ferguson and C.R. Morris, *Computer Wars: How the West Can Win a Post-IBM World.* New York: Times Books, 1993, p. 151.
[11] S. Coons, "Outline of the Requirements for a Computer-Aided Design System," Technical Memorandum 169, Massachusetts Institute of Technology, Electronic Systems Laboratory, 1963.



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