Engineering Design Graphics: Into the 21st Century

La Verne Abe Harris, Ph. D.
Purdue University

Frederick Meyers
The Ohio State University

Abstract

Graphical plans for construction of machinery and architecture have evolved over the last 6,000 years beginning from hieroglyphics to drawings on printable media, from the "Golden Age" of engineering graphics to the innovation of computer graphics and prototyping. The evolution of engineering design graphics as a profession has also evolved. Years before we entered the 21st century, higher education began to address the changes that technology brought to the curriculum. Now that we have entered the 21st century, we must move forward with technological innovations and creative thinking, but be cautious that we do not lose the art of freehand sketching. This paper traces the journey of engineering design graphics and the impact it has had in the academe and on the profession and the way designers work. It addresses the future of the field and the inevitable changes that emerging technologies will bring.

INTRODUCTION

Whether an idea is scratched on stone or comes in the form of freehand sketching on a napkin, visualization in engineering design is paramount. Scott Berkun of Microsoft states that unsuccessful ideas should "come out on sketch paper or in prototypes, not in the product, and you can only do that by expending the energy to explore lots of ideas" (Berkun, 2000). Sketching ideas on paper is a essential skill set for product design. Einstein was quoted as saying "the physicist's greatest tool is his wastebasket" (Berkun, 2000), and his Theory of Relativity began as a sketch on a scrap of paper (Lawrence, 2005).

The ability to accurately perceive the visual-spatial world and transform these perceptions is one of the eight human intelligences (Gardner, 1983/2004). Basic spatial skills, which are necessary for success in engineering design, are based on the ability to "mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli" (McGee, 1979). The creative thinking team process of brain-writing, where the primary mode of communication is freehand sketching, is a popular alternative to the verbal brainstorming technique today (Lieu & Sorby, 2007).

Nothing has had more of an impact on the ability to transform visual-spatial perceptions and the evolution of graphical plans for construction of machinery and architecture than the computer and the Internet. The advent of the computer and the invention and innovation of computer-aided design (CAD) deeply changes how two-dimensional (2D) and three-dimensional (3D) graphics are visualized and designed. CAD, which is the use of a wide-range of computer-based tools for designing and developing products, is an important geometry-authoring tool for the product lifecycle management. It ranges from 2D vector-based drafting systems to 3D parametric surface and solid design modeling systems. In the product lifecycle a physical prototype can be produced from drawings or from a computer-aided manufacturing system (CAM). The prototype is then tested for design compliance and produced for mass production in the manufacturing division.

When Internet technologies were adopted in the engineering design industry in the 1990's, work in engineering design was restructured. Collaboration is the trend of today in order to benefit both higher education and industry and the Internet facilitates international communication. However, when we move forward into the 21st century with more technological innovations, we must ensure that we take with us the art of freehand sketching as a valuable tool for the visualization process.

This paper examines the timeline of the journey of how graphical plans for construction of machinery and architecture have evolved throughout history. This helps us to appreciate the impact that emerging technologies have had on the profession.

EARLY VISUALIZATIONS

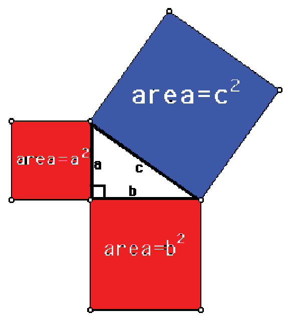
The earliest known engineering drawings are from a Chaldean engineer named Girdea, who scratched a fortress plan view on a stone tablet about 4000 B.C.E. The tablet, which is evidence of the application of early visualization, is on display in the Louvre in Paris.

A thousand years later Egyptian stonemasons

The HISTORY of GRAPHICS

Dr. La Verne Abe Harris
Professor Frederick Meyers

Pythagoras (580-520 BC) was a Greek mathematician, philosopher, and religious leader. His study of geometry and the relationship of parts lead to the discovery of the Pythagorean theorem of a right triangle (525 BC).



35,000 - 4,000 BC

600-500

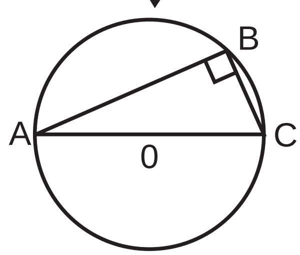
447 BC

35,000 to 4,000 BC
Cave drawings (petroglyphs) of the Paleolithic and Neolithic eras were drawn on walls.

Perhaps the earliest known drawing in existence is the plan view design of a fortress drawn by the Chaldean engineer Girdea that was engraved upon a stone tablet.

3100 BC to 394 AD
Egyptian hieroglyphics

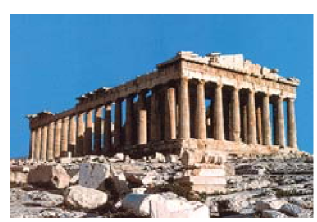
Ancient Egyptian stonemasons used papyrus, slabs of limestone and sometimes wood as substrates for drawing pyramid plans.



Thales and the discovery of the Circle Theorem. Thales, our first western philosopher, scientist, and mathematician, lived in Greece around the end of the sixth century B.C.E (2600 years ago).

He is viewed as the first person to use reason instead of religion to explain natural phenomena, and the first to believe in an underlying, natural, unity within all things.

The Parthenon architects were Ictimus and Callicrates. Through the use of foreshortening and converging parallel lines, perspective was used.



made their plans for pyramids on papyrus, wood or stone. In the 5th century B.C.E. geometry was being developed in Greece by mathematicians including Pythagoras, Archimedes and Euclid. Greek architects continued to develop techniques, including perspective, for structures such as the Parthenon through the 4th century B.C.E.

In the last century B.C.E. a Roman architect, Marcus Vitruvius Pollio wrote a ten-volume treatise titled De Architecture. This was apparently lost in the Middle Ages and rediscovered in the 15th century. It remained a principle text until the 19th century. Among other things Vitruvius noted compasses for drawing circles in his treatise.

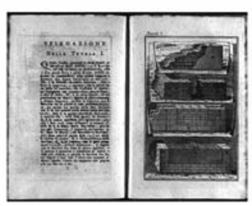
Brunelleschi, an Italian architect, laid out the mathematical approach to drawing and introduced perspective drawing in the 15th century. Later in that century Leonardo DaVinci produced architectural and mechanism drawings, which show skill and ingenuity, admired to this day (Collins, 2006).

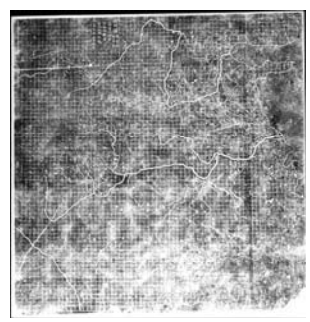
In the 18th century, Gaspard Monge, a French mathematician and draftsman, laid out the principles of descriptive geometry that solved many problems without tedious calculations. His work was considered so important by the French government that it was kept a military secret for almost 20 years. By 1795 he was responsible for establishing a school for training engineers and published a text based on his lectures (Reynolds, 1976).

The United States Military Academy (USMA) became a pioneering center for graphics in the United States. Christian Zoeller brought engineering drawing classes to the Academy in 1807. Another faculty member of the USMA, Claude

Euclid with his students.

Euclid wrote the first text on geometric optics, which defined the terms visual ray and visual cone. Euclid presented the concepts that light travels in a straight line, and the law of reflection.





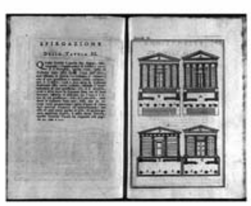
Yü Chi Thu (Map of the Tracks of Yü the Great)

300-200 BC | 100 -1BC | 10th - 12th C.

Archimedes (287-212 BC)

Archimedes, who combined a genius for mathematics with a physical insight, must rank with Newton, who lived nearly two thousand years later, as one of the founders of mathematical physics.

100-1BC – was a Roman architect of the first century B.C. He used a compass of sorts, defined elevation and perspective and published a ten volume treatise, De Architecture. This was rediscovered in the 15th century and was a "standard" until the 19th century.



10th C. First known plot graph

1100 AD China produced the first data maps; example: Yü Chi Thu (Map of the Tracks of Yü the Great).

Crozet, introduced descriptive geometry to the Academy in 1816. By 1821 he translated Monge's work into English. Crozet is also credited with introducing the blackboard and chalk for the teaching of graphics. Other authors continued writings in English in the 19th century.

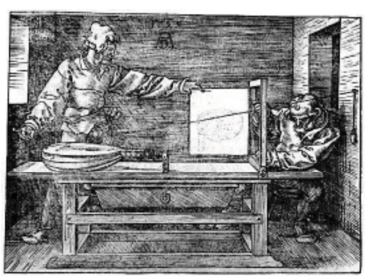
Two major improvements stimulated graphics in America in the latter half of the 19th century: the Alteneder family established a factory in Philadelphia for manufacturing drawing instruments and blueprinting was introduced at the Philadelphia Centennial Exposition in 1876. High-quality drafting instruments no longer had to be imported, and the "art" of drafting rapidly disappeared. Before 1876 if additional copies of a drawing were needed, the drafter produced each drawing individually. After 1876 only one "master copy" was needed and as many blueprints as needed could be made in hours (Land, 1976).

GRAPHICS PROFESSIONALIZED

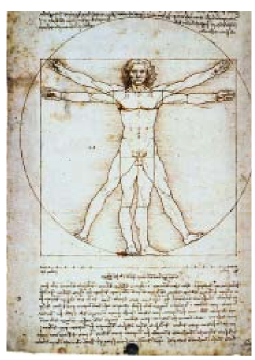
A group of engineering teachers meeting at the World's Columbian Exposition in Chicago founded the Society for the Promotion of Engineering Education in 1893. Today they are known as the American Society for Engineering Education (ASEE). The American National Standards Institute was established in 1926 and two years later the ASEE drawing division was founded, which was known as the Division of Engineering Drawing and Descriptive Geometry. Today the division is known as the Engineering Design Graphics Division. The international division publication The Engineering Design Graphics Journal began publication in 1936 as the Journal of Engineering Drawing (Grayson, 1993).

THE "GOLDEN AGE"

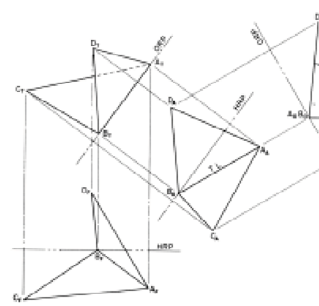
The demands of industry, two World Wars, and



A woodcut from Albrecht Dürer's treatise on measurement
Underweysung der Messung, 1527



Vitruvian Man
by Leonardo da Vinci



Gaspard Monge (1746-1818)

13th - 16th C.

Nicole d'Orseme (1352-1382), bishop of Lisieux, was the first to take pictorial elements and represent quantitative data in da Vinci's texts.

Because of the invention of the printing press by Johann Gutenberg (1400-1468), graphics became etchings on blocks and text became pre-manufactured. The combination of text and graphics became more difficult to reproduce.

15th C. Nicolas of Cusa created graphs of distance versus speed.

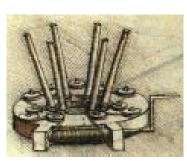
Filippo Brunelleschi (1377-1446)
Brunelleschi was well known for his introduction of the theoretical principles governing the laws of perspective drawing and for his mathematical approach to drawing. He is considered to be the father of Renaissance architecture.

Durer (1471-1528) is remembered for his first basic knowledge of orthographic projection and scientifically formulated in 1795 in a book written by Gaspard Monge.

17th C.

17th C. Gottfried Wilhelm Leibniz is the founder of symbolic logic.

Leonardo da Vinci created a combination of text and graphics in his Treatise on Painting. Leonardo de Vinci was a creative genius in art, the human form and military machines.



Sir Isaac Newton (1642-1727) documented gravity by combining handwritten text and graphics.

17th C. Rene Descartes (1596-1650) used analytic geometry for display of mathematic functions. He also used graphs in his text.

18th C.

1786 Playfair's The Commercial & Political Atlas, published in London, used 44 graphics, which were predominantly line charts.

Gaspard Monge (1746-1818) is considered the "father of descriptive geometry."

Desarques was a French mathematician, whose interest in graphics stemmed from problems he faces as a military engineer. Desarques is regarded as one of the founders of modern projective geometry.

The United States Military Academy (USMA) became a pioneering center for graphics in the United States.

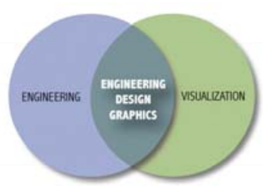
increasing engineering enrollments heightened the interest and demand for training in graphics in the first half of the 20th century. This demand also produced many outstanding American texts during this period. Among the authors were Svensen, Giesecke, French, Hoelscher, Luzadder, and Smith.

Freehand sketching was a significant part of the engineering design process (Aulich, 1938). The tools were the traditional "hand tools" of graphics: T-square, triangles, drawing boards and an assortment of French curves. Many specialized drafting tools were also invented – parallel rules, proportional dividers, special ruling pens (example: "railroad pen" – two parallel pens on one handle) and planimeters. Engineering college students were required to take a full year of graphics – most included descriptive geometry.

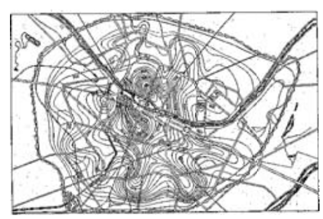
It was during this time that co-author Meyers, with four years of public school graphics by age 16, worked 50 hours a week as a "tracer" for Curtiss-Wright, a warplane builder. Young women "Cadettes" with six months training and boys too young for the military draft were the tracers. Engineers made design drawings in pencil, and the customer – the US Navy – wanted permanent records in ink. So skilled teenagers traced the engineers' drawings onto translucent starched linen cloth. If a mistake was made by the draftsman the work had to be erased or started over.

1950's-1990's: 20th CENTURY CHANGES

The rumbles of change began as we approached the second half of the 20th century. Government and several universities were testing giant computers with thousands of vacuum tubes. Computers, who were primarily number crunchers, began to emerge as graphical computer workstations.

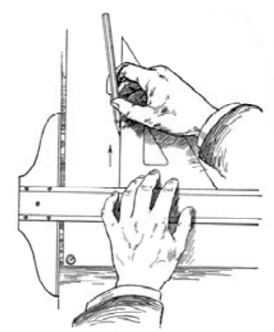


Mid-19th C. John Venn (1834-1923) made the Venn Diagram famous. The concentric and overlapping circles visualized logical relationships. 18th C. Leonard Euler actual was the first to use what is called the Venn diagram.



Contour plot .

This map of Paris by L. L. Vauthier (1874), shows the population density by contour lines.
It is the first statistical use of a contour map.



19th C.

Early 20th C.

1801 William Playfair's Statistical Breviary publication introduces area charts.

William Playfair (1759-1823) was the first to use line, bar, and pie charts as a graphics journalist. 1805 Playfair's Statistical Abstract of the United States introduced the pie chart.

Charles Joseph Minard (1781-1870), a French engineer, advanced data maps. Prior to this, cartography focused on geography, not linking geography to history and statistical data. Data of time and amount was stressed over geography in his information graphic of Napoleon's 1812 Russia campaign.

1854 John Snow (VD31) created a data map showing the number and location of cholera deaths near a pump in London's Broad Street.

The first half of the 19th century might well be called a formative period in the development of engineering drawing.

"Draughtmanship" was an art expressing itself in fine lines, shading both by lines and washes, ornate borders and lettering and the use of colors. In 1876 the blueprint process was introduced in the United States at the Philadelphia Centennial Exposition. "Draughtmanship" techniques became unnecessary after the introduction of blueprinting. The art of "draughting" was completely lost and the technology of "drafting" was discovered. This was the onset of today's engineering and technical drawing.

Society for the Promotion of Engineering Education was founded in 1893. Today they are known as the American Society for Engineering Education (ASEE).

The first half of the 20th century could be characterized as the "Golden Age of Drafting" in the USA. The graphic technology of drafting was accepted and applied to engineering, design, manufacturing, production, architecture, etc. There was an increase in interest in drafting in engineering, technical and vocational training. Nearly every drawing produced in the world was done with pencil or ink on paper.

The American National standards Institute (ANSI), the American Society for Engineering Education, the Society of Automotive Engineers, and the American Society of Mechanical Engineers, have been collaborating since 1926 to establish drafting standards.

ASEE drawing division was founded in 1928. In 1936 the Journal of Engineering Drawing was first published. It is now known as The Engineering Design Graphics Journal.

In the higher education arena at many universities, however, hand tools continued to be used well into the 1990's. Gradually CadKey was introduced for descriptive geometry. This application was replaced on the market with KeyCreator (KUBOTEK, 2006).

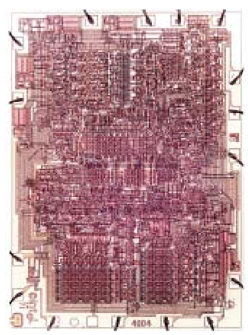
The 1950's: A leader emerges in academia. Massachusetts Institute of Technology's (MIT) Lincoln Laboratory was a leader in the academic world. They developed the first graphic system in the mid-1950's for the United States Air Force for SAGE (Semi Automatic Ground Environment) air defense system. Computer-processed radar data were displayed on a cathode-ray tube (CRT) display.

In 1957 PRONTO, the first commercial computer-aided manufacturing (CAM) software system, was developed by Dr. Patrick J. Hanratty. This Arizona State University graduate is called the "father of computer-aided design and manufacturing (CAD/CAM)." His program was a numerical control programming tool (CADAZZ, 2007).

The 1960's: CAD is launched. Three years later (1960) the project "Sketchpad" was produced by Ivan Sutherland with a TX-2 computer as a part of his Ph.D. dissertation. This MIT Lincoln Laboratory project is considered a milestone to the launch of the computer-aided design (CAD) industry, and Sketchpad is considered the world's first CAD software (CADAZZ, 2007; Sutherland, 1963).

McDonnell Douglas Automation Company (McAuto), founded in 1960, played a significant role in the development of CAD. Initially the earliest CAD programs began with two-dimensional simple algorithms displaying patterns of lines, which were then transformed into 3D.

Tom Watson on the cover of Time Magazine.



Intel 4004 microprocessor in 1971, from Intel Museum

1950s

Computer Graphics:
In the 1950s the first computer-driven display was attached to MIT's Whirlwind I computer to produce basic images.

In the late 1950's MIT's TX-0and TX-2-interactive computing became feasible and interest in computer graphics began to increase rapidly.

In 1953 Tom Watson, Jr., led IBM to introduce the model 604 computer, its first with transistors, that became the basis of the model 608 of 1957, the first solid-state computer for the commercial market.

In 1957 PRONTO, the first commercial computer-aided manufacturing (CAM) software system, was developed.

1960s

1962- Ivan E. Sutherland's PhD thesis "Sketchpad: A Man-machine graphical communication system" provided evidence that interactive computer graphics was a significant field of research.

Vector display terminals, assembly language software applications, and huge mainframe computers were typical of the mid-1960's. Large computer graphics research projects were begun at MIT, GM, Bell Telephone labs, and Lockheed Aircraft.

In 1968 primitive 2D drawing systems were available using mainframe computers and terminals.

1970s

In the 1970's intereactive computer graphics systems, wireframe, and polygonal modeling schemes began to develop.

By the mid-1970's Intergraph's "Interactive Graphic Design System" (IGDS) was applied to mapping. By the end of the decade early modeling software was released.

Michael Riddle, the founder of Evolution Computing, wrote the first micro-based computer CAD software "MicroCAD," which was released in 1979.

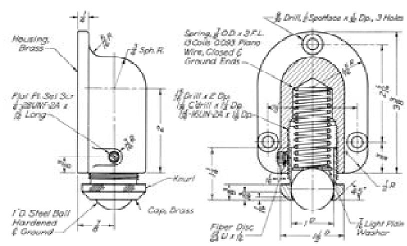
Vector display terminals, assembly language software applications, and huge mainframe computers were typical of the mid-1960's. At this time Control Data Corporation's Digigraphics Division was the only organization attempting to create a commercial CAD system, which sold for half a million dollars.

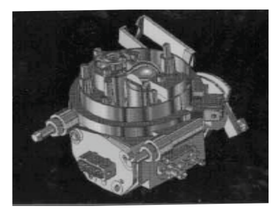
In 1968 primitive 2D drawing systems were available using mainframe computers and terminals. That same year Syntha Vision was considered to be the first commercial solid modeler program. It was released by MAGI Company.

1968 also produced research by Donald Welbourn, who is now at Cambridge University. He envisioned the possibility of solving the modeling of intricate 3D forms by using computers (Bozdoc, 2006a). In 1968 Evans and Sutherland was founded by David Evans and Ivan Sutherland. Computervision, which sold the first commercial CAD system to Xerox, was founded in 1969. Implementing production drafting through CAD systems was the overall mission of Computervision.

Computer-aided design "fundamentally changed the way design is done" (Bozdoc, 2006b). For about $250,000 a company could have an electronic computer and a plotter with a six-foot bed for making plots of glass melting furnaces. Other industries also adopted computer graphics and plotting to replace drafting.

The 1970's: The foundational code is written. As the decade of the 1970's began, Hanratty founded Manufacturing & Consulting Systems (MCS). Industry analysts have credited MCS's original code to be the basis for 70% of all the 3D mechanical CADD/CAM systems (Matson, 2007).





B-Rep model imported from Unigraphics (EDS)

1980s

Apple and IBM PC's popularized the use of bitmap graphics. This resulted in an explosion of easy-to-use and inexpensive graphics-based applications.

1981- VersaCad, a PC-based CAD system.
1982 - 1983 AutoCAD developed by Autodesk .

January 1983 is technically determined to be the birth of the Internet, since that was when the National Science Foundation (NSF) built the early version of the NSFNet, a university network backbone.

By 1984 the technology hit another milestone with the advent of more powerful mini-computers on the market that were competitively priced. The target market for many years for engineering computer design was aircraft design. Because the hardware became more affordable, domestic products with intricate forms could be designed by computers.

Mid-1980's:proliferation of CAD software.

Early 1990s

CAD users increased in numbers during the 1990's. It took until the 1990s before the Internet moved from the university setting to corporate and industrial settings.

1991 Open GL for Windows NT
Autodesk released ArcCAD, an architectural application. Now computer programs specifically designed for architecture enable designers to create, review and modify designs quickly. Plans can also be sent to customers electronically.

1992
Autodesk's 3D Studio and Canvas for Windows
3D Studio version 2 for DOS AutoCAD
Autodesk's Release 12 for DOS

1993
The first Windows platform AutoCAD was released in 1993.

SolidWorks
AutoCAD v. 12 for Windows

Mid/Late 1990s

By 1994 AutoCAD had one million users, CadKey had 180,000, and Microstation had 155,000.

In 1994 Hewlett Packard released PE/Solid Designer (version 3.5), which was its high-end solid modeling application at the time.

1994
Hewlett Packard v. 3.5 PE/Solid Designer
ArchiGraph's PowerDraw v. 6.0 for Macintosh computers
HP's PE/Solid Designer (version 3.5)

CATIA-CADAM AEC plant solutions was released in 1995. The cutting edge "smart" object-oriented plant modeling system streamlined the workflow between the design, operation, and construction system.

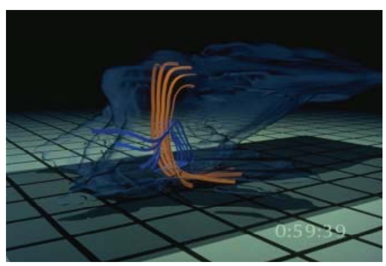
Progress continued. By the mid-1970's Intergraph's "Interactive Graphic Design System" (IGDS) was applied to mapping. Tektronix developed a 19-inch display terminal, which was an improvement from the 11-inch standard. By the end of the decade early modeling software was released.

Michael Riddle, the founder of Evolution Computing, wrote the first micro-based computer CAD software. He wrote a CAD program called MicroCAD, which was later called Interact for the Marinchip 9900. This program was released in 1979. The first version of AutoCAD was based on his code (Eastman, 2007). By the end of the 1970's, an engineering design graphics business could purchase a 16-bit mini-computer with a maximum of 512 KB memory, and 20 to 300 MB disk storage for $125,000 U.S. dollars.

The 1980's: The Internet is born. Higher education continued research and development in engineering graphics. In 1981 the computer graphics division of Cornell University introduced 3D and graphics technology from 3D/Eye Inc., which was a innovative 3D graphics technology. In the same year Unigraphics released "Uni-Solid," as the first solid modeling system.

April 1982 Autodesk was founded by 16 people in California headed by John Walker. For the two years previous Walker ran Marinship Systems. Walker's goal was to construct a CAD application, which could run on a PC format and sell for $1,000. At the 1982 COMDEX trade show in Las Vegas Walker and his partners demonstrated the first CAD program in the world that could run on a PC. AutoCAD was released and by December 1982 deliveries began. A year later Uni-


Rapid prototyping has moved from just modeling to manufacturing and a recent article notes work in England on rapid prototyping systems that reproduce themselves and produce a wide range of other products. This could allow third-world countries to produce needed goods locally rather than importing.



Visualization of storm patterns combines 3D graphics and actual metrics.

Another emerging technology is the high-dynamic-range imaging (HDRI) display market.

Early 21st C.

Today emerging technology in hardware products is finally keeping up with software. Most computer graphics applications are not limited by hardware anymore, except for finite element modeling.

By the turn of the century, innovative applications, such as ImageModeler from REALVIZ were announced. It is a high-end software that produces 3D models from photos or still images of video.

In 2000 SensAble Technologies released FreeForm v. 2.0, a haptic modeling application, and I-DEAS 8 software was released for design automation.

Today soft prototyping, which is the process of generating a 3D model design that can undergo computer testing, is the emerging technology. It is the most significant contribution of computers to the design process.

The client base for engineering design graphics industry players is expanding. The market is growing much wider. More than Fortune 1000 companies with large/deep pockets are leveraging these tools to optimize business practices or even market products.

graphics II was introduced into the market.

January 1983 is technically determined to be the birth of the Internet, since that was when the National Science Foundation (NSF) built the early version of the NSFNet, a university network backbone. It was the first TCP/IP-wide area that was working. It took until the 1990s before the Internet moved from the university setting to corporate and industrial settings (Wkipedia, 2007).

By 1984 the technology hit another milestone with the advent of more powerful mini-computers on the market that were competitively priced. The target market for many years for engineering computer design was aircraft design. Because the hardware became more affordable, domestic products with intricate forms could be designed by computers.

While industry was developing CAD applications, interest in teaching traditional graphics waned, particularly the teaching of descriptive geometry at many universities. Why project auxiliary views to get the true length of a line or the true size of an area when the computer would do it more quickly and with greater accuracy?

Early in the 1980's The Ohio State University graphics staff were experimenting with an IBM program for graphics: one computer with two screens. Enter a command on one screen and lo! A line appears on the other screen (or a circle or just an arc). An article appeared in the Engineering Design Graphics Journal titled, "Engineering Graphics Instruction and Computer Graphics — A Necessary Merger," which noted the changes in time allowed for graphics instruction and the graphics knowledge currently needed in industry (Jenison, 1982).

In the mid-1980's Graphsoft Company began with a 3D CAD program written with Pascal for the Macintosh computer. What was remarkable about this innovation was that it had political implications. Owning personal computers was illegal in Communist countries until the time of economic well-being beginning in 1988 (Yamokoski, 2006). Gabor Bajor, a Hungarian physicist, had to smuggle two Macintosh computers into Hungary to write this application in Pascal. A teenager named Tamas Hajas was his programming partner. Together they wrote a Macintosh 3D CAD application (Collins, 2006).

By the mid-1980's AutoCAD led the way in sales and popularity with 50,000 users worldwide. From 1986-1996 AutoCAD was honored with "The Best CAD Product" award from PC World magazine (Bozdoc, 2006a).

Gamers with high-end machines and software and computer-graphics developers were the primary users of 3D technology in 1987, along with engineering designers and architects. There was interest in product design, personal entertainment, and corporate presentations, but because early 3D technology was costly and required high-end processors, consumers had little interest. Most businesses believe that not having a media player standard for 3D usage on the Internet has hampered 3D technology (Leavitt, 2001).

Deneba company is credited with the first release of Canvas in 1987, which combined drawing and painting on the same page. The following year (1988) Canvas features included additional features, such as 32-bit color, multi-point Bezier curves, unlimited layers, auto tracing, etc. It received the 1989 Editor's Choice Award and 1991 Best Drawing program from MacUser Magazine, as well as 1991 Best Illustration program from Mac Week magazine (Bozdoc, 2006a).

In 1988 Surfware Inc. delivered the first version of SurfCAM, which was a CAD/CAM application. Pro/ENGINEER by Parametric Technology was introduced to the engineering design industry in 1989.

The 1990's: The decade of CAD innovation. The 1990's continued to introduce more innovative applications for engineering design. In 1990 McDonnell Douglas, which is now Boeing, selected Unigraphics as the industry standard for designing their aircraft. Animator Pro, a 2D painting and animation application for DOS was shipped by Autodesk, and sold over 15,000 copies worldwide by 1993.

Silicon Graphics originally developed Open GL, a 3D color graphics application and rendering standard. In 1991 Microsoft released Open GL for Windows NT, as an API procedural software interface for the production of 3D graphics. Engineering designers had 120 drawing commands at their disposal, along with features such as shading, anti-aliasing, texture mapping, atmospheric effects, and lighting and animation. The same year (1991) Autodesk released ArcCAD, an architectural application.

In the 1990's Evolution Computer's FastCAD, FastCAD 3D, and EasyCAD2 were awarded numerous accolades from national and international publications. At the same time (from 1990-1998) AutoCAD received the Best CAD Product award from Byte magazine.

In 1992 Autodesk's 3D Studio and Canvas for Windows were released. That year industry's CAD/CAMM leader award was given to Riddle, and he was nominated by Design News as their "Engineer of the Year" finalist (Evolution Computing website, 2007).

3D Studio version 2 for DOS and AutoCAD Release 12 for DOS was shipped by Autodesk in 1992. AutoCAD included AutoCAD Render and AutoCAD SQL Extension (ASE)/Autodesk SQL Interface (ASI), which established links between SQL databases and AutoCAD.

The first Windows platform AutoCAD was released in 1993. The computer required 34 MB of hard dish space and 8 MB of RAM for installation. This Windows version of AutoCAD was one of the most successful releases.

In 1993 SolidWorks Corporation was founded by John Hirschtick from ComputerVision. SolidWorks, a 3D CAD program is a midrange CAD market software that competes with Pro/ENGINEER and SDRC I-DEAS, which is now Unigraphics NX.

Figure 1. Engineering Design Software

ENGINEERING DESIGN SOFTWARE

The decade of the 1990's introduced a plethora of engineering design graphics software applications. Here is a list of some of the innovations from that decade:

YEAR	APPLICATION
1991	Open GL for Windows NT
1992	Autodesk's 3D Studio and Canvas for Windows
	3D Studio version 2 for DOS AutoCAD
	Autodesk's Release 12 for DOS was
1993	SolidWorks
	AutoCAD v. 12 for Windows
1994	Hewlett Packard v. 3.5 PE/Solid Designer
	ArchiGraph's PowerDraw v. 6.0 for Macintosh computers
	HP's PE/Solid Designer (version 3.5)
1995	3DStudio MAX for the NT platform
	CATIA-CADAM AEC plant solutions
1996	Intergraph's Solid Edge v. 3.0
	Solid Works
	Lightscape v. 3.0, a high-end rendering and animation application with Illuminating Engineers Society (IES) standards
	New Tek's Lightwave 3D v. 5 and 5.5
	Intergraph's Solid Edge (version 3)
	SolidWorks
	Corel's CorelCAD
	3D/EYE's Tri Spectives Technical (version 2),
	Lightscape (version 3),
	New Tek's Lightwave 3D (version 5 and 5.5),
	AutoCAD LT 95
	Diehl Graphsoft's MiniCAD 6 for Windows
	Pro/E (version 17)
1997	Autodesk's 3DStudio Viz
	Autodesk's 3D Studio Max (release 2)
	Form Z Window's platform version
	SDRC's IDEAS Artisan Series
1998	Autodesk Architectural Desktop
	IronCAS (version 1.0)
	Autodesk's 3D Studio Max (version 2.5)
	Lightwave 3D (version 5.6)
	Intergraph's Solid Edge (version 3.0)
	Solid Works 98.
1999	CATIA (version 5.0) for Windows NT and UNIX
	New Tek's Lightwave 3D (version 6.0)
	VectorWorks takes the place of MiniCAD.
	Think3's thinkdesign software

(CADAZZ.com, 2007)

In 1994 Hewlett Packard released PE/Solid Designer (version 3.5), which was its high-end solid modeling application at the time.

CATIA-CADAM AEC plant solutions was released in 1995. The cutting edge "smart" object-oriented plant modeling system streamlined the workflow between the design, operation, and construction system.

The first parametric modeling CAD/CAM application and the first high-end solid modeling software package available on the Windows NT platform was Parametric Technology's Pro/E (version 15).

CAD users increased in numbers during the 1990's. By 1994 AutoCAD had one million users, CadKey had 180,000, and Microstation had 155,000. Only a year later (1995) the first website for Autodesk was published and the users increased to three million with 1.3 million AutoCAD users and 300,000 AutoCAD LT users.12

The year 1996 proved to be a year of 3D software releases. Intergraph's Solid Edge (version 3) was released in 1996. The same year SolidWorks, a 3D application which was founded on Parasolid modeling Kernel was introduced. Additional applications released were: 3D/EYE's Tri Spectives Technical (version 2), Lightscape (version 3), New Tek's Lightwave 3D (version 5 and 5.5), AutoCAD LT 95, and Diehl Graphsoft's MiniCAD 6 for Windows. Pro/E (version 17) featured file exportation into VRML format for Internet display.

By 1997 Canvas software was used to generate images on Steven Spielberg's The Lost World, and also to illustrate the Mars Pathfinder.4 The second release of Autodesk's 3D Studio Max in 1997 was introduced into the market along with a reduced version called 3D Studio Viz. For the next five years, a new version of EDS's Unigraphics, including WAVE, is considered to be one of the most noteworthy emerging technologies in the CAD/CAM/CAE industry. Form Z, which was initially only available on the Mac platform, has a Windows platform version released in 1997. The same year SDRC's IDEAS Artisan Series dubuts its first version.

In 1998 Autodesk Architectural Desktop was released, which was founded on AutoCAD 14. Additional software releases included: IronCAS (version 1.0), Autodesk's 3D Studio Max (version 2.5), Lightwave 3D (version 5.6), Intergraph's Solid Edge (version 3.0), Solid Works 98.

In 1999 Autodesk announced their sale of one million LT applications and 100,000 3D Studio MAX users. That was roughly 38% of the 3D PC market and 29% of the 3D animation market.13 Applications released in 1999 included: CATIA (version 5.0) for Windows NT and UNIX, and New Tek's Lightwave 3D (version 6.0). VectorWorks takes the place of MiniCAD. Think3 also introduced thinkdesign software in 1999. It was unique because for the first time 2D drafting, wireframe technology, advanced surfacing, and parametric solids were features of one mechanical design application product.

Even with all the technological innovations in engineering design, business processes had a tendency to be resistant to change in the 1990's. This factor inevitably delayed its effective integration with computer-based techniques. New technological tools were being used the same way that the old tools were used. Workflow needed to be integrated. Initiatives needed to be developed for industry standardization. Once Internet technologies were adopted into the engineering design industry, a convergence occurred and how work was done was restructured (Fallon, 1998).

INTO THE 21ST CENTURY AT THE UNIVERSITY LEVEL

The Bottome Line As we entered the 21st century more universities were reducing or eliminating manual graphics and teaching more CAD. Knowledge was constantly expanding and there was pressure on faculties to include more new ideas and compress the time allowed for each subject. Manual graphics is slower than CAD so it disappeared in many curricula. A problem presented to faculty became the choice of which software package to adopt based on cost, ease of use and teaching aids.

A detailed paper published in the Engineering Design Graphics Journal in 2004 provided a methodology for the selection of software and noted that industry was moving toward 3D systems (Okudan, 2004). An effective CAD package speeds instruction and the ability of students to produce a useful drawing within a few hours of practice.

Despite the emphasis in many universities and industrial companies on the selection of computer-aided design software to be used as tools for engineering design graphics, the true bottom line is the communication of a design – the graphics and visualization (Riddle, 2007).

Dr. Raul Herrera of The Ohio State University acknowledges that the value of CAD applications in industry and academia is not to be questioned. His concern is that the student remains "focused on training their minds to improve their visualization skills and on applying graphical solutions to engineering problems" (Herrera, 1998).

Hand-drawn sketching is a skill that is often undervalued by students who are eager to learn the latest "sexy" graphic application. Riddle believes that hand sketching is a significant skill in engineering design graphics (Riddle, 2007). He states:

*We have a woeful lack of tools that are of real help in the "napkin space" stages of brainstorming ideas. For much of history, the pencil and paper has reigned supreme because our tools are *not* transparent. We must take our mind off our ideas to focus on the tool, and this disruption greatly impedes creativity and early analysis.*

A product to address this transparency is being developed by Riddle. He was not prepared to announce it at this phase of development; however, he did say:

Until another tool that is as transparent to a person as pencil and paper is available and proves itself in use, hand-drawing skills will be essential. Now this is not to understate the use of artistic computer graphics (CG) tools, but they have a long way to go to reach the pencil's transparency. This makes them useful more for delivering content, rather than in spatial idea development and expression.

What is being lost is the ability to make useful freehand sketches anywhere and without tools or laptops. The authors believe that students who are not exposed to hand-drawn sketching do not gain maximum visualization skills — the ability to "see" ideas in the mind and translate them into useful drawings or explain them to others. For this reason Arizona State University and The Ohio State University still include freehand sketching in their beginning graphics courses.

Today, design and design-intent communication needs improvement. "In the real world, good design is not enough — it is the skill at communicating the design that makes or breaks projects" (Riddle, 2007).

It is important to note that the values of solid modeling are many. Solid modeling provides easy modification of a design and the capability for analyses such as strength, thermal effects and dimensional checks on related parts. Once the model is produced, it can be used for technical animation to explore the design in motion and to augment its appearance (Clark, 2005). This process has been applied to architectural modeling to produce 3D models of proposed buildings (Kirton, 2006). Some universities have provided facilities for students to produce rapid prototypes of their designs and hold the 3D object in their hands (Barr, 2002).

Figure 2. Other university notables in engineering graphics

Other University Notables (Second half of the 20th century)Several noteworthy academics have delved into the world of engineering design graphics.

Charles Eastman
Professor in the Colleges of Architecture and Computing
Georgia Institute of Technology

Professor Eastman is a well-know researcher in the area of CAD, solids and parametric modeling, engineering databases and product modeling. Much of his research in drafting systems was done in the CAD-Graphics Laboratory at Carnegie-Mellon University (Eastman, 2007).

Jon M. Duff
Professor of Graphic Information Technology
Arizona State University

Professor Duff previously taught at The Ohio State and Purdue University, and has been a prolific writer in the field of engineering design graphics. He published 17 textbooks in his career and was awarded the Orthogonal Medal by North Carolina State University for his influential achievements in the field of graphics (Amazon.com, 2007).

INTO THE 21ST CENTURY IN THE ENGINEERING DESIGN GRAPHICS INDUSTRY

Advances in technology and business practices have impacted the engineering design graphics industry. With the international accessibility of the Internet, Web-based tools have changed how work is done. The speed at which data can travel from one computer to another has also made it easy to share engineering design ideas and graphics online on an international level. With so many applications available, the initial cost of software and updates and the complexity of these programs are factored into the selection process (Harris & Sadowski, 2001).

One of the challenges of technology innovation is that computer graphics software programs, written by software engineers, often come with so many features that the product becomes overwhelming to learn and therefore becomes unworkable. User-friendliness and simplification are qualities of a software product, which would increase usage

Hardware Advances Today emerging technology in hardware products is finally keeping up with software. Most computer graphics applications are not limited by hardware anymore, except for finite element modeling. These limitations have "completely driven the design of our industry's products, and its time to undertake a real rethinking" (Riddle, 2007). Hand sketching can be done today using a portable tablet PC, which often comes with 16 hours of battery life, is reasonably priced, and can store creative learning objects for future review Hewlett Packard, 2007). The value of the digital sketching is the topic of future studies by co-author Harris.

Emerging Technology By the turn of the century, innovative applications, such as Image-Modeler from REALVIZ were announced. It is a high-end software that produces 3D models from photos or still images of video. In 2000 SensAble Technologies released FreeForm v. 2.0, a haptic modeling application, and I-DEAS 8 software was released for design automation (Bozdoc, 2006a). Most advances in computer graphics software emerge from the gaming industry, so engineering designers should keep a focus on that technology.

Rapid prototyping has moved from just modeling to manufacturing and a recent article notes work in England on rapid prototyping systems that reproduce themselves and produce a wide range of other products. This could allow third-world countries to produce needed goods locally rather than importing. This concept of machines, which reproduce themselves and produce other useful items, may be years away but it is a concept that may be realized yet in this century (Thilmany, 2006).

Today soft prototyping, which is the process of generating a 3D model design that can undergo computer testing, is the emerging technology. It is the most significant contribution of computers to the design process. Soft prototyping is faster and less expensive to build than real prototypes. It can undergo revisions, and can be used for testing marketing (Bozdoc, 2006a).

Another emerging technology is the high-dynamic-range imaging (HDRI) display market. It can "provide an order of magnitude or better improvement in realism and visual information display" (Riddle, 2007). Riddle is collaborating with Arizona State University to establish a computer lab with HDRI technology, video facilities, and other display technologies. Details will be announced within the year.

According to Christine Kelly, Regional Sales Director for CGK & Associates and emerging 3D and interactive simulation market consultant, designers today and in the past have been programmers. Kelly's primary client is EON Reality, Inc. She sees the future trend to focus toward designers, rather than programmers being more immersed in the industry (Kelly, 2007).

The client base for engineering design graphics industry players is expanding. The market is growing much wider. More than Fortune 1000 companies with large/deep pockets are leveraging these tools to optimize business practices or even market products. More than just CAD engineers are able to apply software tools to different areas of a company to leverage the company's digital assets. This interactive product content management (IPCM) is expanding to all sizes of businesses (Kelly, 2007).

Outsourcing Technology changes our society, our lives, and has a profound impact on our economy. The economic health of the United States is dependent on technologically-competent workers (Harris, 2004). In addition to how technology has transformed the engineering design graphics industry, the way that business is conducted has also changed. The most prominent change to current practices in the engineering design graphics field is "the ascendancy of cost saving by outsourcing being carried to extremes, so the bottom line looks good in the short term." This results in "long term loss of key skills and IP" (Riddle, 2007). This has led to a shortage of technically-competent workers in the United States, especially computer programmers.

The brain drain phenomenon of outsourcing has economic and political implications. Riddle (2007) believes that "the current glut of investor cash seems to be all in the wrong hands for our national best interest." In the past, universities have played a key role in addressing this issue: "Universities have always been on the front lines of this war, but this has seldom been properly recognized or funded" (Riddle, 2007).

CONCLUSION

We have seen great changes through tracing the journey of engineering design graphics and the impact it has had on the academe and industry. What is next? More change! Design has become an international endeavor as the Internet opens up opportunities in far different time zones for designers to collaborate on projects. This has resulted in efficient workflow with projects being completed in half or one-third of the time required if all design were done at one site.

As we move forward in the technological innovations of engineering graphics, it is important not to forget the foundational skill of freehand sketching. Industry and the academe must also work together to improve collaboration and software redesign for simplicity of use if we are to produce creative and technically competent engineering designers of the future.

REFERENCES

Amazon.com (2007). Jon M. Duff's Books. Retrieved from the World Wide Web on Feb. 5, 2007:

http://www.amazon.com/s/ref=sr_pg_1/102-2134161-0701730?ie=UTF8&rh=n%3A1000%2Cp%5F27%3AJon%20M%20Duff&page=1

Barr, R. E., Krueger, T. J.& Aanstoos, T. A. (2002). The New Digital Engineering Design and Graphics Process. Engineering Design Graphics Journal, 66 (3), 6-11.

Berkun, S. (2000). Why good design comes from bad design. March/April 2000; Microsoft

Developer Network. Retrieved from the World Wide Web on Sept. 11, 2007:

http://msdn2.microsoft.com/en-us/library/ms993290.aspx

Clark, Aaron C. (2005). Technical Animation: A New Concept for the Engineering Design Graphics Discipline. Engineering Design Graphics , 69 (3), 14-23.

Collins, Dan (2006). Visualizing 3D: Between measurement and illusion; a Powerpoint presentation from Arizona State University about PRISM. Retrieved from the World Wide Web on November 1, 2006: http://vizproto.prism.asu.edu/modeling/visualing3D 2-06.ppt.

Evolution Computing website (2007). Retrieved from the World Wide Web on Jan. 3, 2007:

http://www.fastcad.com/x-about.html.

Fallon, K. (1998). Early computer graphics developments in the architecture, engineering, and construction industry. IEEE annuals of the History of Computing. April-June 1998 (Vol. 20, No. 2) pp. 20-29.

Harris, L.V. (2004). Dancing with dragons: Social construction of technology during times of resource stress. A dissertation submitted to the faculty of the Center for the Study of Higher Education; University of Arizona. UMI Dissertation Services; ProQuest. Ann Arbor: MI.

Harris, L.V. & Sadowski, M.A. (2001). Alternatives for saving and viewing CAD graphics for the Web. Winter 2001 issue of The Engineering Design Graphics Journal; Vol. 65: No. 1; pp. 14-18.

Herrera, R. (1998). "Problems encountered when substituting the traditional drawing tools for CAD systems in engineering graphics courses," IEEE pp.677, 1998.

Hewlett Packard (2007). HP product website. Retrieved on the World Wide Web on January 15, 2007 at:

http://h10010.www1.hp.com/wwpc/us/en/sm/WF04a/321957-321957-64295-321838-306995.html

Kelly, Christine. (2007). Interview with the Regional Sales Director for CGK & Associates and Consultant in the emerging 3D and interactive simulation markets on Jan. 9, 2007.

Kirton, E. F. & Lavoie, S. D. (2006). Utilizing Rapid Prototyping for Architectural Modeling. Engineering Design Graphics Journal, 70 (1), 23-28.

Lawrence, E.O. (2005). Super Science Newsletter. Retrieved from the World Wide Web on Sept. 11, 2007: http://www.llnl.gov/PAO/com/super_science_newsletter/2005/super_science_physics.pdf

Leavitt, N. (2001). 3D Technology: Ready for the PC? from Technology News. Retrieved from the World Wide Web on January 30, 2007: http://leavcom.com/articles.htm

Okudan, Gul E. (2004). A Methodology for Optimum Selection of Solid Modeling Software. Engineering Design Graphics Journal, 68 (3), 22-33.

Riddle, M. (2007). Interview with Michael Riddle about engineering graphics at Arizona State University. Jan. 3, 2007.

Thilmany, Jean (2006) Like Life. Mechanical Engineering, 128 (7), 38-40.

Yamokoski, A. (2006). Financial Well-being in Transition: A Study of Economic Elite in Poland, 1988 to 2003 in Continuity and change in social life: Structural and psychological adjustment in Poland. Kazimierz M. Slomczynski and Sandra Marquart-Pyatt. IFiS Publishers: Warsaw. December 2006.