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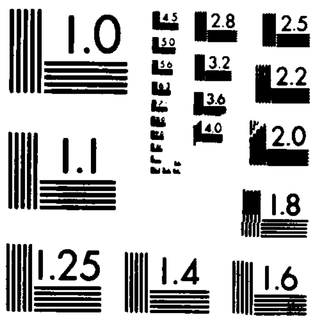

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REPORT NUMBER 87-0880

TITLE MICROCOMPUTER CADD AND THE AIR FORCE CIVIL ENGINEER

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Air Force civil engineering organizations have recently begun to examine the use of computer aided design and drafting (CADD) to increase the efficiency of their planning and design functions. However, these investigations have centered almost exclusively around minicomputer based CADD systems. Due to the high costs associated with these systems, the pace of incorporating CADD workstations into base level civil engineering operations has been extremely slow. This study analyzes the ability of microcomputer based CADD systems to meet the design and drafting needs of the Base Civil Engineer. It concludes that microCADD can adequately meet most base level requirements at a much lower cost. It also proposes a plan for implementing microCADD into base level civil engineering organizations.

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PREFACE

As you will read in the introduction to Chapter One, there is a revolution going on in the engineering and architectural communities. Computers are revolutionizing virtually every phase of work -- design, drafting, analysis, specification preparation, and project management. Slide rules have long since been laid to rest with the dinosaurs; typewriters have yielded to the power and convenience of the word processor; and now too, the drafting table, triangles, and lead holders are being pushed aside by the computer aided design and drafting (CADD) workstation.

Of all the changes, CADD stands out as the one offering the greatest impact to the profession. Designs can now be accomplished faster, with fewer mistakes, and at a lower cost. This translates into better service and a higher quality product for the client. However, the revolution has not yet embraced all corners of the engineering community. A notable example, and one of particular interest to me, is the Air Force Civil Engineering community.

As a government agency, we are inherently tied to a budget process that normally operates in a mode unstimulated by the profit and loss motive that drives decisions in the corporate world. Even great ideas must stand in line for funding. For that reason, when we buy something, we have to use it for a very long time. Therein lies the dilemma that CADD faces in the Air Force. The funding is normally not available for the system we really want, but on the other hand, we are afraid to invest in a smaller system that may not meet every need in the future. Thus the decision process lapses into a paralysis which slows the incorporation of new technologies to a painfully slow pace. We end up prototyping new systems adnauseam, and we continually stay several paces behind current technologies.

There have been initiatives over the last several years examining CADD systems for Air Force Civil Engineering. However, they have focused almost exclusively on large, expensive minicomputer based systems. While these systems are certainly capable of meeting our needs, their costs have placed them out of reach for the average Base Civil Engineer. This paper proposes an alternative in the form of microcomputer based CADD. Although microCADD may not offer all the advantages of the larger systems, it meets the majority of needs and offers increased productivity today at a price that is within reach.

As an instructor of civil engineering at the United States Air Force Academy, I had the opportunity to serve as the course director for the Civil Engineering Department's architectural course for the 1985 Fall semester. During that semester, we used microcomputers to implement the first use of a

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commercial CADD software package into the Academy's curriculum. That experience made me a firm believer in the power of microcomputers and in the ability of CADD to make life a little easier for Air Force engineers. This paper is written in an effort to share that enthusiasm and to encourage the rapid introduction of microCADD into the Air Force Civil Engineering work place.

ACKNOWLEDGEMENTS

I want to thank the people who assisted in the development of this study. First, thanks go to the folks at Autodesk, Inc. and AT&T Information Systems for their generous loan of software and microcomputers to the Academy's Civil Engineering Department. Without those assets, I would not have been able to experiment with microCADD in the Academy's curriculum. My deep thanks also go to Lt Col Dennis R. Topper whose initiative, drive, and vision furnished the real impetus behind the microcomputer efforts at the Air Force Academy. His "silver tongue" also deserves note for having arranged the loan of both the computers and software mentioned above. I am indebted to Major Robert L. Peters who served as my advisor for this study and provided both guidance and feedback in its preparation. And last, but not least, I want to thank my wife, Elizabeth, for her patience and understanding and for her editing and proofreading skills in the wee hours of the morning.

ABOUT THE AUTHOR

Major Neil H. Fravel graduated from the United States Air Force Academy in 1972 with a Bachelor of Science Degree in Civil Engineering and in 1973 completed his Master's Degree in Sanitary Engineering at the University of Illinois. He was subsequently assigned to England AFB, Louisiana, where he spent 3-1/2 years as the Base Environmental Coordinator and a civil engineering design officer. In 1976 he was transferred to Shu Lin Kou Air Station, Taiwan. There he served as the Chief of Engineering and Construction until the station was deactivated in 1977. His next assignment was a 26-month exchange tour with a Navy Seabee battalion homeported in Gulfport, Mississippi. During that period he served as the assistant operations officer and a company commander and participated in deployments to Okinawa, Guam, and Diego Garcia. He has since completed tours at the Air Force Engineering and Services Center (AFESC) as a readiness staff officer and at the Air Force Academy as an assistant professor of civil engineering.

Major Fravel completed Squadron Officer School in 1976. He is a registered professional engineer in the State of Colorado and a member of the American Society of Military Engineers. He received the 1981 HQ AFESC Meritorious Service Award for a Company Grade Officer, was selected as the 1985 Military Educator of the Year in Civil Engineering at the Air Force Academy, and was included as an Outstanding Young Man of America in 1985. He is a member of the Air Command and Staff College class of 1987.

Major Fravel's experience with microcomputers dates back to 1977. As the assistant operations officer with the Seabee battalion, he incorporated the battalion's first microcomputer into administrative and construction operations. At the Air Force Academy, he was the principal investigator researching possible uses for microcomputers in Air Force RED HORSE squadrons. He also served as the course director for the Civil Engineering Department's architectural course where he introduced the first commercial computer aided design and drafting (CADD) software into the Academy's curriculum. This unique opportunity let him experience first hand the trials and tribulations associated with setting up a CADD system. It also allowed him to observe the benefits and limitations of microcomputer based CADD in the engineering design process.

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REPORT NUMBER 87-0880

AUTHOR(S) MAJOR NEIL H. FRAVEL, USAF

TITLE MICROCOMPUTER CADD AND THE AIR FORCE CIVIL ENGINEER

I. Purpose: To analyze the need for microcomputer based computer aided design and drafting (CADD) at base level civil engineering (CE) and recommend a plan for implementing this technology.

II. Problem: There have been initiatives over the last several years examining CADD systems for Air Force Civil Engineering. However, they have focused almost exclusively on large, expensive minicomputer based systems. While these systems are certainly capable of meeting our needs, their costs have placed them out of reach for the average Base Civil Engineer.

III. Data: CADD allows designs to be accomplished faster, with fewer mistakes, and at a lower cost. This translates into better service and a higher quality product for the client. At least 95% of all architectural and engineering drawings are two-dimensional and do not require the increased processing powers offered by the minicomputer systems. Also, less than 10% of the engineering analyses performed by base engineers include the design of new facility construction. The most prevalent types of projects Air Force engineers design involve small structural modifications, maintenance and repair of existing facilities, and changes to electrical and mechanical layouts. MicroCADD systems are well suited for the production of engineering drawings and analyses required by these types of jobs. The ability to exchange files allows microCADD to interact with the larger CADD systems when

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necessary, yet carry the majority of the CADD workload during the day-to-day operations at base level. The hardware and software cost for a microCADD workstation is about $6900, which amounts to a total expenditure of a little less than $125,000 for a typical base. That compares with the miniCADD Integrated Graphic System previously considered by Air Force Civil Engineering which was priced at over $460,000 per base. The proposed microCADD system also provides three times as many workstations and the low unit cost of these workstations justifies their use in a wider variety of civil engineering operations than would have been possible using the larger miniCADD system. The $3 million available in the POM to prototype CADD systems over the next 3 years could alone provide the necessary funds to equip over 18% of our bases with microCADD systems.

IV. Conclusions: The minicomputer based CADD systems offer advantages over microCADD in the areas of storage capacity, speed, memory size and processing power. They are also superior in terms of their communications and networking capabilities and the sophistication of their integrated application software. The advantages of microcomputer based CADD include lower initial and maintenance costs, greater versatility, decreased training requirements, and a larger base of applications software. The ability to exchange data between microCADD and the larger systems provides access to large databases. While some functionality is lost by stepping down to the microCADD level, few base level requirements are beyond its capabilities; some tasks require a little more time and effort to accomplish, but microCADD still offers significant productivity enhancement. In the near future, new microcomputer hardware will approximate the computing power of current minicomputers. The paybacks gained by implementing microCADD today outweigh the marginal benefits gained by waiting for a fully integrated minicomputer system tomorrow.

V. Recommendations: CADD funds in the POM should be earmarked to purchase as many microCADD systems as possible and additional funds should be sought to equip the remaining bases. The microCADD software should be standardized Air Force wide to facilitate interchange of drawing files between bases and to ensure existing miniCADD files (such as the base comprehensive plans) can be downloaded to the microcomputers.

Chapter One

CADD FUNDAMENTALS

INTRODUCTION

The discovery that engineers are using computers to enhance their design efforts is not a hot news flash in most circles. After all, commercial computer aided design and drafting (CADD) systems have been available since 1964. However, early systems ran on expensive mainframe computers which meant their availability was limited primarily to academic institutions and large design firms (36:3). What is news, is the recent access to computers by practicing engineers at all levels of the profession. This is due in large part to advent of the personal computer with its attendant desk top computing power and the accompanying spiraling decline in computing costs. As one writer put it, "To an archeologist of the future, Americans in the year 1985 might appear to have had an obsession with two letters: P and C. If the archeologist happened to dig into a design and drafting office, the obsession would have had four additional letters: CADD" (38:44).

Regretfully though, that writer was not looking in an Air Force design office. If he had, he would have found us going about business as usual, back on the drawing boards, surrounded by our drafting machines, triangles, and an assortment of lead holders. With relatively few exceptions, we seem to be plodding along at a steady pace, unhampered by progress, and perhaps even oblivious to the revolution going on around us in the engineering and architectural community. A 1984 article in The Military Engineer magazine warned, "Just as the computer caused fundamental changes in other service industries such as travel, publishing, banking, and merchandising, the low-cost, high-powered CADD systems are revolutionizing architecture and engineering practices" (27:484). Those sentiments were echoed by a second author in the same issue when he said, "Computer use is no longer a luxury or a status symbol; it has become a necessity. . . . Our profession is based on advancement, not on stable performance. Those who decide today, will be ready tomorrow" (43:498). However, a lot of tomorrows have come and gone since these articles were published, and Air Force Civil Engineering organizations are still looking for a way to afford the tools necessary to participate in this revolution.

There is a solution though, and it's not a particularly expensive one. As previously alluded, the solution lies in six letters, PC CADD (also referred to as microCADD). This paper analyzes the need for microCADD at base level civil engineering and recommends a plan for implementing this technology. It shows we could literally be in the CADD business tomorrow at a reasonable cost which would quickly amortize itself.

OVERVIEW

The remainder of this chapter concentrates on laying the foundations for a discussion of CADD. This includes an examination of computer fundamentals and the definition of terms essential to the discussion. Chapter Two looks at the basic capabilities of CADD systems and explains why CADD offers increased productivity to its users. Chapter Three contrasts the capabilities, costs, advantages, and disadvantages of mini- and micro-based CADD systems. At the same time, it evaluates microCADD's ability to meet the needs of the Base Civil Engineer. Chapter Four presents recommendations for implementing a microCADD system into base level civil engineering operations. It outlines equipment and software requirements and points out some of the management actions which must be taken.

WHAT IS CADD?

Earlier, the acronym CADD was defined to represent computer aided design and drafting. This was a deliberate attempt to avoid the confusion that often results when the shorter term CAD is used. Depending on the user, CAD may mean computer aided drafting or it may refer to computer aided design, which is also known as computer aided engineering (CAE). By chosing the more inclusive term, it is obvious we are incorporating in our discussions both the design and drafting phases of the engineering process. If viewed in the narrowest sense, we then see CADD as simply joining the speed and power of the computer with the creativity and skills of the architect, engineer, and draftsman (36:3). However, in the broader sense, CADD can be viewed as just the first step in a more comprehensive automation of the engineering professions. That view is reflected in an article also quoted from The Military Engineer.

> The engineering professions are awakening to the fact that there is a better way to do things at a reasonable cost. However, this awaking will not mature until CAD is no longer thought of as the computer production of the traditional phases of design on a piece-by-piece basis and of drafting drawings by computer-driven plotters. Our awakening will be fulfilled when the total design process is addressed from concept to construction. . . . It is the continuity between the various design phases of a project via a direct software shuffle. It is the ability to access codes and standards and bring them into the decision-making process of the software used. It is the ability to create by-products that can be used for the total design including drafting, cost estimating, project management, shop

drawing preparation, construction data generation, future project information, and quality control (43:496).

In the following chapters you will see that most of these capabilities already exist in minicomputer CADD systems and that microCADD systems are rapidly stretching their capabilities toward these ends. Before we get to that point though, we need to briefly discuss computing in general terms.

COMPUTING TERMS

The unique vocabulary associated with computers may well be one of the most intimidating aspects to the novice user. Therefore, let's take a few lines to define some common terms.

Bits and Bytes

In any digital computer, the most elementary unit of data is the binary digit (bit) which has only two possible values, either 0 or 1. In many respects, a bit can be compared to an electrical switch which is either on or off. Therefore, if we wish to pass meaningful information, we must bundle a number of adjacent bits together to form different combinations which can then represent the various numbers, upper and lower case letters, and punctuation marks which we use daily to communicate. Each of these bundles of bits is referred to as a byte, and it holds the information to describe one character of text. Therefore, a full page of this report represents approximately 3200 bytes of information. In a CADD system, a typical floor plan drawing for a house might occupy 25,000 bytes (also referred to as 25 kilobytes or simply 25K).

Although the number of bits in a byte varies between computers, 8 bits is the most common number used (3:16). Mathematically, this means there are $(2)^8$ or 256 possible combinations available to handle our needs. It also means that when transferring data to and from storage devices such as floppy disks or between memory locations within the computer, the data will be processed using some multiple of this 8-bit data package. Depending on the design of the computer, either 8, 16, or 32-bit chunks of data are normally used. This determines the "word size" of the computer and affects its data processing speed. A 32-bit computer can pass four times as much information per cycle as can an 8-bit computer, based on word size alone. The IBM PC was introduced in 1981 as an 8-bit design; minicomputers and above occupied the 16 and 32-bit domains. However, microcomputers such as the IBM PC AT and the AT&T PC 6300 quickly led the way to the 16-bit plateau and in late 1986 the Compaq 386 became the first 32-bit micro to hit the desks. To fully understand the basics of computing though, we still need to examine a few other areas.

Processing, Memory, and Storage

If information within a computer is to be valuable, the computer must be able to execute instructions which will manipulate the data to meet the needs of the user. This manipulation is accomplished by the computer's central processing unit (CPU) which consists of the circuits controlling the interpretation and execution of instructions (3:166). In essence, the CPU is the brains of the computer. The increases in word size previously discussed, are outgrowths of advances in CPU technology. Newer CPUs are also more efficient in executing instructions, and there has been a continuing increase in their internal clock rate: 4.77 million cycles per second (MHz) for the IBM PC; 8 to 16 MHz for the IBM PC AT; and 16 MHz for the Compaq 386, with newer versions expected to operate at 20 and 24 MHz (24:60-61). All of this equates to increased processing speeds and greater computing power. However, we should not judge a computer by its processing speed alone.

The complement to speed is capacity, in terms of both memory and storage. Looking at memory first, we find it is divided into two basic categories, read-only memory (ROM) and random access memory (RAM). ROM is that portion of memory which is normally unalterable and is used to control the logic and internal functions of the computer. Since we have little control over ROM, we generally tend to disregard its presence as long as it is functioning properly. Therefore, when we talk of a computer's memory capacity we are usually referring to RAM. The integrated circuits of the RAM provide the storage cells wherein the computer's programs and data reside. Each of these cells is individually addressable which enables the user to input, retrieve, and shuffle information within the computer on a temporary basis. Note the word "temporary"; when the electrical power goes off, the computer's RAM is erased. Thus arises the need for storage devices.

The use of storage devices enables us to save information from the computer in a nonvolatile form that can be easily exchanged with other users or simply put aside to be accessed at a later date. The most common methods of data storage employ various forms of magnetic media such as cassette tapes, hard disks, streaming tapes, or floppy disks.

In the not so distant past, storage capacity was a problem for some microcomputer applications. Today though, storage is virtually limited only by financial constraints. A 20 million byte (20Mb - megabyte) hard disk can be purchased for the average microcomputer for under $400. For the retail price of $2200, a 40Mb hard disk can be added to the Compaq 386. For a little more money, it can be outfitted with a 130Mb hard disk with an average data access time of just 19 milliseconds, which, by hard disk standards, is very fast (18:58). Therefore, as storage capacities go up and prices come down, mass storage is becoming more readily available to all levels of computers. That leaves one last question to be addressed by this chapter.

IS IT A MINI OR IS IT A MICRO?

Computers are generally classified into four categories, supercomputers, mainframes, minicomputers, and microcomputers. Although these categories are often compared in relative terms using such criteria as cost, word size, memory capacity, and processing speed, the distinction between these categories is often blurred, and absolute definitions are virtually impossible to nail down. David L. Goetsch put it this way in his book on CADD.

> It would be nice and neat if I could simply say that any computer that has X word size, Y memory capacity, and Z processing speed is a blank computer. Unfortunately, it's not that simple because advances in technology keep changing the specifications. Categorizing computers according to cost, word size, memory capacity, and processing speed--or any other criteria--is like playing a game in which the rules constantly change. As soon as you think you have a handle on the situation, the rules change and you are back to square one (3:17).

He went on to say, "At one point in time, any computer with a 16-bit word size would be considered a mini. Now there are 16-bit *and* 32-bit minis. In addition, a 1985 mini might process data faster than a 1980 mainframe" (3:17). John Walker, the president of Autodesk, Inc., virtually echoed these sentiments when he stated, "If you look at an IBM/AT, you have a machine that would have been called a mainframe in 1969" (11:45).

Because the definitions seem to be constantly changing, it is difficult to definitively distinguish the break point between mini and microcomputers. Generally though, most of the criteria Goetsch mentioned, including costs, tend to increase as we go from the microcomputer category up to the higher levels. Therefore, if we want to minimize costs by using the smaller systems, we inevitably trade off performance in some other area such as processing speed. Such trade offs will be examined in Chapter 3. In the meanwhile, the following chapter will focus on specific capabilities of CADD systems and will examine why those systems offer enhanced engineering productivity.

Chapter Two

CADD CAPABILITIES

This chapter will discuss the elements common to most CADD systems and describe some of the additional enhancements found in more advanced versions. It will also explain why the implementation of a CADD system should offer increased productivity to any engineering organization.

CADD BASICS

Drafting Capabilities

The most obvious capability of any CADD system and the one which initially draws the most attention is the ability to perform routine drafting functions. This ability to manipulate graphics lets the engineer use computer power to translate graphical information into digital data which is again translated back to graphical information and displayed on the computer's screen. In the digital form, this information can be stored for display, editing, or output at a later date. In this respect, the CADD system is analogous to a word processor. While a word processor does not compose a document, it does allow the writer to easily manipulate words (2:2). Like the word processor, a substantial amount of effort is still required to enter new material; however, significant time savings accrue when the documents or drawings must be edited, or when portions of previous projects can be reused with only slight modifications. Since the engineering design process is an iterative operation, this is an important factor. Therefore, let's look at some of the important graphics capabilities we expect to find in a good CADD system.

Perhaps the most basic feature of any CADD system is the ability to combine drawing primitives such as points, lines, circles, and arcs, to form engineering drawings. These standard graphics components may be entered into the computer through the keyboard or by using more efficient input devices such as mice or digitizer tablets (25:176-178). Most CADD systems store this information using a vector based system which employs either a two- or three-dimensional scaled coordinate system. The location and orientation of each primitive is determined using this coordinate system. By selecting an appropriate scale for this axis system, the display screen can be used to represent any size drawing. Obviously, if a 24x36-inch drawing is displayed on a 10, 12, or even a 19-inch diagonal display monitor, objects will appear much smaller on the screen than their actual size when they are output to a plotter. Therefore, several other capabilities are of vital importance.

Prominent among these capabilities are the zoom and pan features. The zoom feature allows the user to scale a display item so it is reduced or magnified on the screen. Although the scale of the image on the monitor changes, the scale of the drawing's coordinate system is not changed (25:209). An example of zooming is shown in Figure 1. The ability to zoom in on portions of the drawing is essential for incorporating the detail and accuracy expected in completed engineering drawings. The pan function compliments the zoom function. Panning enables the user to scroll a zoomed-in window around a drawing. When doing detailed work, it is much easier to move directly to a new area by panning than to zoom out and zoom back in again (25:194).

Another important feature found in most CADD systems is the ability to create multiple layers. Layers are like transparent pieces of drawing paper stacked on top of each other. Each layer can be individually turned on and off for display and hard-copy output (25:179). In addition to this flexibility, the use of layers provides two other benefits. One is time savings; the other is better coordination of engineering trades. For instance, once the floor plan for a building is developed, additional layers can be used for electrical, plumbing, structural, and foundation plans. This means the floor plan only needs to be drawn once. Since the multiple layers can be viewed together, it is much easier to spot conflicts between trades. This ability is further enhanced if the layers are constructed using different colors. Appendix A illustrates how layering can also be used to store a vast amount of facility and planning data for a typical Air Force base.

Finally, in addition to the lines and arcs previously mentioned, a completed engineering drawing will normally include textual information. This alphanumeric data may be in the form of notes, legends, dimensions, titles, labels, or schedule entries. Therefore, every CADD system will have some means of generating text that is clear, legible, and pleasing to the eye (3:76-77). In fact, much of the time savings achieved by CADD when creating one-of-a-kind drawings are attributable to the quick production of text. A good CADD system will offer the user several styles of text and allow custom fonts to be developed if desired. Additionally, the system will offer flexibility in placing text on the drawing as illustrated in Figure 2.

Other capabilities which help speed data input include such things as on-screen or tablet menus, on-line help screens, symbol libraries which can be customized and accessed for insertion into drawings, and the ability to replicate or mirror items on the screen. Another important feature is the ability to "snap" to points on the screen. The snap feature compensates for certain degrees of error when the user does things like joining a line to the endpoint of an existing line, drawing one line perpendicular to another, or locating the center of an arc or circle. In each case, the user must only be in the general location and the software ensures the action is completed with absolute accuracy. This is particularly important for aligning the layers of a drawing or for entering data points quickly, but accurately (25:178). While all of these capabilities help speed the input of data, the ability to quickly create images is only part of the productivity story associated with CADD.

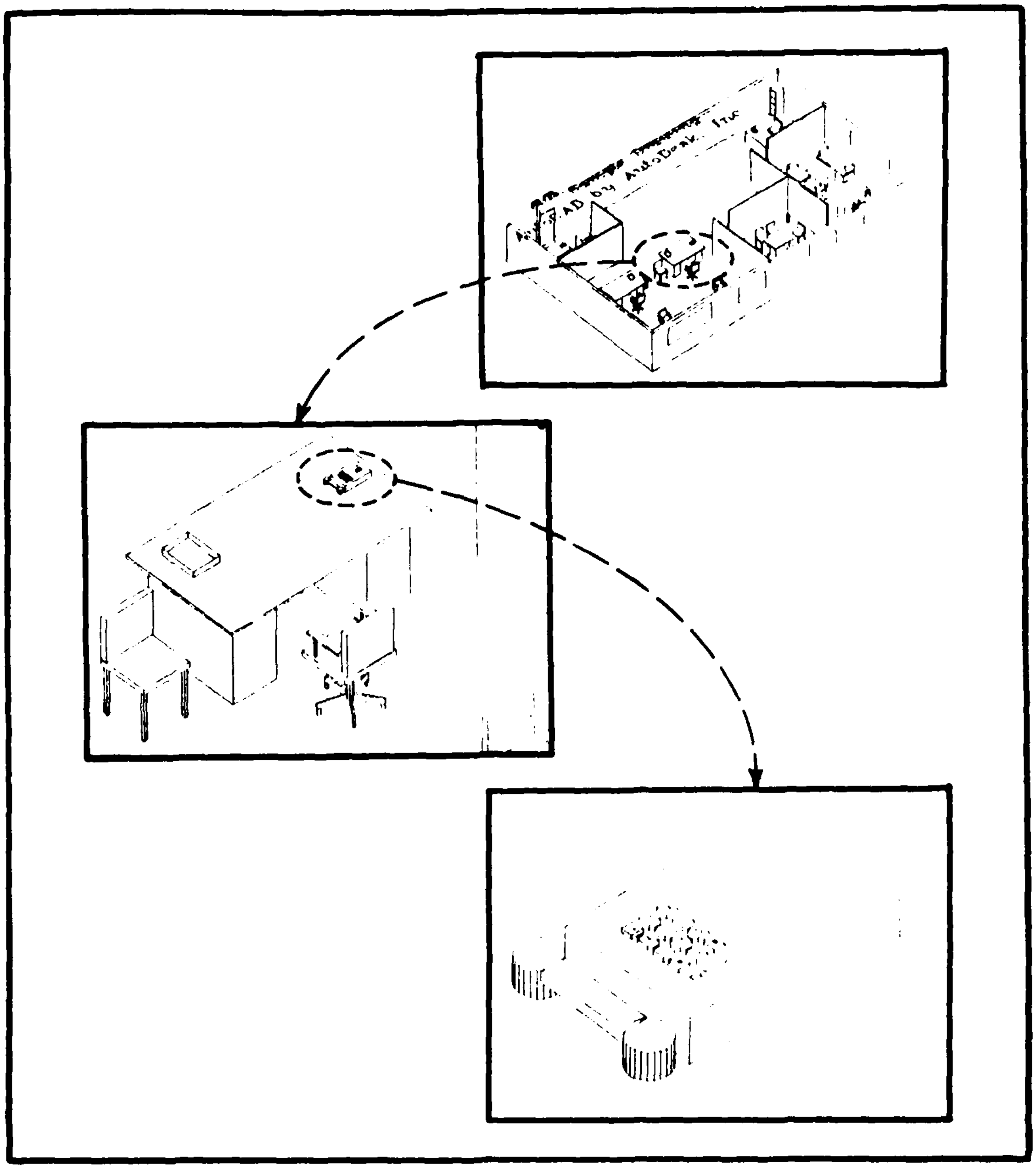

Figure 1. Zoom Capability *

* The three drawings shown above were produced on a microcomputer using AutoCAD software and a demonstration drawing that came with the package. The output was sent to a dot matrix printer. Note the detail that is evident as the display is zoomed in on smaller portions of the original drawing.

Figure 2. CADD Offers Flexibility in Creating Text

The initial input of data represents only the beginning of a CADD drawing; it is at this point that the editing features come into play. They represent CADD's electronic eraser and permit us to swiftly and efficiently modify drawings on the screen, using such commands as erase, delete, and redraw. The "move" command lets us take single entities or whole blocks of data and arbitrarily translate or rotate them on the display monitor. Such editing power means several things to the user. First, routine input errors are easy to correct. Second, the ability to quickly change items on the screen allows the designer to be more creative and encourages the examination of more alternatives and what-if type investigations. Third, review comments made during the design phase of a project are more likely to fall on receptive ears because such changes can be made with a reasonable expenditure of effort. Fourth, as-built drawings are more likely to be kept up to date. Lastly, and probably most important from a productivity standpoint, as the database of CADD projects increases, portions of these projects can be incorporated into future projects with minor revisions. For these reasons, the editing features are the true productivity enhancement tools of CADD. As one user stated, "The people I work with say 4:1 or 5:1 is about right on overall productivity enhancements. The first set of drawings on a project show 2:1 to 3:1 margins, and revisions show 10:1 or so, depending on their scope" (29:109-110). Since these numbers will vary with the the experience level of the CADD operators and type of CADD system used, the exact ratios are not the important point. The significant fact is that the biggest CADD savings arise from the capacity to modify existing drawings, not from the ability to create new drawings. This will become even more evident when we examine the topic of CADD productivity a little later in this chapter.

Design Capabilities

So far in this chapter, we have concentrated almost exclusively on the drafting side of CADD systems. In this section, we will briefly look at the other "D" in CADD, namely the design aspect. While drafting is essentially a technical operation, engineering design work represents a mixture of both art and science. It encompasses such things as structural or flow analysis, material takeoffs and cost estimating, and project scheduling. All of these tasks involve more than just graphic manipulations. However, in many cases, these functions are tied into the drafting process.

Design analysis software is often tied to symbol libraries. For instance, in an electrical circuit analysis, specific symbols may be needed to activate the analysis (2:3). In larger systems, the software required to accomplish these design activities may be specifically developed by the CADD vendor to act as a highly integrated package. However, since most of these applications are specific to a particular engineering discipline, they are developed as separate, add-on packages which can work with a variety of different systems. The CyberCAD Handbook put it this way:

> Because of the complex and sophisticated nature of design analysis software, it often originates from companies other than the supplier of the original CAD system. In fact the best design analysis software usually comes from users of the CAD system in that particular engineering field. They usually understand the needs of the users best and the requirements of their designs. Because this software comes from users, the CAD packages with the largest selection and probably the best packages of compatible analysis software are those with the greatest number of users (2:3).

To illustrate the kinds and amount of application software available, Appendix B lists some of the third-party software that supports AutoCAD, the largest microcomputer based CADD package.

Enhanced Capabilities

In addition to the design and drafting capabilities we have already examined, a good CADD system will possess several features which can be referred to as enhanced capabilities. It is these types of features that separate the low end CADD systems from the higher end systems. These include such things as custom menus, semi-automatic dimensioning, hidden line removal, the use of macros, and the ability to designate object attributes. Each of these increases either user speed or flexibility of the CADD system.

Let's look first at those which increase drafting speed. Custom menus allow tailored interfaces between the computer and the user. These may be developed for specific applications or a generic menu can be organized to reflect the user's frequency of use for individual commands. Semi-automatic dimensioning is a real time saver where drawings contain large numbers of items that must have their dimensions shown. If done manually, the user would individually construct the extension lines, dimension lines, arrowheads, and text needed to express dimensions on an engineering drawing. Instead, with semi-automatic dimensioning, the user simply designates the two points to be dimensioned between; the computer automatically draws the required components, measures the distance, and inserts the dimension text unless overridden by the system operator. The other speed enhancing feature is the use of macros which was well described in a Byte magazine article.

Macros and command files are groups of program instructions and other data-entry items that can be executed with a single keyboard sequence. For example, if it takes you five steps to merge a disk file into your current drawing, you can place the necessary instructions in a macro/command file and execute it with a single command. You can even place these macros as selections on your menu.

Further custom flexibility exists if the software lets you stop during macro execution and issue a prompt for data entry. For example, you can develop a menu item that creates a shape; goes to a particular location; enters text mode; sets the font, size, and direction; and prompts you to enter the text string. The more powerful the macro capability, the more you can develop custom or turnkey applications (25:178).

The other two enhancements previously mentioned were hidden line removal capabilities and the ability to designate object attributes. Both increase the flexibility of the CADD system. The first of these is shown in Figure 3. In that figure, the computer has removed the lines from a drawing that would not be visible to the eye if viewed from a certain perspective. This is particularly useful when trying to visualize three-dimensional drawings. The other enhancement, the use of object attributes, permits the user to tag drawing entities with information such as part numbers, tolerances, room numbers, electrical amperage requirements. These attributes can then be scanned visually or accessed by other software such as the database management programs shown in Appendix B. In this way, the graphics power of CADD can be combined with the number crunching power of management systems.

WHY INVEST IN CADD?

Up to this point we have concentrated on CADD in terms of its basic capabilities; i.e., how data can be input, modified, and retrieved. While this type of information provides some feeling for how a CADD system operates, it does not answer the more basic questions that arise. How do we justify an investment in CADD? What are the real benefits?

Is CADD Really Productive?

Elias Tonias' article in The Military Engineer offered a good outline for justifying CADD. He says, "The basic reason for automation is to better use one's limited resources to increase productivity, minimize costs, and improve the quality of both service and product. The result is manifested as an increase in savings or profits. In the engineering design profession, limited resources are people, time, space, and money" (43:496). With this outline in mind, let's look at some of the advantages of CADD, as cited by other writers.

In his book on CADD, David Goetsch listed the advantages as faster, less expensive modeling; faster, more accurate analysis; easier, more reliable reviews; faster, neater, more consistent, and more accurate drafting; easier

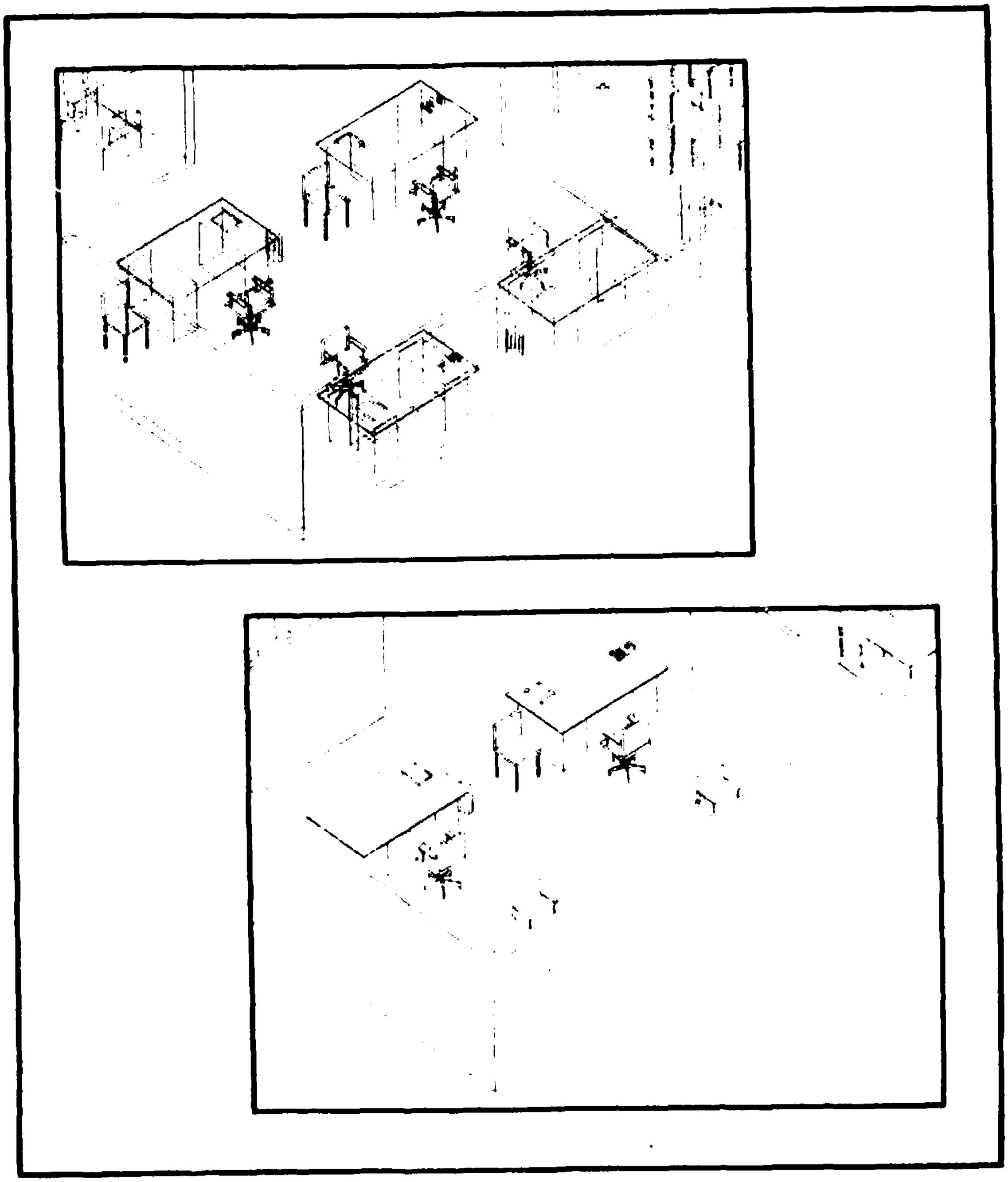

Figure 3. Hidden Line Removal *

* The hidden line removal feature is illustrated in the two drawings shown above. It is particularly useful in visualizing three-dimensional drawings.

storage requiring less space; and simplified, faster revisions and corrections (3:38). Another author described the advantages as improved precision, better on-time performance, and enhanced detail. He went on to say these attributes lead to reduced job site confusion and more expeditious handling of inevitable changes (29:109). It is easy to see how all the advantages listed above support the ideas of lower cost, better service, and higher quality products. Other benefits could also have included such things as the ability to consider more design alternatives, more coordination between trades, and more accurate as-built drawings because less time and effort are required to update changes.

All of these advantages blend together to influence that somewhat nebulous term referred to as productivity. Many companies that sell CADD systems tout increased productivity ratios of 3:1, 5:1, and even 12:1 (3:37). Some of these claims are viewed with skepticism as pointed out in the following quote.

> Productivity ratios are surrounded by myths. They are difficult, if not impossible, to measure, are linked to the fear of redundancies, and their main value often seems to be to give the company accountant figures to play around with during the cost justification phase. The real benefits of CADCAM [computer aided design/computer aided manufacturing] accrue from greater control throughout the design-to-production cycle, improved product quality and better inter-departmental communications, along with shortened lead times that get the product out to market quicker (19:607-8).

In defense of the CADD companies though, some examples can be shown which do support their numbers to one degree or another. For instance, Table 1 shows the results of Phase I CADD production tests for San Antonio Real Property Maintenance Agency (SARPMA) at San Antonio, Texas, using an Intergraph miniCADD system. SARPMA's evaluation of this data states:

> The total CAD design cost for all projects is $41,150. When compared with the total manual cost of design at $130,370.88, we find that the CAD test provided an average payback of 3.16 to 1. This compares favorably with the St. Louis District Corps of Engineers CAD test, the result of which varied from 2 to 1 for architectural work up to 6 to 1 for electrical work, with an overall payback average of 4 to 1 over a one year period (8:6).

SARPMA's final report on these same CADD tests went on to emphasize a point we have already mentioned; the largest paybacks are achieved when CADD is employed on repetitive projects. This is illustrated in the four street lighting projects were the design costs for the first job were $2110.52 compared to $72.46 for the last job (7:50). The following excerpt from another article also supports this point with slightly different numbers.

> After about 2 1/2 months the initial time to input a drawing was about the same as manual drafting. Time savings occur when changes are needed or new but similar drawings are needed. Average improvements in productivity are about 2:1 over manual drafting; as high as 4:1 for some types of repetitive drawings such as single line electrical diagrams and structural framing plans (35:508).

Project Title	Current Working Estimate	Estimated Cost for Manual Design	Billed Amount Using CADD
OTS Dormitories, Lackland AFB, Bldgs 110, 111,112	$1,933,193	$104,604.38*	$37,080.64
Street Lighting, East Kelly AFB	77,065	7,689.50	2,110.52**
Street Lighting, Duncan Drive, Kelly AFB	39,214	6,321.00	1,022.56**
Street Lighting, 2000 Area, Kelly AFB	32,513	5,878.00	864.71**
Street Lighting, 100 Area, Kelly AFB	47,661	5,878.00	72.46**
TOTALS	$2,129,646	$130,370.88	$41,150.89

Notes: * Actual cost of architect-engineer design for 3 similar dormitories
** Repetition of CAD details in project series brought costs down.

Table 1. Results of CADD Production Tests at SARPMA (8:Tab C)

Not all projects result in such paybacks though. Except when producing large blocks of text, a CADD system may not even match the speed of an experienced draftsman in producing original images (29:110). Productivity improvements do not surface until a large portion of the drawing comes from computer memory; in essence, we want to compose a drawing rather than create it. Therefore, it is vital that we have a CADD system with usable libraries of prestored drawing symbols and details, as well as the capacity for easily entering our own (29:110). It is also important that we identify projects which offer the greatest paybacks. In addition to the repetitive type work already mentioned, CADD is well suited to projects requiring numerous design reviews and changes, or those requiring evaluation of various alternatives, such as office layouts or space utilization studies. It should be noted, however, that the path to increased productivity can also have its pitfalls.

When justifying the required hardware and software, it may seem expedient to base the justification on the ability to perform the engineering tasks with fewer people. However, such an approach can be self-defeating. As one writer stated, "Even the best hardware and software on the market are of little value without the skilled users who accept the change CADD represents and are willing to be creative in finding ways to make it a productive venture" (3:40). But technological innovations invariably prompt two sociological reactions, the fear of the unknown and the fear of displacement (3:39).

Implicit in this threat is the notion that CADD's productivity will eliminate certain jobs or at least significantly change the way these jobs will be performed. In engineering, these concerns focus primarily upon design and drafting jobs (36:5). These employees are simply not going to let a new system succeed if they feel that its success will jeopardize their jobs. Therefore, it is essential we view CADD as offering the opportunity to create more and better products, rather than reducing manpower. CADD provides the means to reduce the work backlogs that always seem to exist in civil engineering squadrons. Even without manpower reductions, costs savings will evolve from increased accuracy of designs, better coordination between trades, fewer change orders, and less reliance on commercial design agencies.

It should also be noted that the use of CADD will not replace draftsmen with more engineers, or vice versa. Just as word processors did not replace secretaries, CADD will not replace draftsmen. Engineers will also continue to provide the intuitive element required in the project design process. For instance, CADD systems are capable of developing bills of material from drawings, but not very good at preparing finished estimates. It is very simple for a CADD system to transfer information on the cubic yardage of concrete required for a job. It is very difficult for a CADD system to transfer information that the concrete must be pumped, or hoisted and then carted (15:32). Qualitative information and engineering judgement are still better provided by an engineer than a CADD system.

From the preceding paragraphs it is obvious the amount of time, money, and manpower saved by using CADD is dependent on a number of factors. These include the capabilities of the CADD system used, the type of work being done, and the ability to incorporate existing libraries into new jobs. However, the bottom line on CADD is constant throughout the literature. Almost every CADD user points to significant increases in both the quantity and quality of work produced. Therefore, only one major question about CADD remains unanswered.

Is This the Right Time to Buy CADD?

That question was answered concisely by Eric Matson in this excerpt from his article "CAD Dollars and Sense".

> The price of some (not all) CAD system hardware is coming down about 10 to 15% per year. Overall system hardware costs are coming down approximately 5 to 10% per year. Now that software suppliers have discovered the market for desk top computers, the trend will level off somewhat because not much more downward migration of programs is in the offing. The direction will be one of increased power for the same money, rather than less money for the same power. Meanwhile, even at productivity increases of 3:1, system paybacks can approach one year. The numbers say do it now (29:111).

Chapter Three

MICROCADD VERSES MINICADD SYSTEMS

Now that we have examined both computer and CADD fundamentals and looked at the basic capabilities of CADD, we are still faced with the question of how to decide what type of computer system is required to meet the needs of the Air Force Base Civil Engineer. This chapter will shed some light on that question by contrasting the advantages, disadvantages, capabilities, and costs of mini- and micro-based CADD systems.

THE DILEMMA

Selecting the proper CADD system can often be a difficult and even frustrating decision. As one writer put it, "Buying a CAD system is like buying expensive wallpaper in that: you shop around endlessly; overspend the budget; wait weeks or months to get it; have trouble installing it and getting it running; are stuck with it, whether good, bad, or indifferent; and next month will see something that looks better" (29:106). Although that statement sounds humorous, there is much truth in it. We are stuck with whatever system we choose for quite some time, and that thought tends to paralyze the decision process. We can't afford the system that we know will do the job but, on the other hand, we are afraid to invest in a system which may not meet all of our needs. That dilemma leads us directly to the heart of the matter which another writer put this way, "You are considering a CAD system to save space, manpower and money. Why pick one that requires more of all three for things that have no direct impact on productivity?" (29:108). When comparing mini and microcomputers, space is generally not a major factor. Manpower and money can definitely be decisive factors though.

MINICADD ADVANTAGES

With an unlimited budget the decision between a miniCADD system and a microCADD system would be an easy one. The minicomputer based systems sold by companies such as Intergraph, Computervision, Apollo, and Sun, just to name a few, represent powerful tools in the hands of engineers. Today's minis have as much storage capacity and speed as the mainframes of the early 1970s, and they have a clear advantage over microcomputers in storage capacity and speed (32:33). The microcomputers are also limited by their memory size and processing power when compared to the minicomputers (40:49). A miniCADD system allows larger databases to be stored and can support more sophisticated applications. Integrated databases allow multiple users to share information easily (32:33). Minicomputers are also more sophisticated in terms of communications and networking capabilities (12:23). All of these advantages represent strong arguments in favor of the larger systems.

The capability to handle large, integrated databases means that vast amounts of related data can be stored in a single, large file which can be accessed by different branches within a civil engineering organization. This ability to communicate to a common database greatly increases the likelihood that everyone is viewing the same picture when they are making decisions. That in turn decreases the probability that different branches will be making separate decisions that are counterproductive to each other.

The advantages of increased system memory and processing speed also mean that system response times are quicker; the user is less likely to have to wait for the computer to catch up. For instance, the time required to regenerate a drawing on the miniCADD display after a zoom command is much less than required by a microCADD system. This equates to more productive time when sitting in front of the screen. The increased memory also means related design functions can be more closely integrated within the system's software. A structural analysis might be performed interactively while creating the structure on the screen, rather than leaving the drafting system and invoking a separate analysis program. As an article in Architectural Record stated, "Although a lot of software is available on personal computers, it is rare to find a high degree of integration in software packages because, by the very nature of personal computer software development and marketing, the applications are developed as small, discrete units. Broad application is simply met best by the larger systems" (32:33).

For these reasons, the Air Force Engineering and Services community chose to use minicomputers to implement the Work Information Management System (WIMS) and the Services Information Management System (SIMS) currently being installed on 130 major Air Force installations worldwide (17:50). A third system, the Integrated Graphic System (IGS), was in the Program Objective Memorandum (POM) for fiscal years 1987 through 1989. This $60 million system was to provide CADD, mapping, and comprehensive planning support for base civil engineering organizations, and it would have been integrated with the WIMS/SIMS databases. Last summer, IGS dropped out of the POM because of fiscal constraints. Only $1 million per year remains in the POM for fiscal years 1988 through 1990, to be used for CADD prototype testing (48:--; 51:--). Therefore, our limited budget forces us to examine less expensive options.

MICROCADD ADVANTAGES

One article refers to the heart of the microCADD revolution as the "80-20" rule. That rule states that microCADD yields 80% of the functionality of large miniCADD systems for 20% of the cost. As a result, the microcomputer has enlarged the number of potential CADD users by more than a factor of ten (21:21). Before Autodesk, Inc. introduced AutoCAD in November, 1982, "all the analysts assumed a CAD system had to be a machine. Meanwhile, AutoCAD, a software package that turned an existing PC into a CAD system, captured a dominant share of the CAD market" (11:44). This change in basic philosophy has resulted in the spiraling use of microCADD as reflected in Table 2. In fact, these estimates have already been proven to be low. AutoCAD alone has delivered over 50,000 copies of its program as of August 1986 (10:11) and 2000 to 3000 addition copies are being delivered each month (50:--).

Let's look at some figures which illustrate the relative costs. The Intergraph system at the San Antonio Real Property Maintenance Agency (SARPMA) was put into service in April 1985 at a cost of approximately $1,000,000 for 16 workstations (47:--). That comes to an initial investment of about $62,500 per seat. Other sources say the average price of a heavyweight Intergraph miniCADD system in 1986 stabilized at about $125,000 (38:44). The cost of a microCADD system is generally less than $10,000 (40:47). In fact, Appendix C shows that based on the current prices from the government's new microcomputer contract, the hardware costs for a top of the line microCADD workstation (excluding the hardcopy device) can run as little as $3000. The software costs depend on the particular programs desired, but generally, they are less expensive than comparable miniCADD software because the software development cost is spread out over many more users. Appendix B provides you with a feel for these costs. It should also be noted that most of the microcomputer programs are third party software. This means the user determines what packages are selected, thus tailoring both the cost and capabilities of each workstation to the needs of a particular discipline.

Even without the benefit of the government contract, microcomputer systems are reasonably priced. At 3D/International, an architectural firm in Houston, the average system runs about $6000 (including plotter, hard disks, modem, and

	1983	1984	1985	1986	1987	1988
Shipments	3,000	8,000	12,000	17,400	24,400	34,200
Cumulative	6,000	14,000	26,000	43,400	67,800	102,000

1985 estimates by Dataquest, Inc.
(subsidiary of Dun & Bradstreet)

Table 2. Estimated Market for PCs With CADD Software (40:47)

graphic screens). If depreciated on a straight-line basis over five years, the accrual cost is $100 per month, equivalent to a few hours of professional time (42:37). This low cost offers an additional benefit. Like telephones, microcomputers are inexpensive enough to be left idle part of the time. Even small productivity increases justify having them readily accessible (42:39).

If a microcomputer system is already being employed for other uses, the marginal cost decreases even further. The same system that serves as a word processor can serve as a CADD station with the addition of the CADD software and a few pieces of peripheral equipment such as a digitizer. This means the hardware is more versatile, an important point to Air Force engineers since they spend less than 50% of their time doing actual design work (6:24).

In addition to the initial costs, microcomputer systems offer savings in maintenance costs when compared to the larger systems. In the case of SARPMA, the maintenance on hardware and software is approximately $220,000 per year (47:--). For other large computer systems, maintenance plans calling for full, on-site, 4-hour response times have cost on the order of 1% per month of the original sale price (29:110). That contrasts with figures from an engineering firm showing maintenance costs for their 22 microcomputers at $21 per year for each $1000 in capital cost (42:39). Using these ratios, if a $100,000 microCADD system replaces a $500,000 miniCADD system, we expect maintenance costs to be reduced from $60,000 down to $2100 per year, an annual savings of $57,900.

MicroCADD offers further savings through decreased training costs. Microcomputer based CADD systems normally take less than a month to learn and use effectively. This compares with around three to nine months for the larger workstations (40:47). While part of this ease of learning is due to the lack of the more sophisticated applications packages normally available on larger systems, it is also due to the easy-to-use graphical user interfaces and on-screen menus found with most micro-based systems (40:47, 12:28). But cost is not the only factor we should consider.

MicroCADD must also provide the drafting and design power necessary to develop the drawings and accomplish the engineering analyses required for project preparation. While microcomputers cannot match minicomputer based systems in this area, the 32-bit architecture of newer hardware is starting to approximate the computing power of minicomputers (12:23). According to Charles Watt, a marketing specialist for MicroAge computer stores, Compaq's new Deskpro 386 has its greatest market potential in the CADD field. He thinks it "will give some real competition to graphics workstation sellers. It will pit Compaq against Sun and Apollo rather than IBM" (23:209). When these 32-bit microcomputers hit their stride, they will leave the current AT-machines far behind. Essentially, they are minicomputers. They run at 4 million instructions per second compared to the IBM PC's 330,000. With a maximum addressable physical memory of 4 gigabytes (256 times that of the AT) and a maximum virtual memory of 64 terabytes (over 70 quadrillion bytes), they will give a huge boost to microcomputer based CADD (26:210).

Meanwhile, CADD software designed for micros is increasing in capability, stretching up to the level of bigger systems (12:23). Programs such as

AutoCAD are, by any objective measure, a mainframe-type program. The only constraints are those imposed by hardware (11:43). The software packages offer powerful functionality and an open architecture, which makes them favorite candidates for application-specific third party software developers (38:44). In fact, in the fast-moving world of microcomputer software, these products are more application-specific than those coming from the broad-based turnkey systems (12:24).

Another factor mitigating the impact of microCADD's limitations is the type of work normally accomplished by Air Force Civil Engineers. At least 95% of all architectural and engineering drawings are two-dimensional (6:36) and do not require the increased processing powers offered by the minicomputer systems. Also, less than 10% of the engineering analyses performed by base engineers include the design of new facility construction (6:30). Even in those cases which do, experience at SARPMA has shown the sophisticated design analysis programs such as STRUDEL do not apply well to our small jobs (47:--). The most prevalent types of projects Air Force engineers design involve small structural modifications, maintenance and repair of existing facilities, and changes to electrical and mechanical layouts. MicroCADD systems are well suited for the production of engineering drawings and analyses required by these types of jobs. Figure 4 illustrates the two-dimensional drafting power a microCADD system offers and Appendix B shows a sample of the analysis software available to accomplish such projects.

Another point in microCADD's favor is that to be effective, it does not need to perform all the functions of the larger CADD systems. Instead, it need only perform a functional subset, where the subset's data structure is designed so that it can be easily used by a larger system, or vice versa (46:52). We see this happening today in the form of graphics translators such as the Intergraph-to-AutoCAD translator which addresses the compatibility issue (13:489). This flexibility can be extremely important.

For large projects like those in the Military Construction Program (MCP), the U.S. Army Corps of Engineers, the Naval Facilities Engineering Command, or a commercial architect/engineering firm is normally designated as the design agent. In many cases this means the designs will be developed on one of the larger CADD systems. The same is true with base comprehensive planning (BCP). Virtually all of the 62 BCP projects currently funded and the 49 future ones include CADD mapping and are being accomplished on a variety of miniCADD systems (4:1). These are typically very large databases. However, a research study at the University of Illinois used AutoCAD running on an IBM-AT microcomputer to update and manage the Chanute AFB BCP files which had been developed on an Intergraph miniCADD system (9:7-8). This ability to exchange files allows microCADD to interact with the larger systems when necessary, yet carry the majority of the CADD workload during the day-to-day operations in a base civil engineering organization. For that reason, the larger CADD systems can be restricted to locations which track extremely large databases. Such locations include places like SARPMA which serves several installations, and major command headquarters where files are stored for numerous bases.

The areas where microCADD significantly falls short of the larger systems are speed, communications, and networking capabilities. However, even in

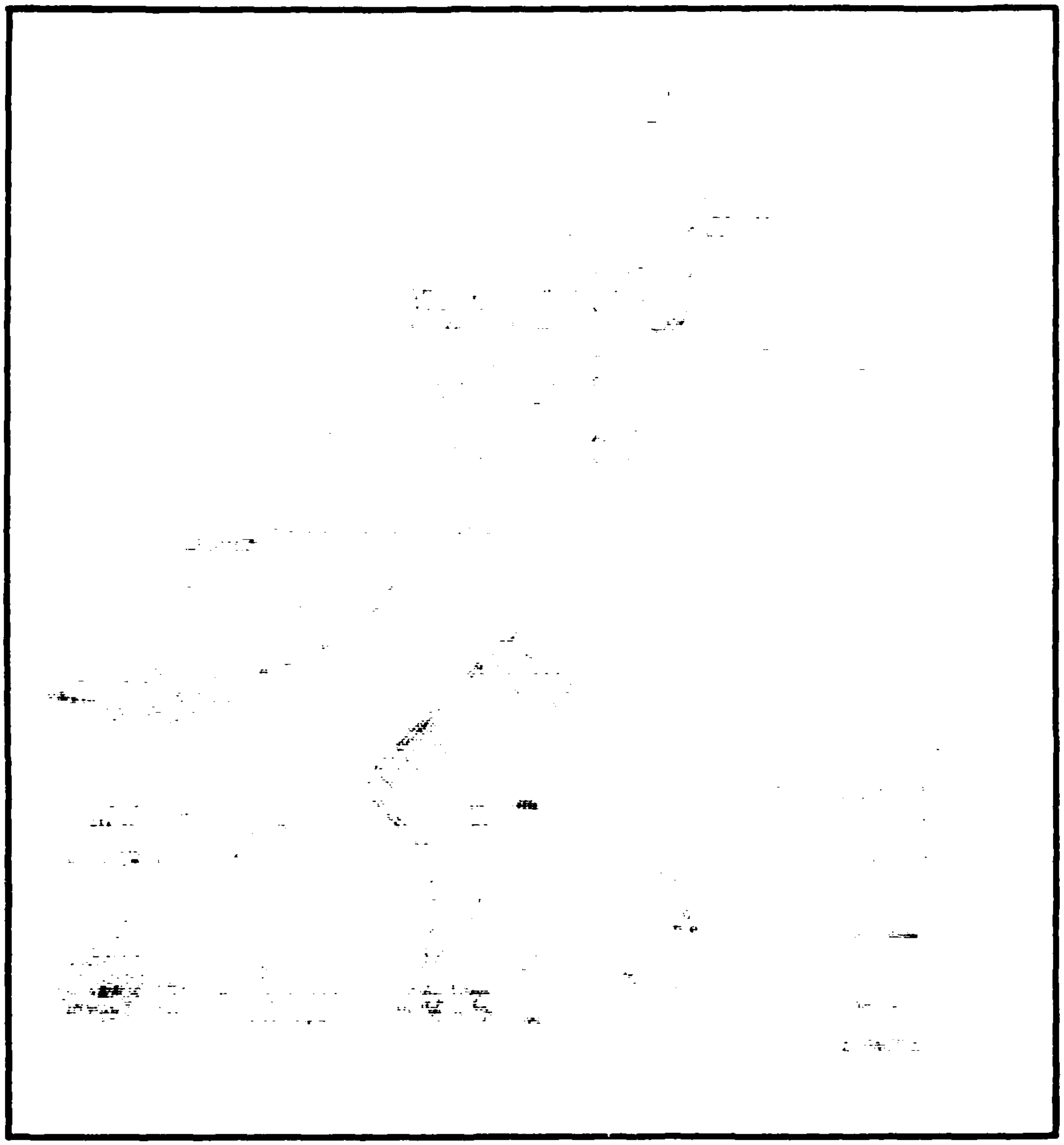

Figure 4. Example of Two-Dimensional MicroCADD Drafting *

* The space shuttle Columbia and the fire hose nozzle shown above are two demonstration drawings provided with AutoCAD software. They are indicative of the quality and detail of work which can be accomplished using a two dimensional microCADD system.

these areas, some points can be made in favor of the microcomputer. For instance, system performance does not degrade with multiple users. Experience on the miniCADD system at SARPMA has shown that CPU-intensive operations such as plotting drawings must be delayed till slack periods, such as lunch time or after duty hours, to prevent significant decreases in system response times (47:). Another point in the favor of microcomputers is, if one system goes down, other workstations are not affected (41:36). Also, even with a multi-user system, only one person at a time can access a file to make changes.

In actual practice, relatively few files need to be shared by multiple users. For those files which must be shared, procedures can be worked out to maintain a reasonably up-to-date copy of the files at each microCADD work-station. An example might be the base comprehensive plan, where typical users include the engineering branch, the planning division, the fire department, and various maintenance shops. Because of the layering capabilities of micro-CADD systems, each user could be assigned particular layers to update. At whatever interval is deemed appropriate, the layers could be manually merged back into a consolidated, current file and redistributed. Granted, this is not a real-time database nor is it an ideal solution; it does, however, put relatively current information at everyone's fingertips at a reasonable cost.

CONCLUSIONS

The minicomputer based CADD systems offer advantages over microCADD in the areas of storage capacity, speed, memory size and processing power. They are also superior in terms of their communications and networking capabilities and the sophistication of their integrated application software. MiniCADD is well suited to base level engineering needs; however, its capabilities come with a price tag that places it beyond the current reach of most Base Civil Engineers.

The advantages of microcomputer based CADD include lower initial and maintenance costs, greater versatility, decreased training requirements, and a larger base of applications software. The ability to exchange data between microCADD and the larger systems provides access to even the large databases. While some functionality is lost by stepping down to the microCADD level, there are few base level requirements beyond its capabilities; some tasks require a little more time and effort to accomplish, but microCADD still offers significant productivity enhancement. In the near future, new microcomputer hardware will approximate the computing power of current minicomputers.

While it would be nice to have all the computing power possible, the paybacks offered by the implementation of microCADD today outweigh the marginal benefits gained by waiting for a fully integrated minicomputer system tomorrow. With that thought in mind, the following chapter discusses the elements essential to the implementation of a microCADD system.

Chapter Four

A PLAN FOR IMPLEMENTING A MICROCADD SYSTEM INTO BASE LEVEL CIVIL ENGINEERING OPERATIONS

This chapter will present recommendations for implementing a microCADD system. It outlines equipment and software requirements and points out some of the management actions which must be taken.

EQUIPMENT REQUIREMENTS

Two problems complicate the task of definitively nailing down the CADD equipment required to support the Base Civil Engineer. First, there is no such thing as a "typical" base civil engineering organization. Variations include such things as the number of people assigned to the design section, the mix between design engineers and technicians, the types of projects being designed, the ratio of projects designed in-house verses by architect/engineer contract, and the backlog of projects awaiting design. Each of these will have an effect on the desirable scope of the CADD system. The second factor is the rapidly changing technology associated with CADD. As one article stated, "If anyone spends more than 90 days making a decision in the CAD area, he needs to start over, because every 90 days the situation is going to change enough that he probably needs to do a bit of reevaluation" (45:9). While there certainly is a lot of truth in that statement, the methodical pace of the Air Force procurement system does not allow us that luxury. Therefore, the best that we can do in this study is to define the "average" engineering organization and identify equipment requirements based on today's prices and current technology. In that light, the system described in the following paragraphs should be viewed as a starting point which needs to be tailored to the individual circumstances of each base. Let's start then by defining our typical organization.

As part of his Master's thesis in 1983, Capt William Duncan polled a cross section of Air Force bases to determine the makeup of a typical base level design section. The number of design engineers varied from 8 to 18 with an average of 12. Assigned draftsmen ranged from 5 to 13 with an average of 8 (6:14). The same study also determined how each of these groups used their time. The design engineers spent 22.5% of their time developing drawings, 13.5% writing specifications, and 7% performing engineering analyses (6:50). The draftsmen spent 85% of their time on drawing production (6:52). With these figures in mind, we must now decide on the number of workstations required to support civil engineering requirements.

To maximize creativity in the design process, our goal is to provide each person who needs one with an individual workstation and the necessary software and databases. This eliminates the inefficiencies that result from forcing a design engineer to report to a terminal when creativity is low and forcing the engineer to quit when the creative ideas are flowing (33:42). However, this goal must be tempered by fiscal constraints. A reasonable compromise appears to be one workstation for each draftsman and one workstation for every two design engineers. Therefore, the average design section will need 14 workstations. We must also consider the needs of other civil engineering sections with valid CADD requirements. These include environmental planners (2 systems) and the job planners (2 systems). This gives us a total of 18 workstations for our "typical" civil engineering unit. Let's now look at how each workstation should be configured.

Appendix C shows a suggested configuration based on the current Air Force Zenith microcomputer contract. Appendix D shows an alternative setup which uses the Wang computer equipment currently being purchased under the Air Force Minicomputer Multiuser System (AMMUS) acquisition. Note that this second option requires supplement pieces of equipment not included on the AMMUS contract. This makes the purchase of new Zenith microcomputers the more cost effective of the two options. Regardless of the hardware option chosen, several points deserve to be highlighted.

The CADD system should be configured with as much system memory as possible (31:70). As a minimum, each microcomputer should have 640KB of RAM to accommodate a variety of microCADD software packages and associated design analysis programs. The CPU should be as fast as possible, preferably a 16-bit processor operating at 8MHz or faster. The unit should be equipped with a numeric coprocessor to further decrease the time required to regenerate screen images. Each system should have at least a 20MB hard disk for storage of databases and software and it should be equipped with a streaming-tape backup unit. The screen resolution should be at least 640 pixels (dots) horizontal by 350 pixels vertical to prevent excessive distortion of displayed images and the system should be able to display at least 16 colors simultaneously to facilitate recognition of different drawing layers. Each workstation should also be equipped with a digitizer tablet to speed up data entry and allow the use of commercial CADD tablet menus. Lastly, the workstation should be capable of running under the Microsoft disk operating system (MS-DOS); i.e., "IBM compatible". Although other operating systems offer reasonably good drafting software, MS-DOS is the only microcomputer operating system with enough users to have spurred development of a large volume of analysis software. The importance of that fact will be discussed in a later section of this chapter. Before that, we will examine the support equipment necessary to complete the CADD system.

The most obvious piece of peripheral equipment required is some type of hardcopy output device. Again, several options are available, including electrostatic plotters, pen plotters, dot matrix graphics printers, and laser graphic printers. These output devices are also available in a variety of sizes with the most popular being A-size (8.5x11 inches), B-size (11x17), C-size (18x24), D-size (24x36), and E-size (36x48). While laser graphic printers are good for A-size drawings, their application to most engineering work is extremely limited. The electrostatic plotters are excellent for most engineering requirements and they offer very high output rates. However, they also come with large price tags ranging from $20,000 to $60,000 per unit (7:29). Therefore, we are left with the pen plotters and the dot matrix graphics printers as the two options offering a compromise between capability and cost. Graphics printers perform faster than pen plotters, they cost much less, and they can be used for tasks other that CADD, such as word processing. However, they are generally limited to B-size output, and they lack the quality required in finished drawings. Therefore, although they can be used by most workstations, their use is limited to producing check copies of drawings. The majority of completed CADD drawings will be output to pen plotters. Pen plotter prices have stabilized in the $5000 to $8000 range for a large, multi-pen, medium speed, high resolution plotter (14:604). The design section should have two of these plotters capable of handling C- and D-size drawings. The job planners should also have a B-size pen plotter available for their use. In all cases, it is important that the user ensure the models selected are compatible with the CADD software to be used.

One remaining piece of hardware that should be considered is a scanner. While the benefits of CADD are considerable, they are attainable only on drawings that exist in the computerized database (22:63). As new designs are produced on the CADD system, the demand to convert old drawings declines (34:29). Nonetheless, the existing civil engineering drawing files offer an excellent source of information for developing a usable database. The problem arises when we consider the huge number of existing drawings. In the case of SARPMA, 60,000 drawings are contained in its flat files. It has been estimated that it would require 10 years to manually digitize and verify SARPMA's floor and plot plans at a cost of 14 to 32 cents per square foot of building space (7:50-51). Scanners offer an alternative.

Sophisticated scanner systems are very expensive, costing from $80,000 to more than $350,000 (34:28). However, some microCADD systems such as AutoCAD provide the capacity to integrate scanned images at a reasonable cost. With Autodesk's CAD Camera software, raster-scanned images can be captured via a Wang PIC or Datacopy camera (12:25). This system uses a high resolution solid state video camera with an appropriate computer interface. Another option uses the Houston Instrument SCAN-CAD plotter attachment to do the scanning. In both cases, the scanned images are converted into individual lines in the database and the resultant "vectorized" image can be viewed, edited, scaled, zoomed, plotted, etc., just like any other drawing. One exception to this rule is the drawing's text which is also scanned as a graphic image. This means it can not be edited by the text-handling features of the CADD software.

The camera can be used on drawings up to B-size in one step, or larger drawings can be digitized in parts and merged together. The SCAN-CAD option can handle drawings up to the limits of the plotter it is installed on. Although a complex drawing may take as long as one to two hours to convert to line segments, a skilled operator manually inputting the same drawing would take 10 times longer (2:38). The CAD Camera software retails for $3000 and the input device costs an additional $3000 for the plotter attachment or $11,950 for the camera.

Using all of the preceding information we can now make an estimate of the CADD hardware costs for our "typical" base civil engineering organization. Table 3 shows this cost to be approximately $79,200 ($4400 per workstation), including the peripheral equipment. However, we must now add in the software costs which are discussed in the following section.

ITEM	NUMBER	UNIT COST	COST
Zenith microcomputers with accessories shown in Appendix C	18	$3,000	$54,000
D-size plotters	2	5,600	11,200
B-size plotter	1	2,000	2,000
Graphics printers	15	400	6,000
Scanner with software	1	6,000	6,000
TOTAL COST			$79,200

Table 3. Microcomputer CADD Hardware Costs

SELECTING THE SOFTWARE

Selecting the CADD software is perhaps a more critical and a more difficult decision than selecting the CADD hardware. Regardless of the sophistication of the equipment chosen, the overall system will only be as good as the software running on it. John Walker, the president of Autodesk, points out, "If you lock a CAD system to one hardware base, you're locking the people who buy that system into one point in the history of this technology" (37:34). In others words, care must be taken to select software that is flexible enough to incorporate advances in technology. If we invest money and manpower in a system today, we cannot afford to sacrifice those investments tomorrow. As another writer pointed out, there are significant costs associated with switching CADD systems. Retraining CADD users can entail up to 2/3 of the original training costs. Drawings, symbol libraries, and menus may have to be transferred. System-specific macros may need to be rewritten and interfacing software may have to be replaced (20:43). Therefore, it is important that we weigh a number of factors when selecting CADD software.

Many articles have been written enumerating a wide range of software priorities. One such article offers the following points. A CADD package should offer (1) cost-effective functionality, (2) ease of learning and use, (3) the ability to use the CADD system for non-drafting applications, (4) the availability of design software that can interact with the drafting features, (5) the availability of high-level programming languages such as FORTRAN, BASIC, and PASCAL, and (6) the capability to create generic figures that can be scaled and inserted into drawings (43:498). A different article lists the earmarks of a good CADD program as (a) price, (b) ease of use, (c) effective documentation, (d) support for a number of popular graphics adapter cards, (e) drivers for a variety of printers and plotters, (f) advanced drafting features such as auto-dimensioning, smooth curve-handling, and mirroring, and (g) control of the aspect ratio; i.e., circles that look like circles on the screen (30:69). A third article advises the user to obtain a system with a capacity to expand to eight times the current or projected use. It also urges the user to beware if application software is limited (28:55). While all of these represent valid considerations, this list needs to be condensed somewhat.

The essence of all these articles can be distilled down to a few simple rules. First, select the software from a financially mature supplier that caters to the engineering and construction industry. This offers some assurance that the software will be easy to use and free of bugs, it will have most of the powerful drafting features found in the better CADD systems, and the company will be around to support its products in the future. Second, don't select a software package that provides only drafting features; ensure it is supported by a broad range of analysis software for each engineering discipline. And lastly, select a system that has a well known and stable database format. This will help avoid a stack of as-built drawing files that must be either converted or discarded in the future. Also, the stable database format, when combined with a large user population, will encourage the development of new third party software packages (including the translators necessary for communication with the larger CADD systems).

While a large number of capable microCADD packages are available on the market, a detailed analysis of them is beyond the scope of this study. However, two packages do deserve some discussion; CADKEY and AutoCAD were both selected by PC Magazine as an Editor's Choice for microcomputer CADD packages (16:7).

CADKEY offers an extremely good drafting system (including 3D) at a very low cost. Since it is the CADD package included in the government's latest microcomputer contract, it is available at a cost of $280 per copy (16:7). This low price makes it an attractive option since most Air Force civil engineering tasks center around the drafting aspects of CADD. However, as previously pointed out, a CADD program must have an accompanying base of analysis software to perform all of the engineering tasks. Because it is a relatively new product (released in 1985), CADKEY's smaller user population has not stimulated the third party software necessary to meet these needs.

The premier CADD package in that respect is AutoCAD. As the oldest and one of the most sophisticated of the microCADD packages, it has captured the majority of the microcomputer CADD market. Because of its open architecture and its large number of users (well over 50,000), it has attracted the largest number of independent software developers. Currently there are between 300 and 400 third party vendors turning out AutoCAD-compatible applications software (50:--). This AutoCAD market also promotes widespread hardware support and provides a wide choice of user training options. An indication of AutoCAD's influence on the market can be seen in the numerous competitors, both mini-based and micro-based, who advertise translators to convert drawing files between AutoCAD and their systems.

For these reasons, AutoCAD has already found applications in some Air Force offices. It is being used educationally at the Air Force Academy in the Departments of Civil Engineering, Aeronautical Engineering, and Geography. The civil engineering squadron at Cheyenne Mountain Complex, Colorado Springs, is currently procuring the hardware and AutoCAD licenses to use in its design and operations branches (49:--). As pointed out previously, AutoCAD was used by the University of Illinois to download the Chanute AFB miniCADD drawings to a microcomputer. However, the functionality and third party support offered by AutoCAD does not come cheaply (by microcomputer standards).

AutoCAD, like most sophisticated microCADD packages, costs over $2500 per license. In fact, the latest version (AutoCAD 2.6) retails for $2850. Although site licenses are not offered, large orders (300 copies or more) generally qualify for discounts ranging from 40 to 50% (50:--). Thus, if a major command consolidated its requirements into one order, the cost would be significantly reduced. Even larger price reductions would be expected if the software were procured on an Air Force wide basis. Of course, the total software cost must include the ancillary programs.

As seen in Appendix B, there is a wide variety of software available to assist in the design process and the prices span a wide range. The types of programs needed at each workstation will vary according to the user. This makes it difficult to definitively establish these software requirements without looking at each Air Force base individually. A general estimate would allow $1000 per workstation for these types of programs. If we add that figure to the cost of the CADD software ($2850 times 50%), the total software cost per workstation is approximately $2500.

Therefore, the hardware and software cost for each workstation is about $6900, which amounts to a total expenditure of a little less than $125,000 for our typical base. While that price may seem expensive, it should be viewed in perspective. The miniCADD Integrated Graphic System previously considered by Air Force Civil Engineering was priced at over $460,000 per base and, as previously shown, it would have resulted in significantly higher annual maintenance costs. Furthermore, the proposed microCADD system provides three times as many workstations. The low unit cost of these workstations justifies their use in a wider variety of civil engineering operations than would have been possible using the larger miniCADD system. In fact, the $3 million available to prototype CADD systems over the next 3 years could alone provide the necessary funds to equip over 18% of our bases with microCADD systems. With that in mind, let us briefly examine some of the actions which must accompany the implementation of the microCADD system.

MANAGEMENT DECISIONS

The period immediately following CADD system implementation is the time when CADD is least efficient. During this time the supervisor must accomplish a number of major actions. These include organizing the design library, determining layering schemes, establishing backup and file handling procedures, and selecting the initial projects to be accomplished using CADD (39:79). Budget provisions must be made for maintenance, supplies, and periodic hardware and software updates (28:55). Probably the most important of all actions is setting up the training for both operators and managers.

The most common mistake is to overestimate the training time required. The initial assumptions of a CAD training program at a midwestern tool manufacturer were that, after 24 weeks, students would be as productive as draftsmen working with the manual techniques. Parity was actually reached after only 4 weeks. Within 32 weeks, the CADD operator was three times as productive as the manual draftsman (36:6). Nonetheless, allowances must be made for an initial drop in productivity and an interruption of the established work flow (3:112). Therefore, the conversion to CADD should be scheduled during a time of year when the interruptions can be best absorbed. In most cases, the training process will occur in two phases, formal training followed by on-the-job practice.

The term "formal" training, may or may not include training purchased from a commercial vendor. In the case of the 1010 CES at the Cheyenne Mountain Complex, three days of commercial training was provided for ten people at a total cost of $2500 (49:--). However, experience at the Air Force Academy indicates most of these training costs can be avoided. At the Academy, only two people acquired an in-depth knowledge of the CADD system initially. This was accomplished with approximately one week of self-paced study using the documentation provided with the CADD software. These people were then able to quickly teach the fundamentals to other users through in-house training programs. Because of the simplicity of microCADD systems, this type approach worked well. In all cases, the majority of the learning came with hands-on practice on actual projects. The trainers were readily available during the first few weeks to answer questions as they arose.

When selecting the initial people to be trained at base level, preference should be given to employees who are highly productive, valued employees that are interested in learning CADD. Hesitancy to use a computer can be readily overcome; a lack of interest cannot (35:506). The training process is further enhanced if the initial trainees are already familiar with the design process and the operation of microcomputers. This permits the trainees to concentrate on applying CADD fundamentals to the manual practices they already know. The initial cadre can then pass on their knowledge to other users, including the draftsmen, project engineers, and managers. With a little encouragement and a few weeks practice, users will soon be developing their own unique CADD applications to assist them in their day-to-day activities. At that point, CADD will begin to reach its potential as a productivity enhancement tool. What's needed now is a decision that microCADD has reached its proper place in the priority line for funding.

SOME FINAL THOUGHTS ON CADD

This study has concentrated primarily on the productivity aspects of CADD. As shown in the previous chapters, CADD provides a tool to expedite the design process, enabling the engineering staff to complete designs faster, thus accomplishing more projects using in-house labor. This in turn decreases the amount of commercial architectural/engineering services that must be used by Air Force bases. While this reduction of direct design costs is the largest single factor driving us to implement the CADD system, there are other, more humanistic reasons supporting implementation.

The Intangibles

CADD provides the capability to increase the quality as well as the quantity of completed designs. Because the editing features allow the user to quickly modify a drawing, CADD makes it much easier to examine a number of different alternatives in detail before deciding on the final solution to a design problem. The ability to edit an existing drawing also encourages the designer to be more receptive to suggested changes during all phases of the design process. After all, how many times in the past have constructive review comments fallen on deaf ears simply because they were too much trouble or there was not enough time available to redo the drawings? CADD should help minimize those situations.

Another reason for using CADD is to improve the appearance of completed engineering documents. The ability to create drawings that are consistent in detail, free from erasures or smudges, and sharp in overall appearance, can contribute to an increase in professional pride. This is particularly true for the young engineer or technician who has only limited drafting experience. With CADD, everyone has an equal potential for turning out a drawing of exceptional quality. Lettering is always consistent, arrowheads are always perfect, and line weights are always uniform. This permits CADD users to shift the emphasis of their efforts from a concentration on raw drafting skills, towards more creativity in the design process.

And last, but not least, there is a certain job satisfaction that derives from being provided the right tools to accomplish a job properly. However, all too often, our people are forced to labor without the benefits offered by modern technology. These people know there is a better way to do things and they want the opportunity to provide a better product to their clients. The final report on SARPMA's CADD system included a survey of 200 engineers and support people. Of that group, 98% said they wanted to move into CADD technology and 65 engineers and architects volunteered to be trained on their own time (7:55). If we expect these folks to be loyal, productive, professionals, it is essential that we in Air Force Civil Engineering get our CADD program together and begin fielding systems for them to use.

Conclusions

While some functionality is lost by stepping down from the miniCADD level to microCADD, few Civil Engineering requirements at base level are beyond the capabilities of microCADD. At a cost of $6900 per workstation, the paybacks gained by implementing microCADD today outweigh the marginal benefits gained by waiting for a fully integrated minicomputer system in the future. At the same time, microCADD's ability to exchange data with the miniCADD systems provides access to large databases now, while preserving the option to upgrade to larger systems if necessary in the future.

Recommendations

CADD funds in the Civil Engineering POM should be earmarked to purchase as many microCADD systems as possible and additional funds should be sought to equip the remaining Air Force bases. The microCADD software should be standardized Air Force-wide to facilitate the interchange of drawing files between bases and to ensure existing miniCADD files (such as the base comprehensive plans) can be downloaded to the microcomputers.

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APPENDICES

Appendix A

USE OF CADD LAYERS FOR BASE MAPPING

The following information provides some feeling for the amount of data which can be stored on the various layers of a computerized base map for a typical Air Force installation (5:Atch 1).

Existing conditions maps	15 layers
Pollution overlays	4 layers
Existing utility systems	14 layers
Natural resources overlays	12 layers
Fire protection data	2 layers
Other planning information	6 layers
	53 layers required

EXISTING CONDITIONS MAPS

Topography

- Contour lines, other significant features
- Data such as elevations, labels

Existing Streets & Railroads

- Layout
- Data on street names, dimensions, pavement thicknesses
- Existing traffic volumes/capacities/levels of service
- Existing mass transit routes, bicycle/jogging/pedestrian paths

Existing Airfield

- Airfield pavements
  - -- Layout by pavement types, thicknesses, etc.
  - -- Data on strengths, cross sections, etc.
- Airspace configuration
  - -- Imaginary surfaces, obstructions, etc.
  - -- Approach/departure patterns/tracks
- Airfield lighting, instrumentation, navigational aids, etc.

Existing Land Uses Other Than Airfield

- Land use overlays, special areas (such as explosive safety zones)
- Land use labels, other data
- Existing real estate, including leased lands, etc.

Existing Buildings and Structures

- Layouts
- Data such as building numbers and labels
- Building types such as semi-permanent, permanent, or other unique info

POLLUTION OVERLAYS

Air Pollution

Water Pollution

Soil/Land Pollution

Hazardous/Toxic Waste Locations/Transfer Systems/Disposal Areas

Air Quality Assessment Model (AQAM)

- Point sources, corridors for vehicles, roads, parking lots
- Pollutant isopleths, data, and contours
- Annual levels of pollution emissions

EXISTING UTILITY SYSTEMS

Water - Layout and data on line sizes, valve locations, etc.

Sanitary Sewer - Layout & data on line sizes, elevations, lift stations, etc.

Storm Drainage - Layout and data on line sizes, elevations, culverts, catch basins, etc.

Natural Gas - Layout and data on line sizes, valve locations, etc.

Electrical - Layout and data on aerial/underground distribution lines, sub-stations, transformer vaults, etc.

Street Lighting - Layout and data

Airfield Hydrants/POL/Liquid Fuels - Layout and data

NATURAL RESOURCES

Land Management and Landscape Development

- Vegetative types
- Land use soil capabilities
- Soil types and data
- Floodplain and wetland mapping
- Improved, semi-improved, & unimproved land mapping

Forestry

- Compartment and stand locations
- Roads, firebreaks, trails, streams, & other natural features
- Forest maps including species, size, diversity, age-group
- Forest management treatment areas

Fish and Wildlife

- Habitat types
- Threatened and endangered species data and locations
- Management activities (existing and proposed)

Outdoor Recreation

- Development plan (existing and proposed)
- Wild and scenic rivers
- Recreation trails

Grazing and Crop Lands

- Prime and unique farmland mapping
- Leased out units (existing and proposed)

Historic Preservation

- Archaeological, historical, and cultural areas
- Candidate natural areas and historic sites

Bird-Aircraft Strike Hazard (BASH)

- Bird attractors
- BASH specific information such as flight tracks, altitudes, etc.

FIRE PROTECTION

Fire Hydrant Layout and Pressure Data

Building As-Built Plans and Pre-Fire Plan Data - Construction, number of occupants, nearest hydrants, valves, etc.

OTHER PLANNING INFORMATION

Proposed Land Use Plan

Proposed Transportation Plan

Proposed Facilities Development Plan

Proposed Improvements to Other Infrastructure -- utilities, etc.

Proposed Energy Plan

Visual Analysis/Special Needs

Appendix B

CADD RELATED SOFTWARE

The following information was extracted from the 196 page, Fall 1985, AutoCAD Applications Manual (1:--). It is not intended as an endorsement of AutoCAD or any of the application software. Instead, it is presented to give you a feeling for the amount, cost, and types of software available to support microcomputer based CADD. It is not intended to be a comprehensive list, since new software is continually being developed.

AUTODESK PRODUCTS

AutoCAD with Advanced Drafting Extensions ($2500) - basic CADD program

CAD/camera ($3000) - combines the power of CADD with scanner technology to automatically enter existing drawings into the computer

AE/CADD ($1000) - a template-driven program, based on AutoCAD, which increases the speed and accuracy of architectural drafting

ARCHITECTURAL, ENGINEERING, AND CONSTRUCTION

Arch Lib ($750) - architectural symbol libraries

Architectural Design Detail Libraries ($450) - landscaping and structural detail libraries

CadPACK Total Drafting/Design System ($750) - AutoCAD tutorials plus over 5000 architectural, electrical, and mechanical symbols

GEOCAD ($800) - graphic/pictorial menu-driven symbol library

LANDSOFT ($975) - Landscape architect modules site planning, irrigation design, takeoff/estimating, and flow charting

Matheson Design Architectural Library Detail Pkg #1 ($89) - architectural details

Plumbing Symbols, Landscaping Library ($29.95) - menu-driven templates

BILL OF MATERIAL, DATABASE EXTRACTION

acadDATUM Series - extracts inserted primitives from drawing file, compares to its database of valid primitives, and prints results

- acadDATUM I ($395) - generic bill of material/job costing
- acadDATUM 1LA ($495) - landscape architect planting schedule
- acadDATUM 1CAI ($495) - capital assets and inventory
- acadDATUM 1C ($395) - bill of material/costing for construction
- acadDATUM 1EL ($495) - bill of material/costing for electrical

ACE [After-CAD Estimator] ($1295) - extracts symbols from drawing files to produce cost/profit estimates

AutoBASE ($295) - extracts information from drawings and provides a direct link to dBASE data base manager

BOMB [Bill of Material Builder] ($495) - extracts symbols from drawing files to produce bill of material

LADS ($195) - converts AutoCAD extract files to either DIF of ASCII formats for use by other programs such as Wordstar, Lotus 1-2-3, etc.

Sun-flex Bill of Material ($500) - uses AutoCAD attributes to create reports such as job costing, material requirements, bid estimates

CADD UTILITIES

ACALC ($150) - an area and perimeter calculation postprocessor for AutoCAD DFX files

AutoCOM ($90) - software to support off-line imaging, directly onto microfilm at high resolution, without plotting

AutoSHAPES ($150) - a utility program that permits easy design of custom text fonts and drawing shapes

AutoTXT ($100) - Converts ASCII text files into Script file which can be inserted into AutoCAD drawing

CADVERT ($179) - automatically converts dimensioning text between English and metric units

INSET ($149) - captures AutoCAD screens and includes them in word processor text documents

CIVIL ENGINEERING

AROSE (Civil) - a full complement of application programs for land development and roadway design

- COGO3D ($2000) - three-dimensional coordinate geometry
- PLANS ($2000) - plotting annotation and subdivision
- EARTH3 ($1500) - road and general earthwork computation
- XPLOT ($1200) - cross-section standards and plotting
- PROFPLT ($1200) - profile standards and plotting
- DSECT ($600) - contour digitizing for earthwork and roadways
- TERRAIN ($1200) - terrain model builder
- CONTOUR ($1500) - Contour map plotting
- XGEN ($900) - Cross section generating
- DIGIT ($600) - terrain model digitizing

AutoMAP ($1000) - a three dimensional contouring and mapping package which can generate contours from up to 2000 random points

FIELD BASED SURVEY SYSTEM ($1575) - menu-driven programs that permit users to download data from most field data recorders, validate and reduce data, and create AutoCAD DFX files to generate plan and cross-section views

FIELD BASED DESIGN SYSTEM ($1500) - a generic design and quantity takeoff package for linear projects such as roads, pipelines, etc.

GRAPHICS TRANSLATORS

ACAD2 - a series of translators for converting files between CADD systems (prices shown are for bi-directional versions)

AutoCAD/CADAM, AutoCAD/Intergraph, AutoCAD/Applicon ($9000 each)
AutoCAD/Computervision, AutoCAD/CALMA ($12,000 each)

AutoIGES ($500) - converts AutoCAD Drawing Interchange File (DFX) to the Initial Graphics Exchange Specification (IGES) format

AUTOINTER/INTERAUTO ($4000) & AutoLINK ($10,000) - both permit file exchanges between AutoCAD and Intergraph systems

STRUCTURAL ENGINEERING

AutoFRAME ($750) - uses AutoCAD to describe all features of a plane frame or truss and performs structural, stress, and deflection analysis using FRAME2D

Beams/Structural Steel Details ($800-$1500) & Steel Detailer ($750) - menus and drawings used to create finished steel detail drawings

FEMSOL/PC ($2000-$4000), SAP86 ($1495), & SCADA ($1200-$12,000) - finite element programs for static and dynamic structural analysis

Strupak A - programs that design or analyze concrete and steel beam and column members

- RCTRCCOL ($475) - rectangular reinforced concrete column
- BUSP ($275) - built-up section properties
- BMAN ($275) - beam analysis
- STLBMDN ($475) - steel beam design
- STLCOLDN ($375) - steel column design
- RCBMDN ($550) - reinforced concrete beam design
- RNDRCCOL ($400) - round reinforced concrete column

Strupak B - programs to solve two-dimensional problems

- 2-D ($400) - two-dimensional frame analysis
- PLNFRAME ($250) - plane frame analysis
- PLNTRUSS ($350) - plane truss analysis
- CONTBEAM ($350) - continuous beam

Strupak C - programs to design pre-cast, pre-stressed one span members

- PSBM ($750) - pre-stressed beam design and analysis
- COMPBM ($200) - composite beam or girder design

CASE for Architects ($3500) - an interactive set of 24 programs that analyze and design concrete, steel, and timber structures and their shallow foundations and prepares quantity takeoff and cost estimates

Appendix C

CADD HARDWARE COSTS USING ZENITH MICROCOMPUTERS (16:5-7, 44:27-28)

Zenith Z-248 microcomputer with two 360KB floppy drives, an 80286 processor running at 8 MHz, 512KB memory, two parallel printer ports, two serial ports, a keyboard, an RGB port/video graphics adapter compatible with IBM EGA (Enhanced Graphics Adapter) board, a system clock/calendar, MS-DOS 3.1, a BASIC interpreter, diagnostic software, Microsoft Windows, 200 watt power supply, an owner manual and installation guide. There are ten total slots: two IBM PC compatible slots, four IBM PC-AT compatible slots, and four Zenith/PC-AT compatible slots. Only the 2 PC slots, 1 AT slot, and two Zenith slots are empty; the disk controller, the CPU board, the video graphics card, and input/output ports occupy the remainder. The disk controller is capable of driving two floppy disk drives and two Winchester drives.

Price for the unit described above	$1103
640KB memory expansion board (1.1MB total)	120
20MB internal hard disk	302
Enhanced color display monitor (640x350 resolution with 16 colors)	302
Summagraphics graphics input tablet	293
Surge suppressor	30
80287 numeric coprocessor	143
21MB tape backup system w/software & 5 tapes	478
Subtotal	2771
8.5% surcharge	236
Total cost per workstation	$3007

Appendix D

CADD HARDWARE COSTS USING WANG MICROCOMPUTERS (WIMS EQUIPMENT)

This appendix examines the costs involved in setting up a microCADD system using equipment procured as part of the Civil Engineering WIMS system. The costs are based on equipment purchased by the 1010 Civil Engineering Squadron, Cheyenne Mountain Complex, Colorado Springs, Colorado (49:--). Prices shown in parenthesis are not included in the total price shown at the bottom of the page.

Wang PC-S3-2 personal computer (8MHz 8086 processor) with 512KB RAM, 1 360KB floppy disk, 1 10MB hard disk, keyboard, MS-DOS, and interpreted BASIC	($950)*
128KB memory expansion (PCPM032)	120
8087-2 numeric coprocessor (200-1115)	225
High resolution Wang monochrome monitor with controller card (PIC-PP01) -- used in 1/2 of the workstations	1400
High resolution Hitachi 3619A color monitor with BNW Precision Graphics card -- used in 1/2 of the workstations	(3800)**
Summagraphics graphics input tablet	310
30MB hard disk (APC-PM025)	1025
Hard disk drive controller	300
Total cost per workstation	$3380

* Microcomputer was delivered as part of the WIMS contract.

** For the color workstation, add $2800 to the total shown above.

For a 1/4" streaming tape backup unit (PCPM 038-1) add $1800.

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