2 Computers and Construction

Harry Mileaf
Alton S. Bradford

Harry Mileaf

Slow Computer Use In Construction

I've been studying the construction industry's involvement with computers since 1979, and have done so in over twenty surveys. Each survey dealt with samples that measured in the thousands. The results of each survey and their cumulative trend analysis have led me to be somewhat *conservative* in my *near-term* forecasting. The studies have repeatedly shown that there is no revolution taking place. Progress and changes have been evolutionary, and will continue to be so in the near term — during the rest of this decade. There are some prognosticators in our industry who have been much more *liberal* in their forecasting, anticipating a revolution in the industry in the not-too-distant future. I agree that revolution will come, but not in the near term. The evolutionary process will continue until after the mid 1990s, when the cumulative effects of computer use by the various influences in our industry, as well as the greater sophistication of computer systems at that time, will speed up the evolutionary pace to that of revolutionary proportions, if left unchecked. Evolution can be controlled, revolution cannot. There is the potential that by the year 2000 a major dislocation can occur in the design industry.

By the end of this decade over 90 percent of the design firms say that they will be using computers. This sounds like this alone will have a major impact on our industry; but, it probably will not, because of what the computers are being used for, and the projected growth of these uses.

The average firm that uses computers has barely scratched the surface of potential applications. The tendency is toward four or five *rote* applications, those applications that are easiest and most inexpensive to get started with, and which appear to have quickest productivity gains: word processing; spec writing; accounting; number crunching. There is little integration of these applications, almost no data base activity, and very slow growth in meaningful graphic design systems. What little is being done with sophisticated graphic design systems (about 7 percent with the small firms and about 12 percent with the large firms — 8 percent overall) is almost limited to drawings not design. This seems to make sense because drawing production is where the major labor effort is in a design office. But productivity gains in this application are scattered and many times unattainable. Even if the productivity gains were attainable, the gain would only show up for the specific projects being worked on. Even with a firm that is heavily involved with computers, only a small percentage of project work is handled by computer. The majority of work is still being done in the age-old, traditional, manual manner. This is why, even though computers have become commonplace in the design profession, they have had little impact on the profession. A staff of thirty sharing one terminal, or a staff of fifty sharing three, or a staff of two hundred and fifty sharing thirty will continue this low impact.

Why Is This?

Even the computers of today do not have the abilities to fulfill the promise of tomorrow. The computers still rely too heavily on the availability of individual applications programs to accomplish individual tasks, and both the hardware and software are still too expensive to put the entire staff at the keyboard. The great advantage of the computer comes from the computer taking over a task and completing it without human intervention. The so-called automated spec writing systems of today are not really automated, but merely mechanized versions of the old cut-and-paste method of spec writing. Too much human interaction is still required. The same is true of the so-called sophisticated drawing systems, and the other specific-task activities being done by computer. As long as the computer continues to merely mechanize the individual tasks with the help of human operators, and particularly without the tasks and data being integrated, progress will continue to be slow.

But We Cannot Be Misled By This

The improvements in the capabilities of computers over the last five years have been immense, and their drop in prices, remarkable. These improvements will continue, likely in an accelerated way to the point where their use will have a dramatic impact on how design offices function, and will likely change the way the entire industry functions. But when?

The specific applications computers of the past and present, which rely on complicated expensive programming, are already evolving into *expert* systems, systems which are not only developed by experts in your field, but which also contain data bases of expert knowledge. Such systems will require less and less complicated specific-task software written in expensive code language. The user's dialogue with the computer will be in straightforward English. Some systems of this type are already being used successfully in other industries. By the end of this decade, expert systems will be a growing force in the construction industry.

Concurrent with expert systems, artificial intelligence systems are receiving a good deal of attention in the academic world; and in the Japanese computer industry, it has become a national effort to make it a realization in the early '90s.

And There Is A New Force In The Marketplace

The new force is the client, the one who funds the new construction. Clients are changing. They are becoming more and more sophisticated. They are starting to computerize more rapidly than the construction designers, Even CADD vendors recognize this, and have diverted much of their efforts from the slow-buying construction designers to the corporate world. Business, industry, institutional, and public sector organizations recognize that CADD use in facilities management represents a good investment, Facilities management, which was heretofore a heterogeneous practice is becoming more organized; and corporations getting CADD systems are starting to lay their construction plans around facilities management data bases. Clients are gaining much more knowledge and are building confidence and relying less on design consultants. Where many once relied on advice, there is a trend toward dictating their wants, While there always were some clients who pulled the strings, there is a growing number of CADD-using corporations making the decisions.

There are shifting influences in the construction industry, and the corporation client is moving into the dominant influence position. To assure the effectiveness of their facilities management programs, these clients are now letting contracts to those design firms who can supply computerized data compatible with theirs. This means that the design firm must have the same computer and software as each of the clients who demands it, or access to the same. And the corporate clients do not go for the small PC drawing systems.

It Will Get Worse Before It Will Get Better

As more and more clients adopt their own CADD systems, the CADD decisions made by design firms will depend on who they want to have as clients. Some firms are already into two or three CADD systems to serve two or three different clients. Little needs to be said about how the proliferation of computerized facilities management in the corporate world will compound the problems of design firms, While designers have always formed temporary convenience partnerships to get contracts, clients' computerization will compound this activity, creating strange bedfellows. And, since most design firms cannot afford to have many CADD systems, there will be a trend toward designers becoming captive suppliers to certain clients, with the ball and chain being the common CADD system, This period of confusion in which the computer will dominate client/designer award decision will grow throughout this decade into the early '90s, but will abate with the new generation of computers and the fewer computer manufacturers that survive the continuing shakeout. Compatibility will be less of a problem, especially with the artificial intelligence systems and the tendency toward more standard data bases. The clients' power will continue to grow, and there will be increasing pressure for even greater productivity gains promised by the system of the 1990s.

The Scenario By the Year 2000

Computers will perform the overall functions of a design office in an integrated manner. No longer will individual manual tasks be replicated; the new generation of computers will form the core of the overall practice, and will be used on all projects, from the initial planning right through construction and the continuing space planning changes, remodeling, extensions, and maintenance.

Designers will use the systems to solve problems, gather information, test designs, and to accumulate knowledge from project to project. The designers' instructions will be accumulated in the computer and arranged into rational, organized instructions. When the design is done, the computer will generate the sets of drawings, specifications, construction documents, schedules, estimates, RFQ's, project control documents, etc., with little or no professional interaction. Ultimately, paper output might not be needed.

The Implications

are that many manual functions in a design office will be replaced. Professional functions in a design office are categorized by: (1) design; which is the creative, decision-making part of a project; and (2) production, which is responsible for producing the manifestations of the design in the form of construction drawings and documents. In the design phase, the computer will be an invaluable aid to the professional, but in the production phase, the computer will function almost alone.

Almost eight out of ten architects will be affected by this. Unlike other professions, almost 80 percent of the architectural professional effort in a design office is devoted to the production of drawing and documents and other rote activities. This figure is derived from the way a 'typical' design office functions on a project. Typically, design expense amounts to about 20 percent of the total, while the drawings account for about 50 percent of the project cost. Drawing production, then, is about 2-1/2 times the cost of design. But draftspersons get paid considerably less than designers. According to a recent New York AIA study of architectural salaries at six professional levels, the average compensation of the high levels is often more than 50 percent higher than the average lower-level architect. This means that for production drawings to cost 2-1/2 times design, about 3.8 architectural draftspersons are used for each designer. When spec writing and other document efforts are considered, the ratio of production to design becomes four to one. About four out of five architects are threatened with dislocation from their profession in fifteen years — by the year 2000.

In the engineering profession the problem is similar, but the engineers themselves will be affected less. The engineering draftspersons, who are generally not professionals, will be seriously dislocated, but the engineers, only partly so, due to the growing number crunching and analytical capabilities of the next generation of computers. The growing independent action of the computer as it accumulates repeatable and broadening analysis capabilities will continually reduce the need of certain engineers performing those functions today.

The Solid Modeling Craft Will Be Automated

In many instances, the 3-D color graphics of the next generation of computers will reduce the need for solid models, particularly as holography continues to develop. When solid models are needed, the computer driving a laser sculpturing device will create the model.

Spec writers, cost estimators, and interior designers will be affected in similar ways. The need for specification and cost specialists will be reduced to the caretaking, updating, and quality control functions. Interior designers, who function similarly to architects (and often are) will be affected similarly to the architects.

There Will Be Fewer Independent Consultants

Aside from the computer competitive pressures causing this, the convenience and productivity of computer design will cause more clients to do more of their own work in-house. Many of the larger clients who presently have their own design staffs, and use outside services for overflow work will have less overflow. And those that do not presently have their own staffs will find it more convenient to establish their own staffs.

Building product manufacturers, who presently rely on the independent designers to have their products specified will adopt computer practices to compete with independent architects and engineers. In a few engineering trades, this has always been done; the next generation of computers will provide new avenues for more of these efforts.

There Will Be Greater Specialization

Because contract awards will in part be based on computer compatibility and computer knowledge buildup, there will be a greater tendency for specializing in certain types of industries, private vs. public, and agency vs. agency, in addition to types of construction.

Preparing For The Dislocation

There are the optimistic in the design industry that have predicted that those professionals, particularly the architectural draftspersons, who are displaced from their non-design jobs, will merely become designers. Doug Stoker and Nick Weingarten of SOM pointed out the financial fallaciousness of that logic with some cold hard logic in the December 1983 issue of *Architectural Record.* The client simply will not pay for overstaffed design, and the firm will not pay what it cannot bill. The only way for production professionals to be absorbed in design is for the number of design projects to grow. It is unlikely that the construction industry can grow large enough to absorb all of the dislocated — the industry would have to grow 400 percent in about fifteen years. I cannot recall when that has last happened.

Other experts in the field feel the solution will come by itself. They expect other new jobs (now very specific) to be created by computers. While this has been true in some other computer applications where new industries resulted — particularly the computer industry — the same does not necessarily have to happen in construction design. The construction industry can be better equated to the automobile industry as it was impacted by foreign robotics.

This is an issue too serious to be left to chance,

Take It As An Opportunity

Reexamine the role of the construction design profession, There is already a question about whether many firms are really in the design or drawing business. The computer is a two-way street. While on one hand it will displace people, it can also open new avenues for the enterprising. One such avenue is to play a larger role in the growing facilities management business. Bill Mitchell of UCLA has been preaching this for two years. There are probably other potential areas for growth.

This should be made a priority study program by the major institutions in the construction market: AIA; ASCE; ACEC; ASHRAE; CSI; NSPE; et. al., and should include academia. It is entirely conceivable that government grants could be had for this effort. There is plenty of time to prepare.

Today's missed opportunities are tomorrow's problems.

Harry Mileaf is Director of Technology and Product Development, Sweet's Division, at McGraw-Hill Information Systems Company. He is also Chairman of the Coordinating Council for Computers in Construction.

Alton S. Bradford

Our mission is to plan, design and construct shore facilities for the Navy. This amounts to approximately $2 billion in construction a year. We're worldwide with six Engineering Field Division offices to accomplish our design and construction. We also have nine Public Works Centers that handle our operation and maintenance projects. (See Figure 1)

The basic building process is a time-phased, fragmented, ad hoc industry. Separate organizations plan, design, construct, own, etc. In the product acquisition process, we bring people together to do the design on a one-time basis and then competitively bid the construction (with a separate group). One would never do that with an automobile or aircraft. We design in-house, but about 90 percent is done on contract with architecture and engineering firms.

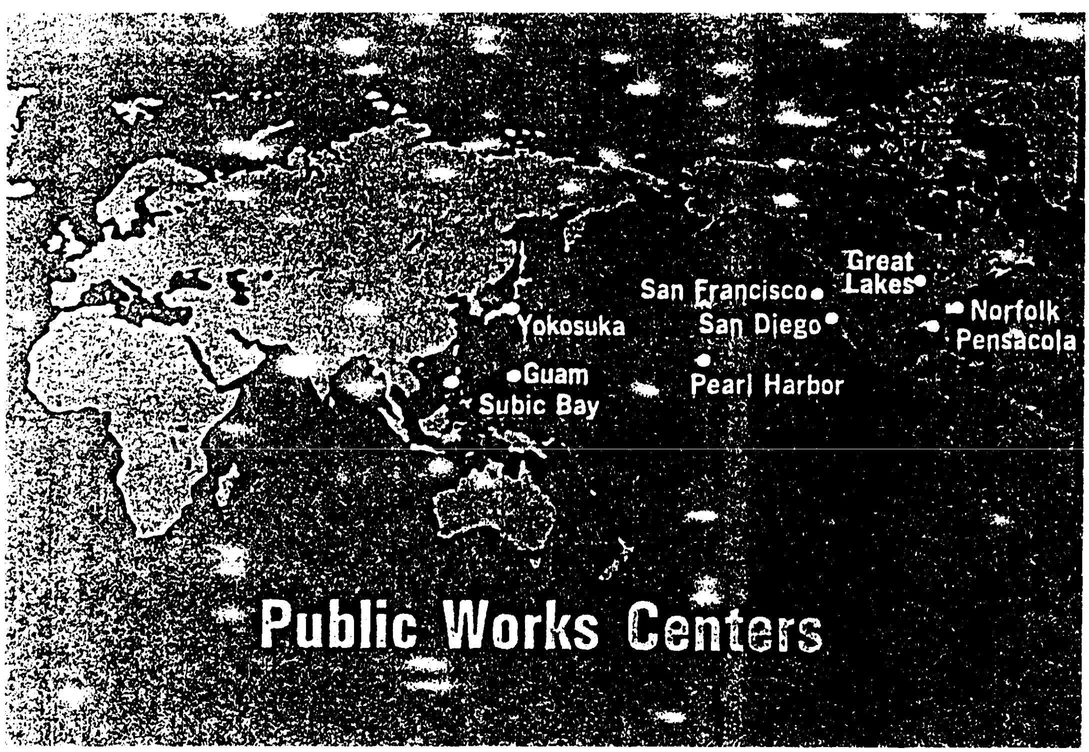
The building process presents many problems and opportunities when we examine it for computer applications. (See Figure 2) In-house, we are doing computer-aided design (design calculation) using time-sharing and personal computers. This includes structural analysis, energy analysis of buildings and such. The work is being done by the engineer at his desk, or the nearby computer computer terminal.

We also do guide specifications, as Harry Mileaf mentioned, using a word-processing system. Guide specifications are documents used to produce a contract (project) specification. The guide specifications and the specific project specifications are both now being done on a word-processing system.

We utilize computers to do project cost estimates. Material quantities are the input and the construction estimate, the output. The factors for labor and material costs, location, economic conditions, projected date of bid, etc., are programmed in. The estimate's and actual bids are stored in the system for developing and checking future budget estimates at the programming stage.

Our Graphics Design System, a major advancement in using computers, is well underway. We're installing a computer-based system that uses the language of the architect, engineer and building process people, i.e., three-dimen-

Figure 1



sional (3-D) models. Having always used renderings and models, architects and engineers can now construct and view a 3-D model data base. This model facilitates working with other individuals to define requirements and expectations, We are also able to do two and three-dimensional drawings directly from the data base. Automated production of drawings, specifications, and cost estimates, from the data base, is in the future.

The four basic phases of the building process are quite distinct: (1) plan and budget (market); (2) design; (3) construct; and (4) own, operate, and maintain the building throughout its life. (See Figure 3)

We targeted our computer graphics to that critical decision period (three months) when the parameters and decisions for the building/facility are set. We then use the computer as changes in the design occur. We'd like very much to eventually, say within the next ten to fifteen years, get to the point where we can change the design model and automatically produce the drawings, specifications, and cost estimates.

It's taken us about two years to get computer graphics into our organization. We have installations in our six Engineering Field Divisions and four of our nine Public Works Centers. We are training as many people as possible in the new technology.

The hardware consists of a desk, keyboard, digital pen, and menu of instructions which allows the architect/engineer to sit and do his design work or interact with others involved in the design, (See Figure 4) Individuals, using a computer model, can develop the expectations for a particular project right on the screen. It is simply a work station for the architect or engineer.

We are using some 2-D graphics, but that's only normally communicable between engineers and architects. (See Figure 5) The emerging graphics technology will allow creation of models (three-dimensional) where you don't need a degree in architecture or engineering to understand the project graphics. The technology is increasing as rapidly as the desire to depict objects in the three-dimensional mode. (See Figure 6)

An actual 2-D example is where we take a

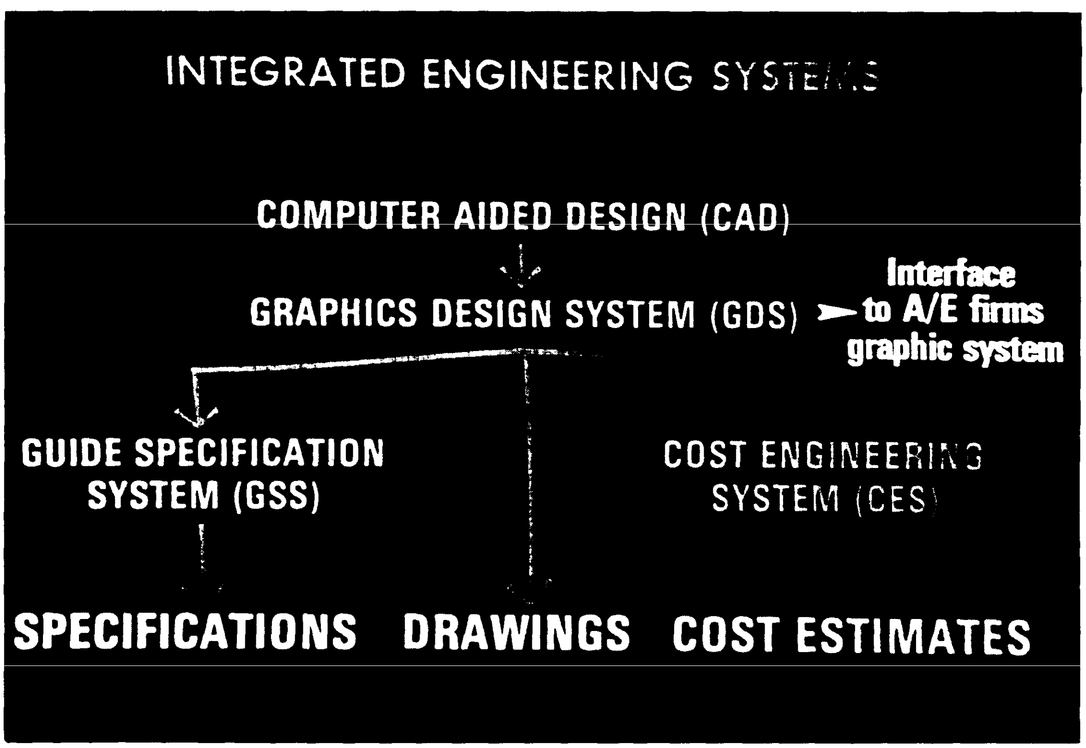


Figure 2

standard room layout and reproduce it until we have a string of rooms. (See Figure 7) We can then mirror image the string about a corridor centerline to produce a floor plan. We add dimensions, notes, etc., and print the drawing. There's no drafting involved. This is an actual drawing that went out to bid. (See Figure 8)

Figure 9 shows a building floor lighting plan. Unfortunately, the black and white print cannot show you the way we use colors. Color is a communication medium, not only between individuals, but between the engineer and the computer system. The Bureau of Standards is working on the IGES (Initial Graphics Exchange System), to enable graphic data communication between different computer systems.

In the future, we'll get away from the big desk units. We're going to see much smaller, flat screen, desk top, 3-D units with more capacity and capability. (See Figure 10)

Maybe a plasma-type screen or something new. We expect, within five years, they will be as common as large desk calculators or personal computers are today. In San Francisco last week, we saw computer graphics on PCs. Technology is increasing rapidly, and prices are in the acceptable range of 15 to 25 thousand dollars. This will be the salvation of many small A/E firms.

He Here are some examples of 3-D graphics. Soon (five to ten years) we will be able to represent an object in the machine as a solid. I have a few slides on this subject. This is a 3-D wire frame model, with some shading. (See Figure 11)

Here is a building with color and shaded surfaces and the lights turned on. (See Figure 12)

And here it is with the lights turned off. We could even pass the sun over the building and get the sun's shading effect. (See Figure 13)

Graphics has always been a communications medium. Now the architect/engineer can communicate with somebody who wants a project, and develop a very clear expectation for the facility or building. One brings a great deal more to, and gets a great deal more out of, a 3-D picture/mode compared to a 2-D floor plan or a list of numbers, letters, or a work description.

We expect widespread use of graphics during the late '80s by the A/E firms (Figure 14).

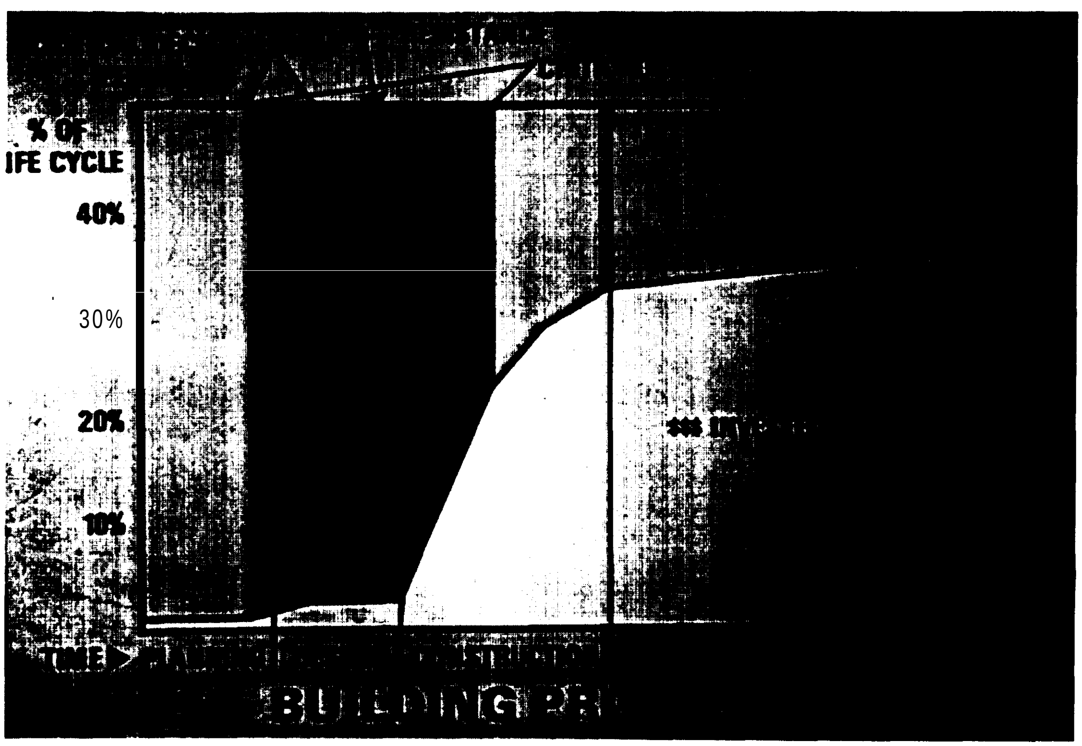


Figure 3

We're training our personnel and getting involved in the contractual aspects. Graphics data exchange capability between systems will be available. By the late '80s, most of our design documents will require digital graphics data bases in addition to the normal plan, specs, and cost estimates. We think the major integration in the building process will be in the design phase. It is the easiest to get a handle on and utilize data bases for the specifications, drawings and cost estimates. Later (early '90s) we need to get the whole process together. The external data base is an area that we should f0-cus on. This includes the Sweet's catalog type information, generic building products information, codes, regulations, etc. A project integrated data base which is a model from which one would be able to directly produce a set of design documents (plans, specifications, schedule, and cost estimate) appears feasible by the year 2000.

The chart on Figure 15 gives another representation of the building process. We use multiple firms in the process. It depicts the ad hoc fragmented, and time/work phased building process. Therefore, data base development and standardization will be very difficult. Here one sees the Sweet's catalog type external product data base, the main data base within the organization, a project generic data base, and the project specific data base. We're learning as we start to do some of this with our in-house design work to get involved in this process.

Impacts

These will be my personal views:

The Nature and Form of Buildings

Use of computer graphics will yield more appropriate solutions. The building is a solution to a problem of need. Solutions tend to be unique. We'll be able to give better solutions. We'll be able to integrate building systems for energy and economy. It's not amazing that most buildings are stand-alone systems stuck together in a big box. There will be some standardization. The manufactured building industry is curious about this item. When we design buildings by assembling computer stored, pre-designed building components, standardization will be re-

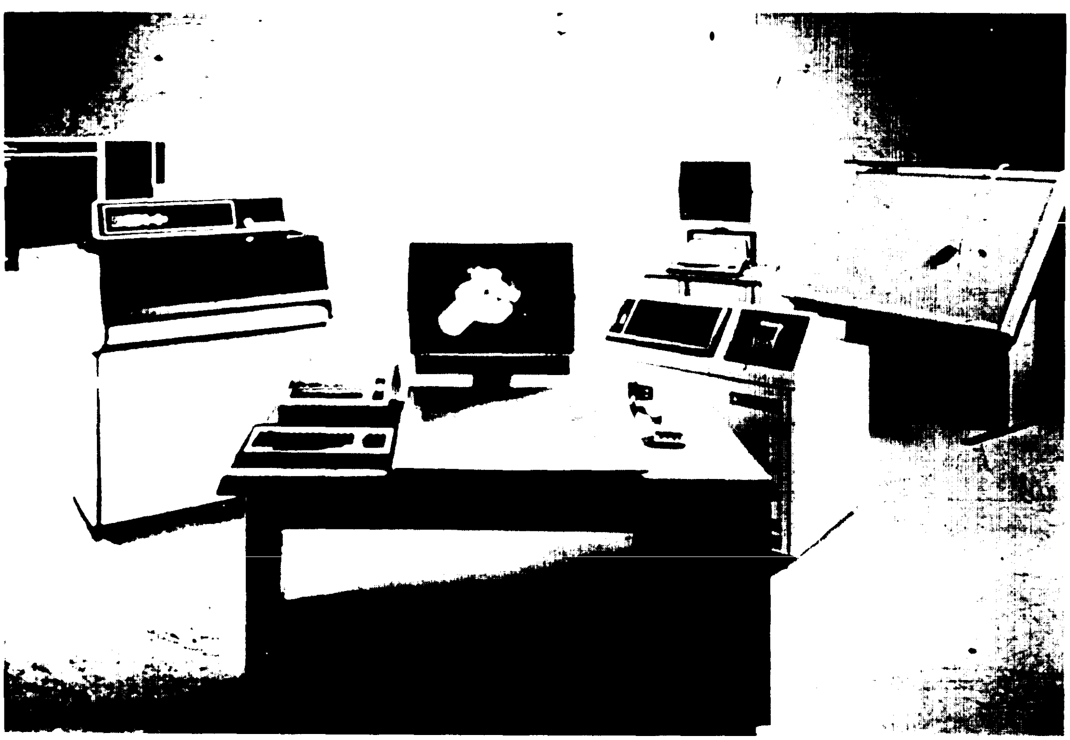


Figure 4

quired. This will allow faster and better designs. It's going to be a slow evolutionary change.

Quality and Safety of Buildings

These factors are driven by codes and regulations. Computers will be used to check project models against the codes, regulations, standards, etc. There will be an increase in attention to functionality (safety and quality) which will yield better buildings. On the whole, however, I expect no major changes resulting from the introduction of computers.

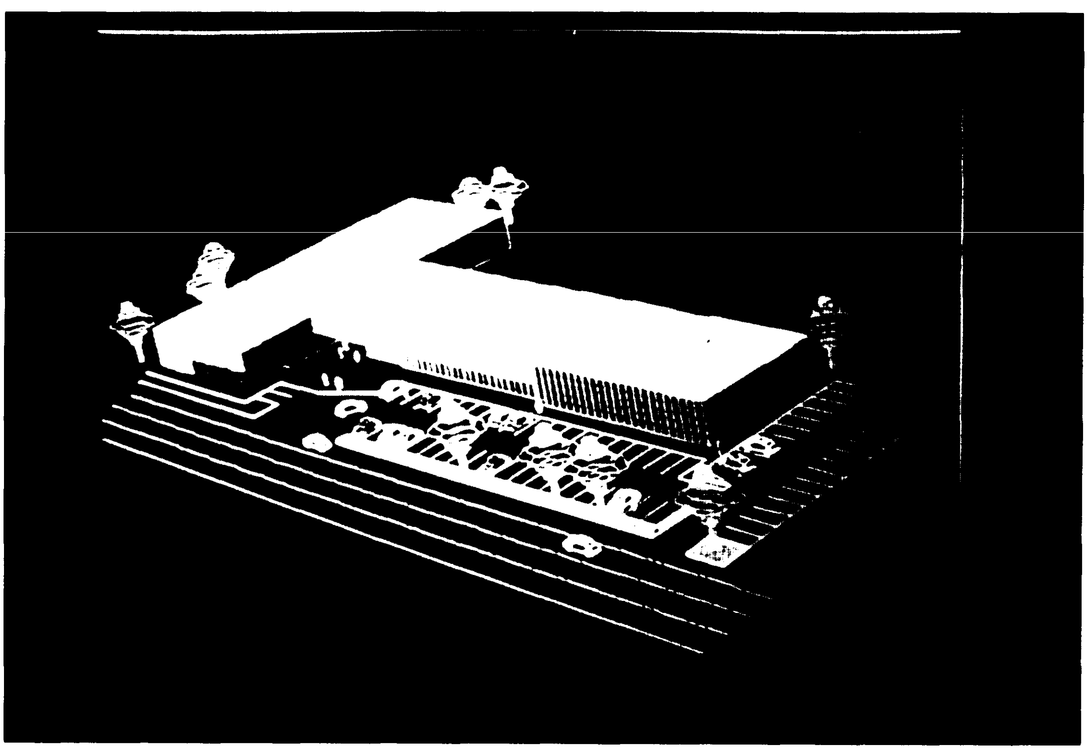
Cost and Affordability of Building

Computers will shorten the building acquisition period. This will reduce the cost and the exposure of the project to change (risk) and, therefore, increase the affordability. We'll be able to better meet expectations. Therefore, the cost and schedules and things of those natures will be firmer, easier to handle, resulting in a noticeable, but moderate change in this area due to computer technology.

Industry Productivity

Computers will decrease the number of changes resulting from misunderstood expectations. Also, with computer technology, we will be able to translate those unforeseen changes quickly into project bid document revisions. This will decrease the time and effort (calendar time and manual effort) required to produce project bid documents, and result in a major increase in productivity. There will also be a decrease in the life-cycle resources. We're going to be putting better buildings together, faster, meeting expectations, and with less changes required during design and construction. The contract documents (drawings) are going to be clearer. They're going to be automated off the system, just like letters coming off a word processor. Drawings will be corrected before they are produced. It's the old bit, that if you produce a good product at the end of the assembly line, you have less returns. We will be studying and analyzing more options, with the objective of reducing, in addition to the initial cost, the life-cycle energy, operation and maintenance, and manning costs.

Figure 5



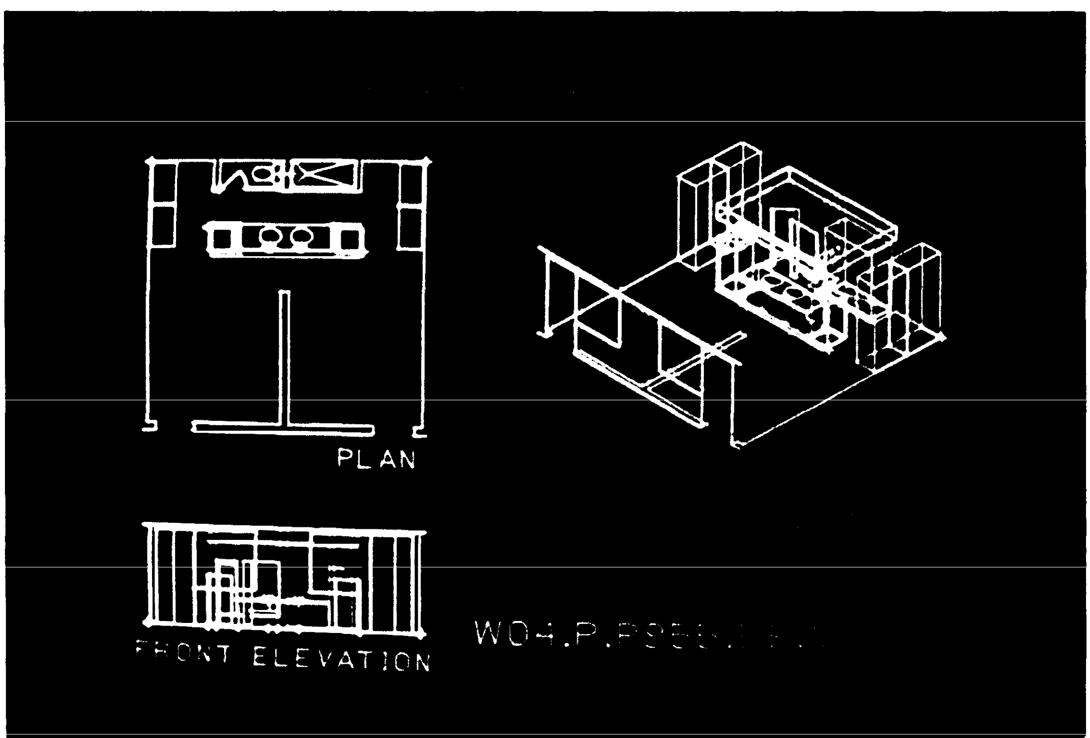
On Changes in Job Skills, Skill Levels, Occupations

This is the big one. There's going to be a slight net increase in jobs. There is great diversity in types of work in the building process. There's going to be a decrease in the jobs associated with engineering calculations and the direct production of contract plans and specifications. Some jobs definitely will change. One doesn't need an architect to set hours and draw a perspective. It can be done with a computer in minutes. I don't know how familiar you are with computer graphics technology, but one can actually walk through a three-dimensional model of a project (structure) after the data base is constructed on the computer. The data base is constructed using simple drafting techniques; by putting lines, circles and squares, or parts and pieces of building systems together. It's rather quick and easy.

A tremendous amount of information can be used beyond the design phase for building operations including management of rental space, and furnishings. To produce the data during the design is not difficult. It's the result of the interior design, structural design, etc. But to operate and maintain a building and you need to know where every person is, their telephone number, what pieces of furniture they're assigned, their floor covering, date of occupancy, etc. When you start managing change, the data developed during the design, planning, and programming phases become very useful. There will be new jobs and skills required in developing and using this type of data. However, there is a major problem in standardization of communications across organizational lines. None of the ad-hoc groups in the building process needs all of the information developed during project acquisition, and there's no single overseer of the process. This creates a big problem area and contributes to the inertia of the building processes. Change will be slow.

The Role of Engineers

Technology will enhance and improve the designer's and consultant's capability to create, view, analyze (technically, functionally, and financially) and change the project model prior to documentation or construction of the project.



This project information will be retained and updated in machine usable form for latent uses during the construction, operation and maintenance, and use phases of the project life cycle. As a result, the changes in the engineering office environment will be:

(1) A decrease, if not complete elimination, of manual computations. Technical analysis and design will be by computer from building/project geometry data using external code, standards, and product data bases.

(2) An increase in the need for technical expertise that can use computers at a high level of building systems selection and integration. These experienced technical personnel will need to bring good interpersonal skills to the future team approach to effective problem solving.

(3) A sharp decrease in the amount of labor intensive drafting, coordination, and checking as a result of automated drafting systems. Construction documents will be a relatively fast, automated process. Present technicians and draftspersons will be utilized to create and maintain the computer graphics system and data base.

(4) A change in the role of the engineer from 'a designer of buildings' to 'a designer of computer-based systems and procedures' to be used by experienced designers and skilled technical people (paratechnical) to design buildings.

(5) An increase in the use of computer resident, mapping and building process data bases.

In the future the professional engineering firms will be called on:

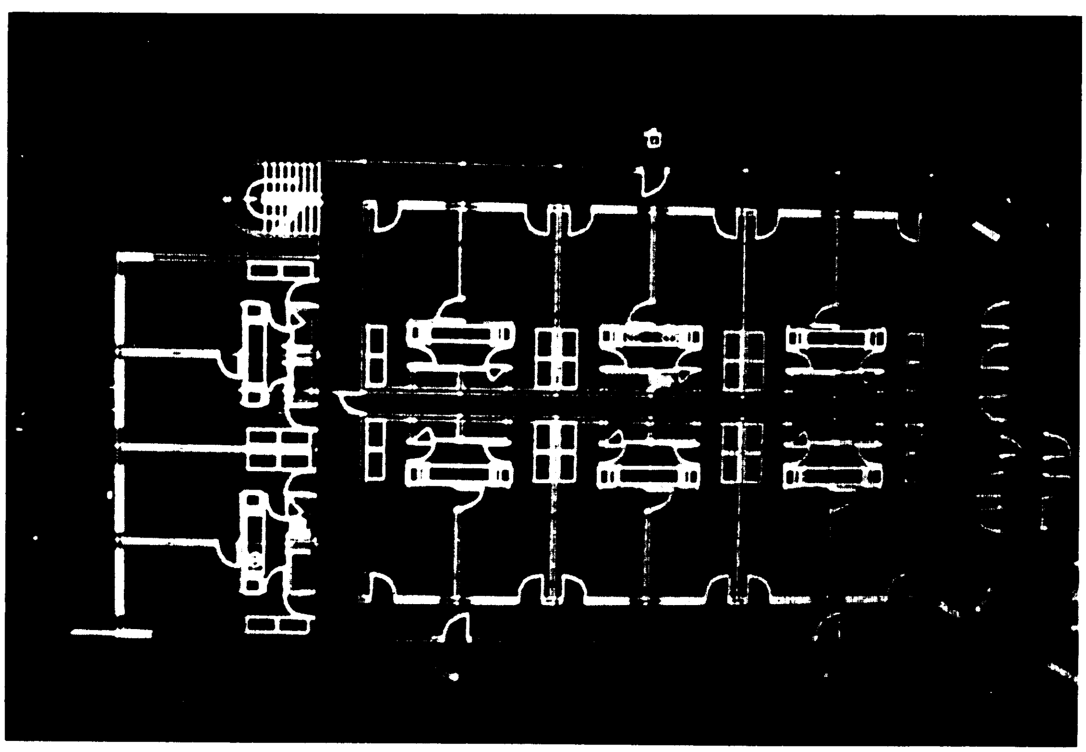
(1) To establish, maintain, and operate computer-resident, mapping and building data bases for the public and private sectors, and operate these throughout the life cycle of the buildings and facilities.

(2) To develop a clear, accurate, complete and timely project definition package (marketing package/budgeting package).

(3) To provide the service of developing the project definition package into a set of accurate and complete construction documents in a sub stantially shorter time than the present.

(4) To provide a management service, using a project data base, throughout the life cycle or

Figure 7



major portion of the life cycle of the project. This could be an independent service or as part of a joint contract arrangement. This would be a design/construct, construction management (CM) effort with some test-operate-maintain role.

(5) To provide a service to the professional standards organizations, large public and private building owners and other firms in the areas of programming, procedures, standards, program certification, project data conversion, etc.

Education

A large percentage of the individuals coming out of school into the building process, architects, engineers, etc., have a good education in their discipline. The problem is we also need architects and engineers to work together in a team to put a building together. We spend a great amount of time and effort training them to work together. They lack intra- and interpersonal skills. When computers are used to accomplish some of the work, they are going to need the skills to shift into a team problem solving environment. Technical education has got to teach team and social skills. The best course I ever had was in construction planning and programming. Working in teams, we developed projects from conception through to final design detail. The building process will need technical people skilled in working as a team player.

Organization, Number and Size of Enterprises

Small A&E firms are going to survive. Service firms are emerging to do computer-aided design and drafting and to translate documents from one computer system to another. The use of computers in the building process is presently vendor-stimulated and user driven. Data base development, a necessity in the future use of computers, is hampered by lack of standardization, and the very nature of the process. However, the process is changing. Education needs to concentrate on the changes facing peopie, organizations, standards and traditions in the application of computers in the building process. Teaching technology is not the problem.

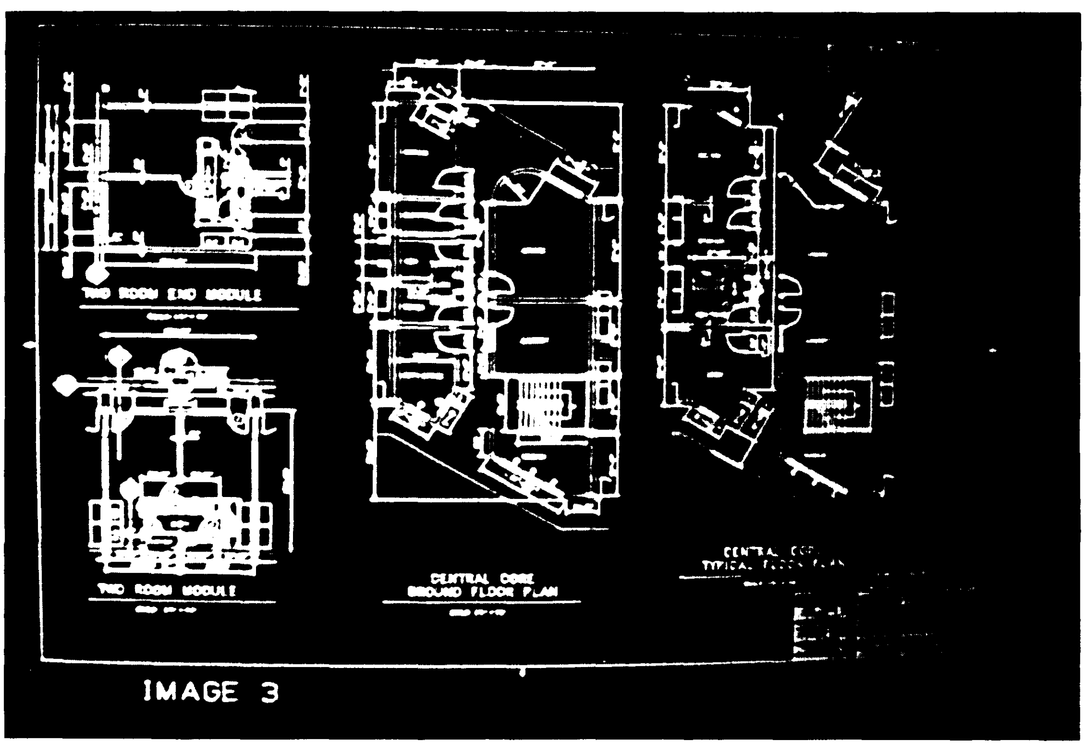


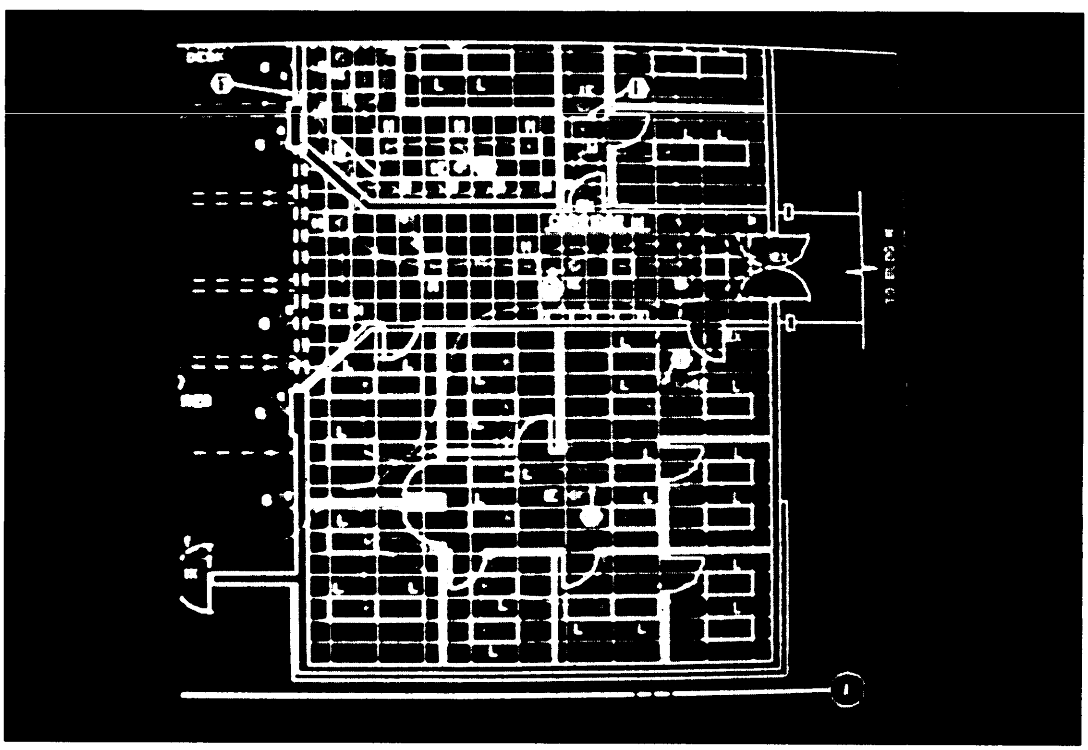
Figure 8

Establishment of structured informational data bases in the building process is one key to the growth of computer utilization. The National Research Council (Building Research Board) is looking at this and other questions on new technological impacts to the building process. Based on some of the study work, there are major changes occurring in the number, size and types of enterprises in the building process.

Conclusion

The federal building process can be described as a sequential, somewhat overlapping, set of easily definable functions. They are: planning, programming, and budgeting; design and engineering; procurement and construction; operation and maintenance; and use. Or more simply, planning, design, construction, and use. Although these basic functions will probably remain the same, the trend in the federal sector is to contract out combinations of these functions. Combining the design and construction functions into a single 'turnkey' or 'two-step' type contract, contracting for the building using a performance specification, and at the extreme end of this construction, staff, maintenance and operation and the user simply pays for the service. Because of major social, environmental, safety, and of course, political concerns, there will also be an increase in the complexity, number and types of predesign (planning) studies required to identify the benefits and disbenefits of the proposed construction. The list of studies will, in addition to the present cost, scope, environmental, energy and schedule studies, be expanded to examine the functional, visual, esthetic, economic, social, etc., impacts on the public and organization environment. There will be an increased need for easily understandable project definition and fast, accurate schedules and cost estimates to confirm and track project expectations. There will be an increasing emphasis and therefore need to deal with change throughout the building planning and design functions in order to hold major financial commitments to the latest possible point to assure the lowest possible risk. This emphasis on deal-

Figure 9



ing with change will require early, more accurate, rapid communications of expectations of the building configuration, function, and cost. Likewise, there will be a need to expend less time and personnel resources on those buildings that don't undergo drastic changes, or are of a less risky nature. This will result in an increase in standardization of building designs (or modular designs), more reuse of acceptable designs, and a major emphasis on having the accurate design data available in an analytically usable form. There will be an emphasis on having ready access to and using the latest, most cost-effective materials, equipment, procedures, and building systems, in lieu of waiting for these to show up in federal standards, design guides or specifications. In summary, there will be a need to proceed from idea to construction start in the shortest period of time with the least risk of financial loss.

Computer Technology

Computer technology, presently available to the building process, is changing more rapidly than our ability to use it productively. Predictable trends over the next 10 to 20 years are that the amount of storage available for computer programs and data will be unlimited or very cost effective. The cost of better and more functional computer hardware will continue to drop at a steady rate while software capability will increase at an exponential rate. The cost of specialized software together with the availability of trained personnel will continue to be the major factors in system utilization. The computer terminal's physical size will continue to diminish while storage capacity, speed and ease of use will continue to increase. Probably the most significant advancements in the next two decades will be the further development of computer graphics modeling, hardware and software, for use in both the visual and analytical interface mode. New software technologies that will evolve include: a neutral, machine-t&machine language; expert programs for building system design; automated drawings, specifications, schedule and cost estimates directly from computer graphic model; micro and macro project products and building systems data

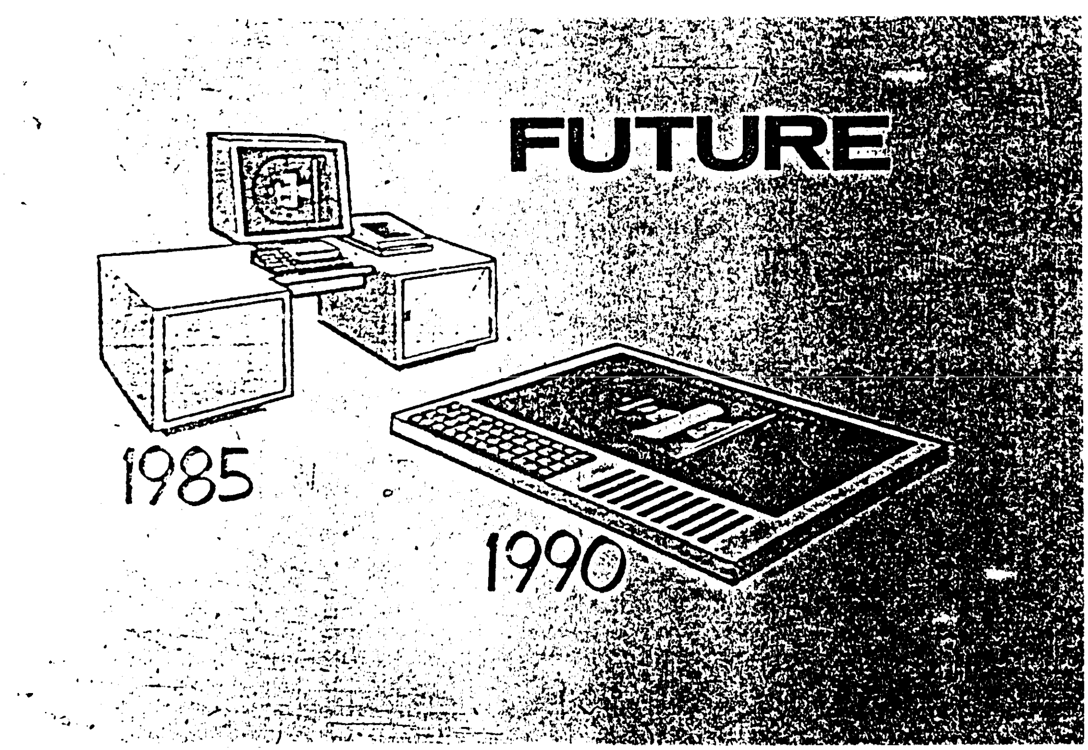


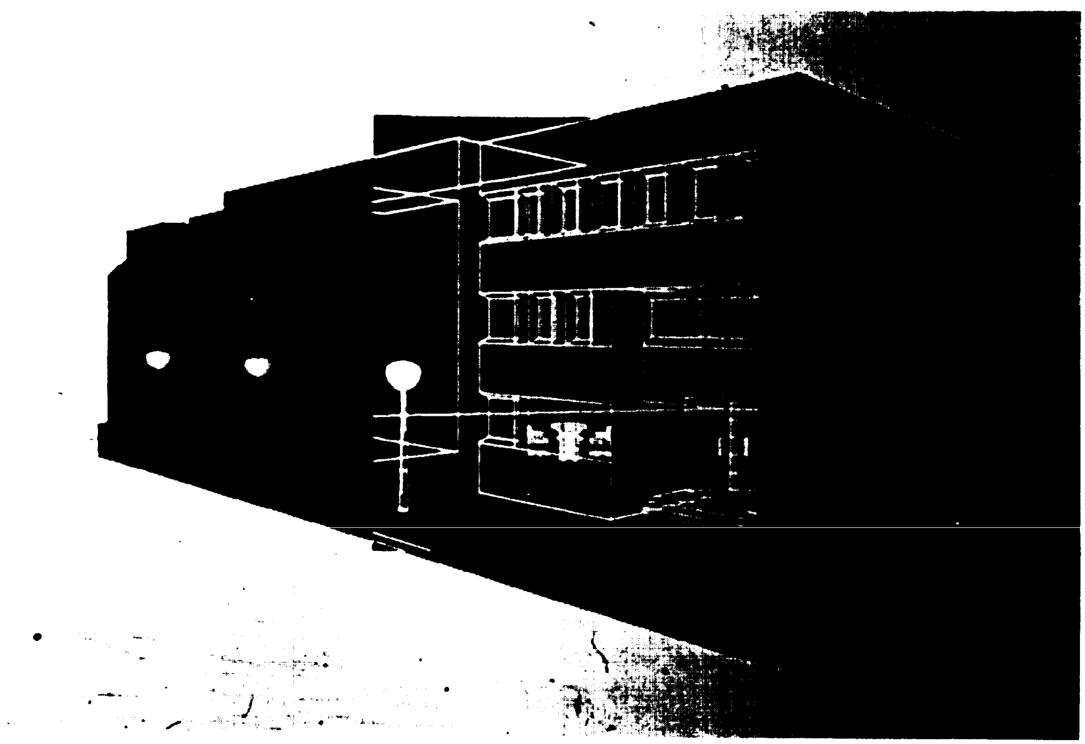
Figure 10

bases; and computer graphics solid modeling. Hardware advancements will include: flat screens; laser readers, printers and storage devices; highly-specialized, plug-in ROM chips and even holographic screens or units.

In summary, the changes in the building process and the concurrent changes in the product and services provided by the engineering profession, will be as a result of needs of the building owner/user. Of course, there will be some iterative interplay between the capability of the professional firms and the perceived needs of, or benefits to, the owner/operator. The major advance in the use of computer technology in the building process will be the engineer's ability to communicate real expectations with the owner, and to communicate with the computer, both using the language of graphics. This use of the technology will enable the professional to provide the owner/user with the much needed project information on which to base critical planning and financial decisions while also being able to react to change without major project delays.

Alton S. Bradford is Assistant Commander for Engineering and Design, at the Naval Facilities Engineering Command of the United States Department of the Navy

Figure 11



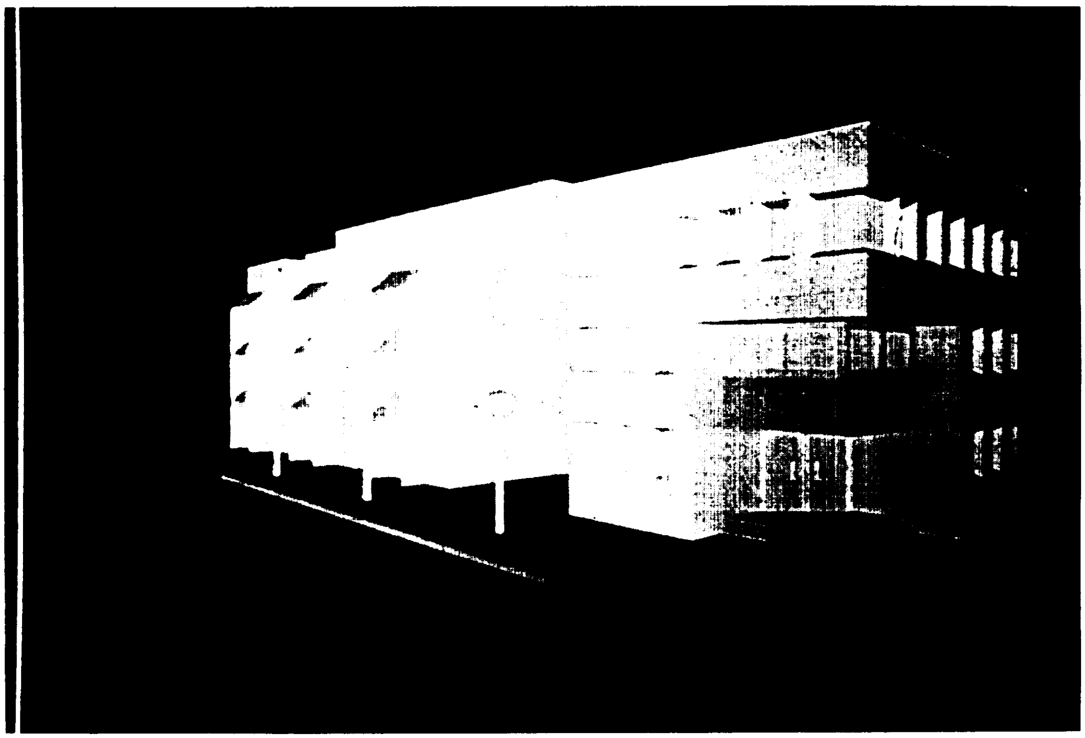


Figure 12

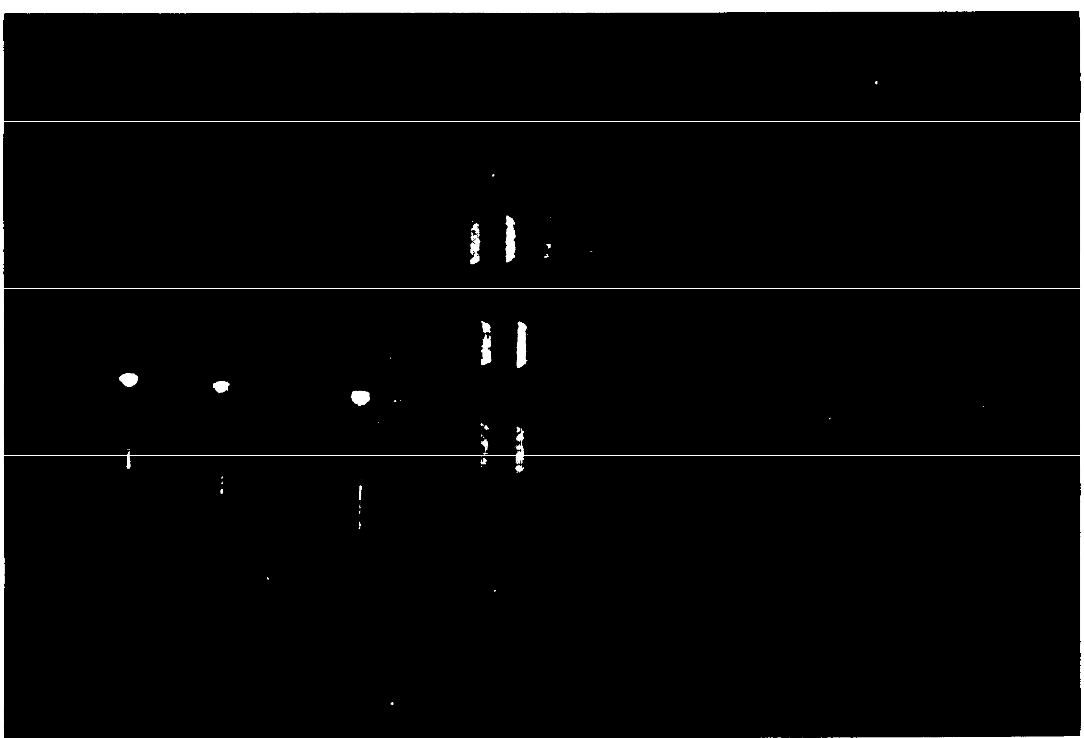


Figure 14

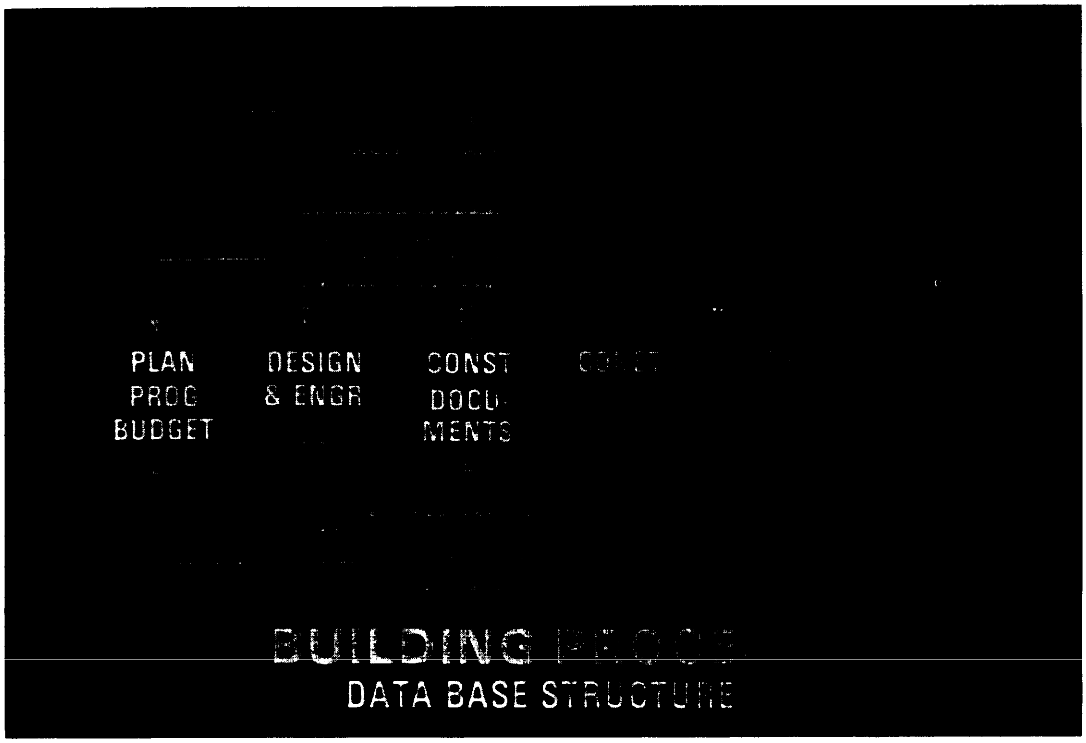


Figure 15