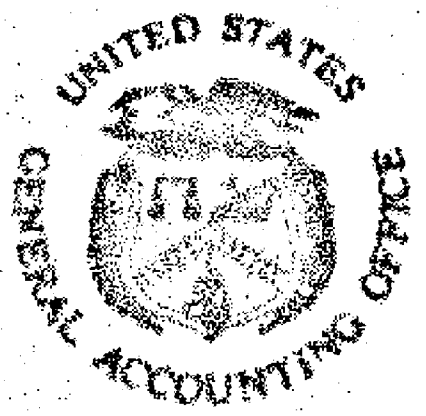
STUDY BY THE STAFF OF THE U.S.

General Accounting Office

COMPLETED

ORIGINAL

Computer-Aided Building Design



186

LCD-78-309
JULY 11, 1978

FOREWORD

Developments in computer technology in the past decade have opened a broad potential for qualitative, quantitative, and cost-effective changes in how nations produce their goods and services. These changes are frequently most apparent and dramatic in manufacturing industries, where computers are increasingly being employed in integrated systems for designing and manufacturing products.

For example, in the aerospace and automotive industries, systems are evolving in which the computer data bases generated by designers to assist in design of a product are constructed so that they can be used directly for planning, controlling, and executing the manufacturing process for that product.

Because the Federal Government is such a large purchaser of manufactured products, the General Accounting Office has completed a number of studies on the application of computers in the manufacturing environment.

In a broad context, the processes for creating the built environment in which we live are not unlike the processes for creating the products we use. The buildings and other structures and components are first "designed," just as are aircraft, ships, automobiles, or computers. The designers' creations must then be used to engineer, manufacture, or build to the design specifications. And, as is the case with manufacturing, the engineers and builders frequently have to use the same data and the same or similar calculations in building as the designers (architects) used in designing.

The Federal Government is the largest user of architect-engineer services in the United States. Thus, in addition to being interested in how the built environment is created for the Nation as a whole, the Federal Government has a direct interest in how its own buildings and other structures are created.

The General Accounting Office studied the use of computers in the design of buildings in both the United States and abroad. The results of that study will be useful in our future studies of specific construction projects contracted for by the Federal Government.

In the process of performing the study, we obtained a rather comprehensive overview of the status of computer applications in the design and construction of buildings and other structures.

Therefore, the Office prepared this document in the hope that the information gathered and the observations made may be useful to others both inside and outside of Government in policymaking, evaluating, and planning for the use of computers in their architectural and engineering work and construction procurement and management activities.

This document was prepared by the staff of the Logistics and Communications Division. Questions regarding the contents should be directed to Joseph Normile, Associate Director.

Fred J. Shafer
Director
Logistics and Communications
Division

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ABBREVIATIONS

(used in body of report)

APEC	Automated Procedures for Engineering Consultants
CABD	computer-aided building design
CAEADS	Computer-Aided Engineering and Architectural Design
CASDAC	Computer-Aided Ship Design and Construction
CEPA	Society for Computer Application in Engineering, Planning and Architecture

COMRADE	computer-aided design environment
IPAD	Integrated Programs for Aerospace Vehicle Design
NASA	National Aeronautics and Space Administration
NIBS	National Institute of Building Sciences (used in appendix II)
CEDAR	Computer-aided Environmental Design Analysis and Realisation System
EUROCOPI	European Computer Program Institute
GENESYS	General Engineering System
GFK	Gesellschaft fur Kernsforschung
ICE	British Institute of Civil Engineers
MBB	Messerschmitt-Bolkow-Blonm
NCC	National Computing Centre

GLOSSARY

Analysis	A process that is based on scientific knowledge and uses mathematical processes which permit the precise prediction of the behavior of objects of specific dimensions and material when subjected to known requirements of loads, capacities, behavior, and so forth. Results of analysis are susceptible to rigorous mathematical proof and are, therefore, unique, repeatable, and reversible for each set of specific conditions.
Applied research	The studious inquiry or examination aimed at developing methods or processes which will permit or test the transfer of pure research results of new or revised concepts, theories, or laws into practical application.

Computer-aided building design (CA8D)	All methods and procedures to assist in planning, performing, and directing the design process through the application of computer technology, under the direction of an architect-engineer.
Computer graphics	The art of making visual artistic representations, such as perrpect-ives and drawings using a computer, in accordance with mathematical rules.
Design	The determination, by a design logic, of the general and specific shapes and all the specific dimen-sions required to construct a facility so that it will perform the function for which it was created and will safely withstand the influences of man and nature which will act upon it through-out its useful life. Design also includes such considerations as selection of building materials and specification of construction methods.
Design process	Used in its broadest sense, from building programing and architec-tural conception through prepar-ation of working drawings and construction specifications.
Designer	An architect or engineer of any discipline (mechanical, civil, electrical, or other), who draws, lays out, or otherwize creates or participates in the creation of a building design.
Documentation	A written record describing the rationale or the logic employed in developing a particular com-puter program. It usually in-cludes, but is not limited to: User's manual, programer's manual, system manual (when applicable).

	An up-to-date flowchart. Explanatory text. Listing of source program. Input-output and file formats. Original coding sheets--amended to correct any errors. Source program recorded on some storage device mechanism, such as punched cards or magnetic tape.
Graphics display	A drawn image of a temporary nature created by a computer, generally on some type of display screen.
Graphics workstation	A collection of computer terminal equipment at one location for use by a single designer, typically comprising some or all of the following: graphics display screen(s), keyboard, digitizer, graphics hard-copy unit, and teletype.
Heuristic	A design logic, method or procedure, the complex decisionmaking process through which a designer, in designing a facility, proceeds along empirical lines to find solutions or answers to design problems or to meet the requirements of the client, man, or nature. The method relies on hypothesis, experimentation, and observation using scientific principles in combination with logic and practical experience. Although the design logic may be, particularly in the case of the engineer, in the form of mathematical expressions and decision tables, it is heuristic in that it is not susceptible to rigorous mathematical proof. Therefore, although the results may be entirely satisfactory and acceptable, the design logic used is not the only one permissible.
Integrated CADD system	A computer software system comprising many applications from various disciplines drawing off

	and feeding a common data base and built on a common software infrastructure.
Integration	To bring parts together and make whole, unified, or complete. There are many types of integration, but the two this report is primarily concerned with are integration within a single discipline and integration cutting across all building design disciplines.
Iterative design process	Repeating successively modified analysis and design functions (normally until the design falls within the desired specifications or criteria).
Portability	That property of software which permits software to be used with various computer models especially of different manufacturers, without requiring extensive modifications to the software.
Pure research	The studious inquiry or examination aimed at the discovery of new theories, the interpretation of facts, and the revision of accepted theories as laws in the light of new facts in order to add to the body of truth, information, and principles known to mankind without intent of specific application.
Specifications	Explicit written descriptions of a construction project, or any part thereof, to which the finished product is intended to conform.
Technological innovation	"A unique chronological process involving science, technology, economics, entrepreneurship, and management is the medium that translates scientific knowledge into the physical realities that are changing

society. This process of technological innovation is the heart of the basic understanding which the competent manager, the effective technologist, the sound government official, and the educated member of society should have in the world of tomorrow."
- James Bright

CHAPTER 1

INTRODUCTION

REASON FOR INTEREST IN COMPUTER-AIDED BUILDING DESIGN

"While our Nation today has more capability in science and technology than ever before, we are using it less--less as a fraction of its full, beneficial possibilities. Science and technology, fully employed, could improve the value of our resources, natural and human." 1/

In recent years, there has been increasing pressure to save both time and money in the development of new public facilities. At the same time there have been pressures to conserve energy, to consider life-cycle costs when acquiring new facilities, and to improve the ability of public buildings to fulfill public needs and national objectives. Design professionals state that all of these concerns tend to increase the time they need to design a new building and increase the total cost of design and construction.

The energy crisis of 1973 and the realization that we must conserve energy are sharply impacting building design. The clear design objective is to reduce the amounts of energy that will be consumed by the structure being designed over its entire operating life. It is our perception, and that of experts in the field, that the building industry in the United States can design and construct energy-efficient buildings. Such buildings will consume, in operation, substantially less energy without any basic impact on the building users and will also conserve energy through conservation of building materials, thereby saving the energy consumed in the production of building materials.

The importance of the built environment to mankind is enormous in:

--terms of resources consumed in providing and employing the materials of construction,

---

1/From an address by Dr. Simon Ramo, vice chairman of TRW, Inc., and then chairman of President Ford's Advisory Panel on Contributions of Technology to Economic Strength, delivered at the National Bureau of Standards, Washington, D.C., on Apr. 2, 1976, in celebration of the Bureau's 75th anniversary.

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--terms of resources consumed by operation and maintenance of the structures during their life-cycles, and

--the implications of how well the built environment serves its intended functions. 2/

The ways in which we acquire a building or facility are changing and will probably continue to change. These changes affect all stages: justifications, plans, designs, management of construction, and, finally, management of a structure once it is in use. Today, Federal construction costs are skyrocketing, the quality of Federal building design is criticized, and there is a national concern about energy consumption of buildings.

These factors exert powerful influences that point to the need for studying changes in procurement and construction practices; in design methods, emphasis, and conception; and in occupancy and use. The full knowledge and experience of all segments of our society need to be brought to bear on developing insights and laying out approaches that will help our country and the world to acquire better built environments--environments that people not only can afford but which will also improve the quality of their lives. 3/

Affordability, now and in the future, is closely related to productivity. Improving the quality of life by enlarging and refining the built environment depends largely on affordability and on the quality of plans and designs. Thus, we should increasingly strive to enhance design and achieve a related productivity. 4/

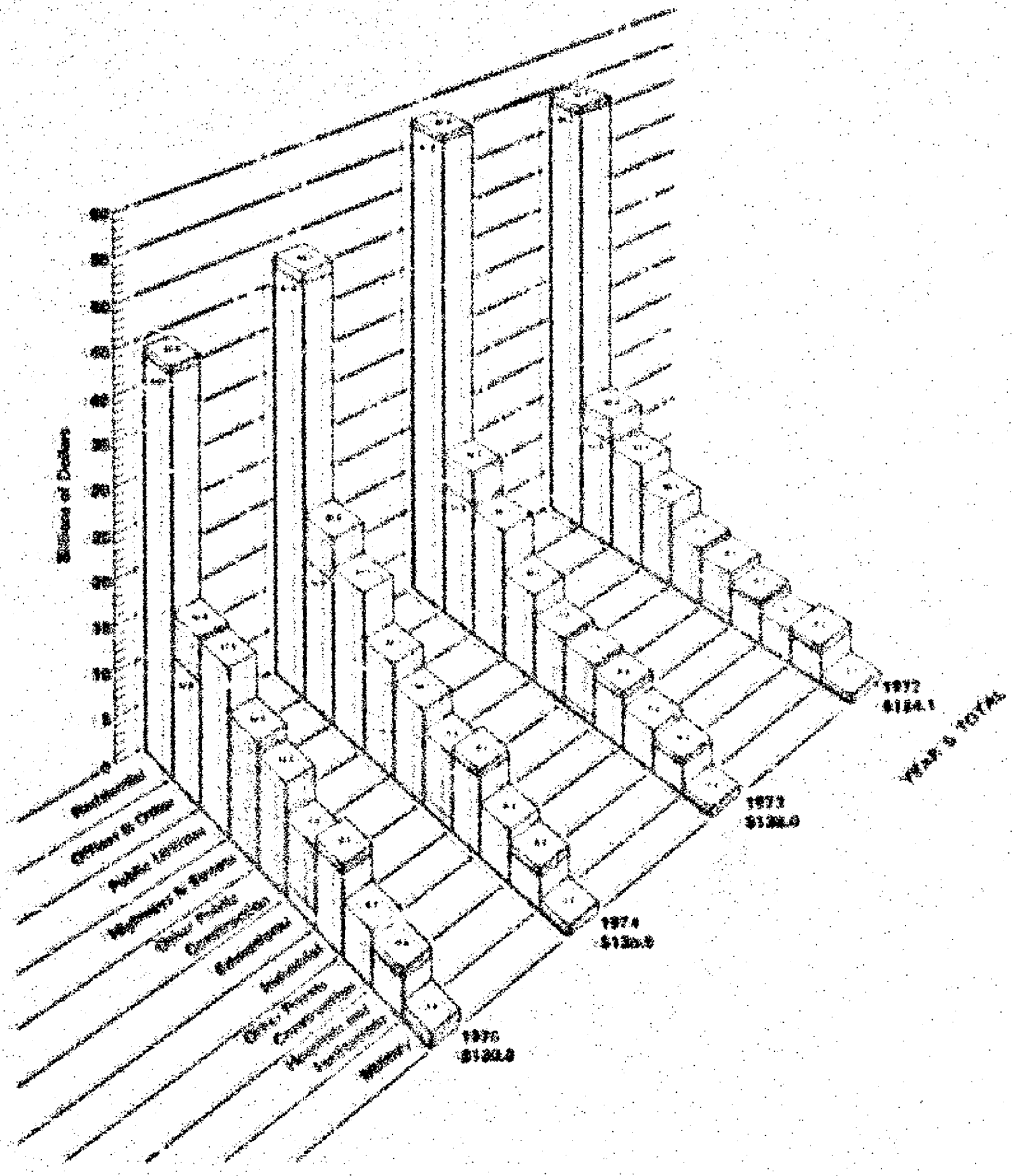
IMPACT OF DESIGN AND CONSTRUCTION ON THE U.S. ECONOMY

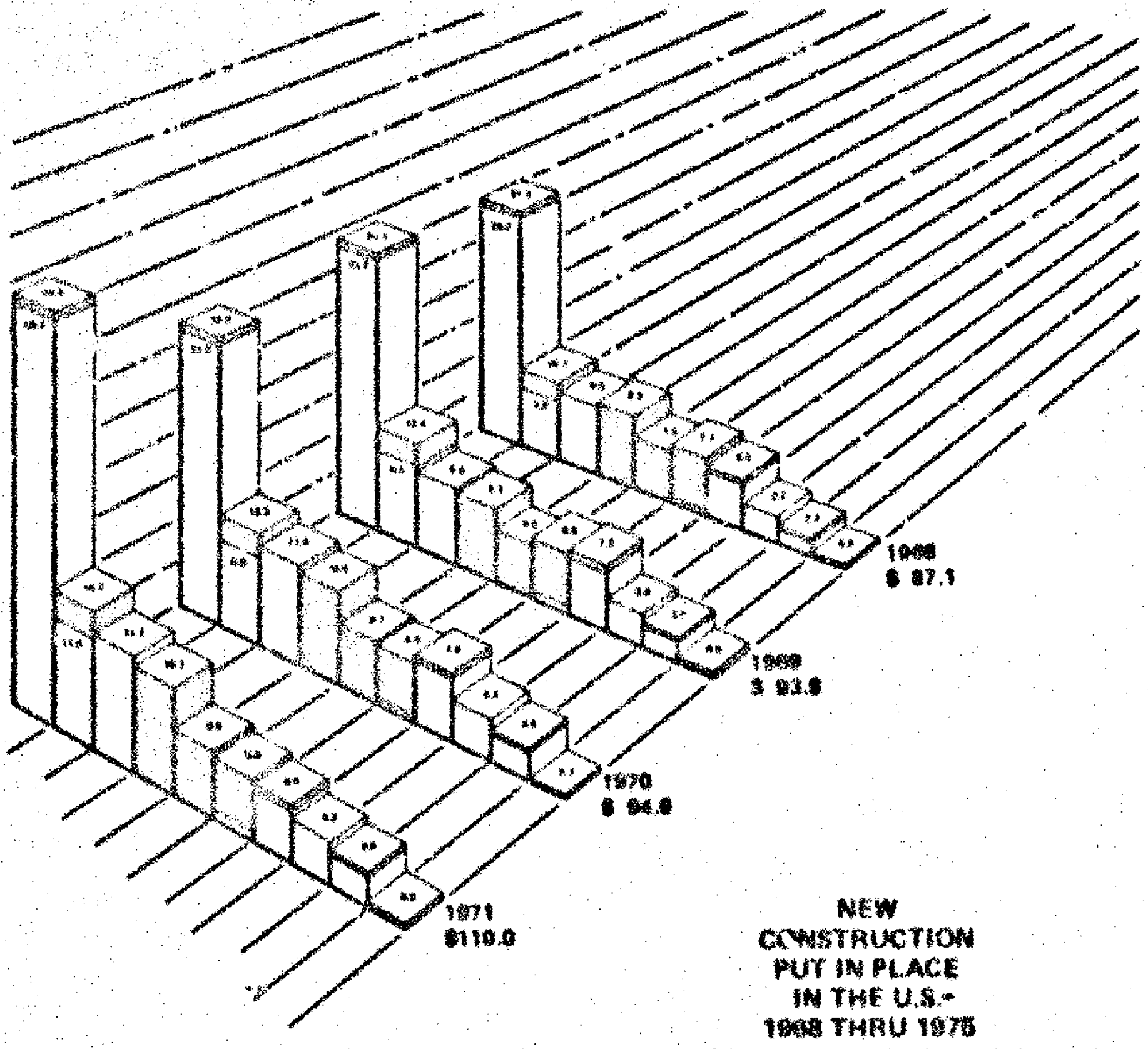
The building industry is one of the Nation's largest. Almost 5 percent of the American work force is employed in or dependent upon this industry for its livelihood.

2/Elmer B. Staats, keynote address to a National Symposium on Answers for the Building Community--"Optimizing the Choices," delivered at the National Bureau of Standards, Mar. 24, 1976.

3/Ibid.

4/Ibid.


1972
$154.1
1973
$138.0
1974
1975
$120.0



NEW CONSTRUCTION PUT IN PLACE IN THE U.S.- 1968 THRU 1975 (IN BILLIONS OF DOLLARS)

PUBLIC OWNERSHIP

PRIVATE OWNERSHIP



(Courtesy of Data General Corp.)

Figure 1-2. An integrated circuit on a silicon chip (on tip of finger), a microprocessor, a microcomputer board, and a complete semiconductor minicomputer.

Notable savings and increases in efficiency and productivity have been achieved through the use of computer technology in design. Diverse applications and functions can be accomplished at speeds and with accuracies that far exceed unaided human abilities. The end is not yet in sight, as the variety of computer uses continues to broaden and becomes accessible to even the smallest organization.

SCOPE OF STUDY

We studied the state of the art of computer-aided building design (CABD) in the United States and computer aids

being used by American design firms in the building industry. We also surveyed foreign activities relating to the use of computers in architecture and engineering.

The study involved inquiries at various Federal agencies, research organizations, professional organizations, architectural and engineering firms, design-construct firms, computer industry firms, universities, and foreign and international activities to obtain information and user experiences. (See app. I for a complete list of study participants.) An extensive literature search was also made to gather pertinent information. (Reports on certain related studies by the General Accounting Office are listed in the bibliography.)

CHAPTER 2

THE EXISTING BUILDING DESIGN ENVIRONMENT

In this chapter we synthesize the results of our (1) review of the literature, (2) interviews and discussions with professionals in industry and academia, and (3) participation in conferences and seminars into a picture of what we perceive to be the existing building design environment.

In the United States the architect has traditionally been the leader of the building design team. As such, his or her role includes safeguarding the owner's interests during design and construction. Due to the widely divergent and highly technical nature of many aspects of building design, the architect has to depend on professional engineering consultants, such as structural, civil, mechanical, and electrical engineers. The design team may also use cost estimators, interior designers, and specialists in acoustics, illumination, landscaping--and increasingly--energy.

Building designers are primarily using manual methods, although we found that there are some applications of computer aids. Due to increased owner and public requirements, designers are under constant pressure to save time, money, materials, energy, and other resources. Their clients, including Federal agencies, expect them to design energy-efficient, minimum life-cycle cost buildings which satisfy user needs and provide future flexibility. They are expected to do this in the same time, or less, than previous designs which did not always have these requirements.

Building codes and standards are increasingly reflecting greater energy, environmental, health, and safety concerns, and there is an increased demand that new buildings be more responsive to the needs of the users. As a result, the buildings of today are becoming increasingly more complex and sophisticated and, therefore, more difficult to design. Building designers are faced with requirements for increased analytical work, such as earthquake analyses, energy consumption predictions, and life-cycle cost calculations. These requirements and advances in the state of the art, as well as the new building materials available to the designer, represent an enormous amount of information and data which should be considered, analyzed, and/or evaluated during the design of even the most basic structure.

PRESSURE TO COMPLETE DESIGN

Designers told us that in designing a new building, they often are not given sufficient time to consider more than one or two design alternatives. Consequently, the resulting design may not be the best possible product. Given time constraints in the design process, a building may not provide the best value for the money spent, nor respond most effectively to the building requirements or environmental considerations. Since design is a heuristic and iterative process, the more alternatives that can be considered the greater the likelihood that the final design will be an energy-efficient, aesthetically pleasing, less costly design. A study 1/ made by the British Department of the Environment and the Royal College of Art, London, in 1974, on the performance of a CABD system compared to the manual design process in designing a one-story frame building, indicated that 7 to 8 percent savings in the frame's capital construction cost could be achieved through redesign or multiple design iterations, along with a 1-percent savings in design costs, compared to the manual process.

Overdesign

A number of designers told us that, within the profession, building designers also frequently overdesign. The overdesign reportedly tends to occur when an inadequate number of alternatives are considered or an insufficient number of iterations are made due to the pressure to complete a commission. Under such circumstances, designers will rely heavily on their experience and select factors they are certain will not fail or will, without question, fulfill the safety requirements and/or owner's specifications. Some estimates are that structures on the average are overdesigned by 5 to 10 percent. This means columns, beams, and footings (1) are larger than needed, (2) cost more to construct, and (3) require more raw materials, including energy, than necessary to meet safety requirements. Information we received indicates that, prior to the use of computers for structural analysis, it was not uncommon for building structural systems to be overdesigned by as

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1/B.G.J. Thompson and J. Hughes, "An Experimental Investigation of the Performance of a Computer-Aided Building Design System," IFIP Congress 1974.

much as 40 to 50 percent, 2/ and that mechanical systems, which impact on the energy efficiency of a building, are still often oversized by 30 to 50 percent.

ALLOCATION OF DESIGNER RESOURCES

A number of authoritative sources--Commission on Government Procurement (1971); Department of Health, Education, and Welfare (1975); General Services Administration (1975); Applied Research of Cambridge (1976); Case and Company (1976); Committee on Federal Procurement of Architect-Engineer Services (1976); and others--have issued study reports discussing the problems of resource allocation. In addition, the members of several design firms commented on these problems.

Designers stated that traditional design practices and methods of resource allocation, and existing fee structures, present problems in assuring that resources are allocated to those phases of design in which the returns on investment are the greatest.

The building design process includes three types of information-processing activities:

--assembling, analyzing, and evaluating information in ways that will define design requirements or goals,

--developing and testing design alternatives and selecting and refining a concept into a final design, and

--providing construction information on the final design.

The last activity listed absorbs the most resources, as was shown in a study by Applied Research of Cambridge 3/ (see fig. 2-1), but has the least impact on the building's eventual operating and maintenance costs. Whereas only a

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2/Gordon Wright, Managing Editor, "Experiences of an Architect, Engineer and Contractor," (Comments by Fred Bernheim of architects Bernheim, Kahn and Lozano), Building Design and Construction (March 1977), p. 45.

3/Applied Research of Cambridge Limited, "Integrated Computer-Aided Building and the OXSYS Project," p. 3.

small proportion of the designer's resources, probably less than 20 percent, are actually devoted to the task of developing a conceptual design. The bulk of the resources are channeled into the accumulation and administration of information during the design process.

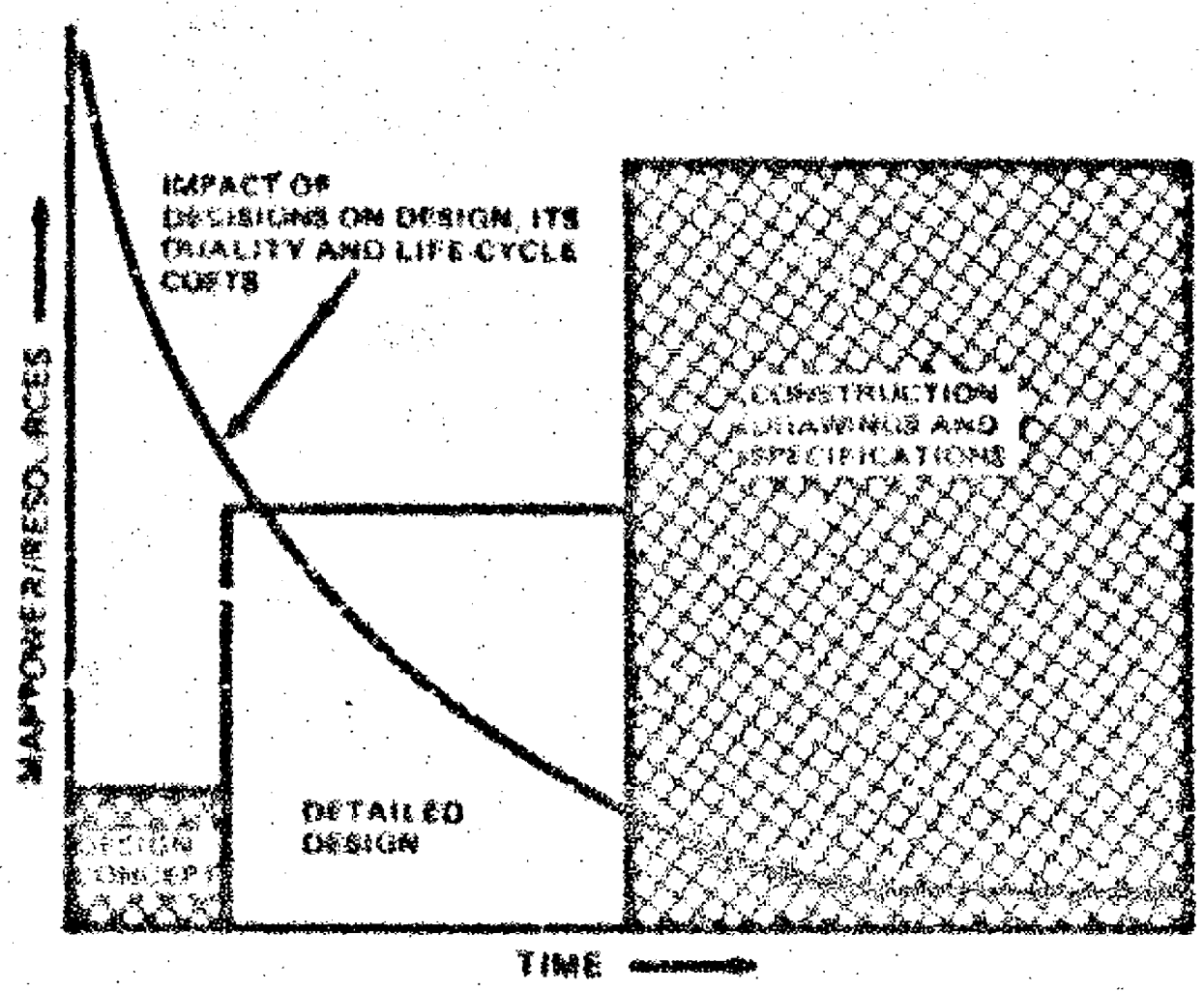


Figure 2-1. Impact of Decisions as Related to Resources Expended in Major Design Phases.

Comments by other researchers and practitioners support these statements.

Only a small part of the design fee is allocated to matters that will determine the follow-on costs, which are huge by comparison. For example, the General Services Administration 4/ allocates the design fee as follows when making payments to the designer.

4/Public Buildings Service, General Services Administration, Instructions to Contract Architect-Engineers, PBS P3410.1c, December 1974, ch. 12, pp. 4-5.

Design Stage	Payment Percent
Concepts	12
Tentatives	18
Midpoint working drawings check	28
Final working drawings	30
Postconstruction contract services	12
Total	100

Many designers and consultants told us that, although the expenditure of funds during design is comparatively small, decisions and commitments made during this phase have orders of magnitude of greater influence on what later expenditures will actually be, as illustrated in figure 2-2. We were told that, typically, about 75 percent--and possibly as much as 95 percent--of the total life-cycle costs of a building are thus locked in by the time the working drawings are prepared.

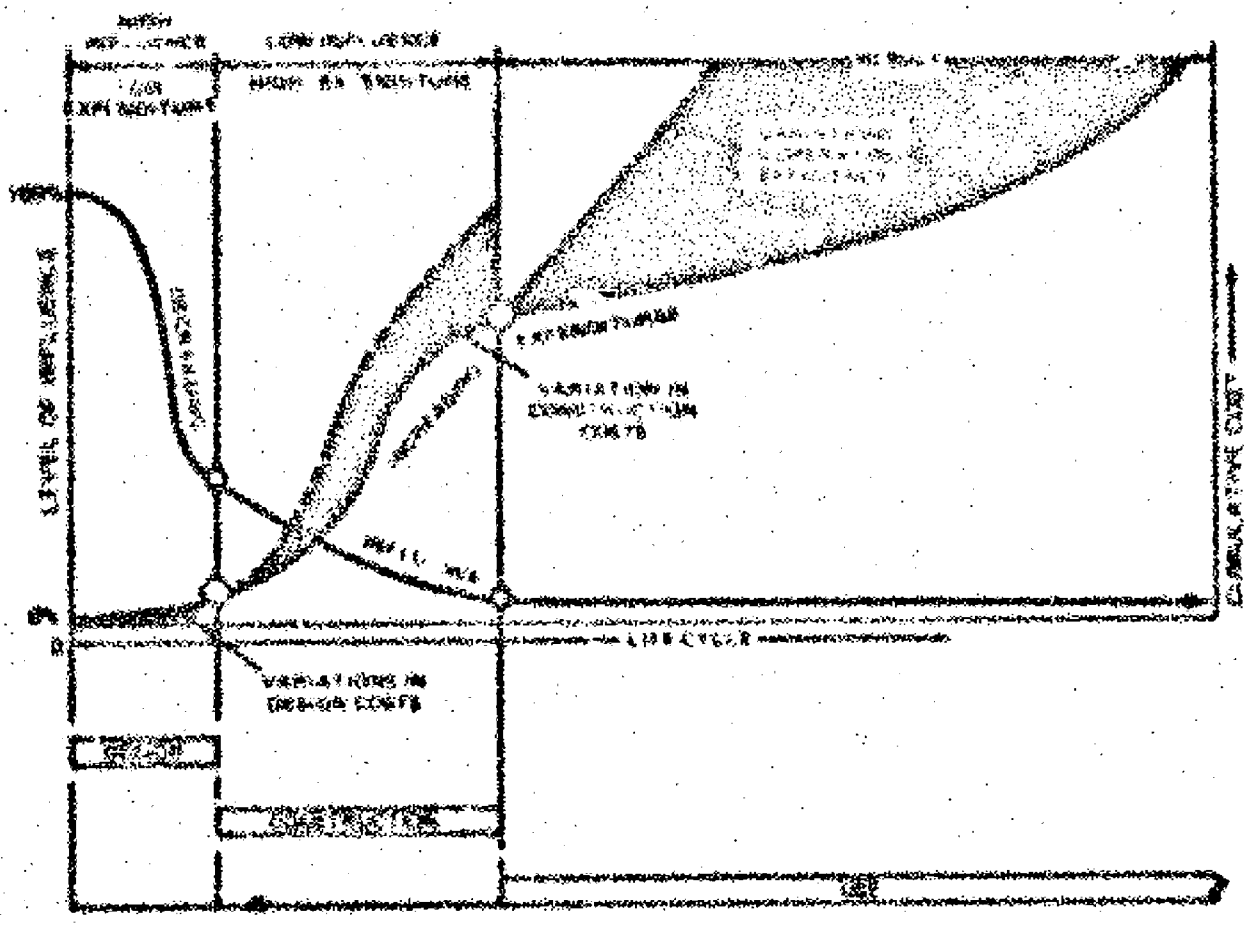


FIGURE 2-2. LEVEL OF INFLUENCE ON LIFE-CYCLE COSTS

Another way of looking at the expenditure of resources is to compare design costs with the total life-cycle costs of a building. As can be seen in figure 2-3, building design costs represent a very small proportion, probably less than 1 percent, of the costs that will be incurred over the life of the building. Decisions made during the expenditure of this less-than-1-percent determine and freeze nearly all of the costs which follow.

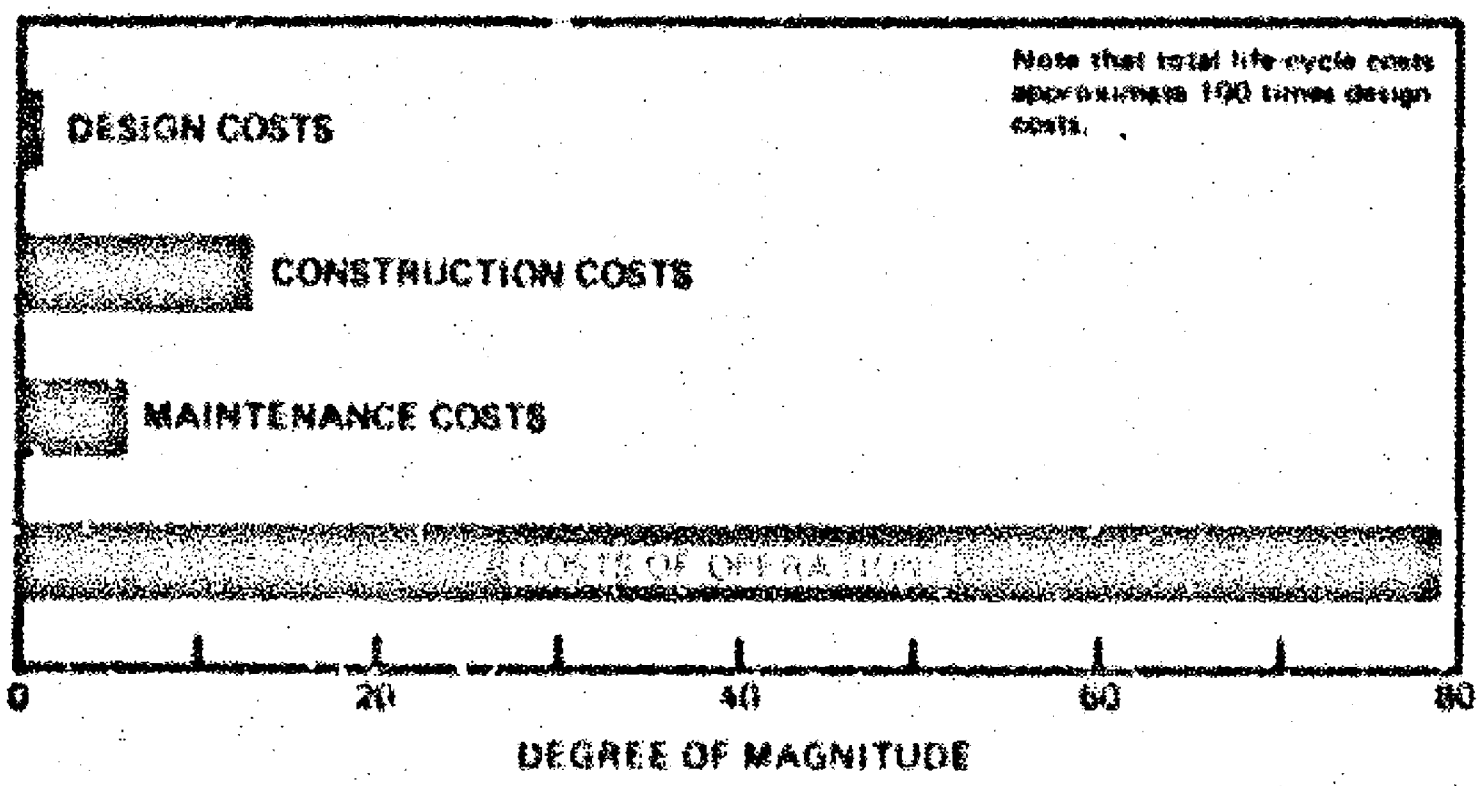


FIGURE 2-3. COMPARISON BY AVERAGE MAGNITUDE OF THE ELEMENTS OF LIFE-CYCLE COSTS

DESIGN OPTIMIZATION AND SPATIAL INTERFERENCES

A frequent design practice is to place major emphasis on architectural aesthetics and structural optimization. This means that the other building systems are generally "fitted" into a preconceived arrangement. 5/ Table 2-1 shows the systems or subsystems of a building. These are highly interactive and interdependent. Consequently, any concentration on optimizing, minimizing, or maximizing any one system affects the others.

5/Louis H. Klotz, "A Conceptual Framework for the Synthesis of Building as a System," University of New Hampshire, 1973, p. 1.

Table 2-1. Building Subsystems. 6/

Subsystems	Examples of Components
Structural Skeleton System	Framing arrangements, structural materials, foundations.
Power and Communication Systems	Electrical supply, substations, and equipment; electrical services; telephone systems.
Environment and Environmental Systems	Lighting, heating, cooling, ventilating, water supply, lavatories, sewage disposal, noise and vibration dampening systems.
Material Handling Systems, Equipment and Furnishings	Equipment, furniture, supplies, products, mail.
Transportation Systems	Elevators, stairs, escalators, parking facilities, exterior transportation systems.
Safety and Security Systems	Areas and volumes of restricted access and egress, fire alarm system, smoke detection system, water sprinkler system, emergency pumps, generators.
Spatial Relationships and Systems	Space (volume), square footage and dimensional limitations and requirements.

Using traditional design practices, it is difficult to determine the effects of one system upon the performance of other building systems, individually or combined. Only infrequently are there "feedback loops" between the design disciplines involved in a project. Additionally, each system is generally designed separately, frequently by different firms. As a result, interferences between systems can occur. These occur when two or more systems are inadvertently designed to occupy the same space. System interferences are often found during construction rather than during design. Such situations often result in costly changes and delayed occupancy of the new building.

6/Louis H. Klotz, "A Conceptual Framework for the Synthesis of Building as a System," University of New Hampshire, 1973, p. 1.

CHANGE IN FOCAL POINT

For the most part, designers, builders, and buyers have traditionally tried to minimize the initial costs of a building. In recent years, there has been a shift in emphasis from the initial costs to a concern about total costs--design, construction, maintenance, and operation costs--over a structure's entire useful life. In the past, changes were made in construction based on short-term savings potential; unfortunately, an item with the lowest initial cost usually has the highest life-cycle cost. The result has frequently been buildings which are costly to operate and maintain.

CHAPTER 3

NEED FOR MODERN DESIGN TOOLS

Computer technology offers a productivity-improving potential to the building industry. The computer's versatile memory, speed, data manipulation, and transfer capabilities are well suited for tasks such as energy consumption and life-cycle cost analyses, as well as many of the numerous information-processing functions inherent in building design. The computer could relieve the designer of many mundane design tasks and thus facilitate the reallocation of design resources so as to improve the return on investment. Also, it could help improve coordination among the members of the design team, eliminating or minimizing many of the existing communication problems which result in less than full design optimization and spatial interferences.

Furthermore, the constantly increasing amount of (1) information needed by designers during the design process and (2) technical information about which designers must be aware suggests the potential for more efficient access to this information through the use of computers.

LIMITED USE OF COMPUTER TECHNOLOGY

Using manual methods, it is difficult and managerially and technically costly for a design firm to deal effectively with the problem areas discussed above. Computer techniques, on the other hand, offer the potential for the designer to simplify reallocation of resources, to deal effectively and economically with design optimization and spatial interferences, and to ease the pressures which frequently cause costly overdesign. Although the use of the computer is not widespread in the industry, it is growing.

In engineering, computers--and particularly hand-held electronic calculators, many of which are truly microcomputers--have generally replaced the slide rule in making engineering calculations and doing design-related analysis. Many engineering firms also use the computer as a drafting aid by using computer-controlled plotters (fig. 3-1). Many architectural firms have terminals to time-sharing services to provide computer usage for management purposes and for mechanical and structural engineering applications. We observed that, in both architectural and engineering applications, the computer is rarely used as an aid for design itself (as defined in the glossary), but rather for analytical work and management functions.

Factors mitigating against greater use of computer-aided building design

There are many reasons--educational, attitudinal, economic, political, and so forth--for the limited application of computers in building design.

Our study suggests that the more cogent reasons are:

--CABD is in its infancy, and the cost benefits are not either readily apparent or easily computed.

--The building industry may not be motivated to do the required research and development.

--The capital investment cost is high, and, given the above two reasons, there is little incentive to make the investment.



(Courtesy of California Computer Products, Inc.)
Figure 3-1. A drum plotter with computer controller unit.

—The builder or buyer, while moving towards requiring energy analysis and life-cycle costs, is not motivated to have contractual requirements for computer-aided design or to subsidize the designer ... perimentation and development costs.

Additionally, the builder's or buyer's lack of motivation appears tied to (1) a lack of recognition of whose decisions govern the ultimate life-cycle cost of a building and (2) the proof of potential opportunities for improving the decision process by using CAAD techniques. Figure 3-2 1/ shows that owners and, especially, designers principally influence these costs.

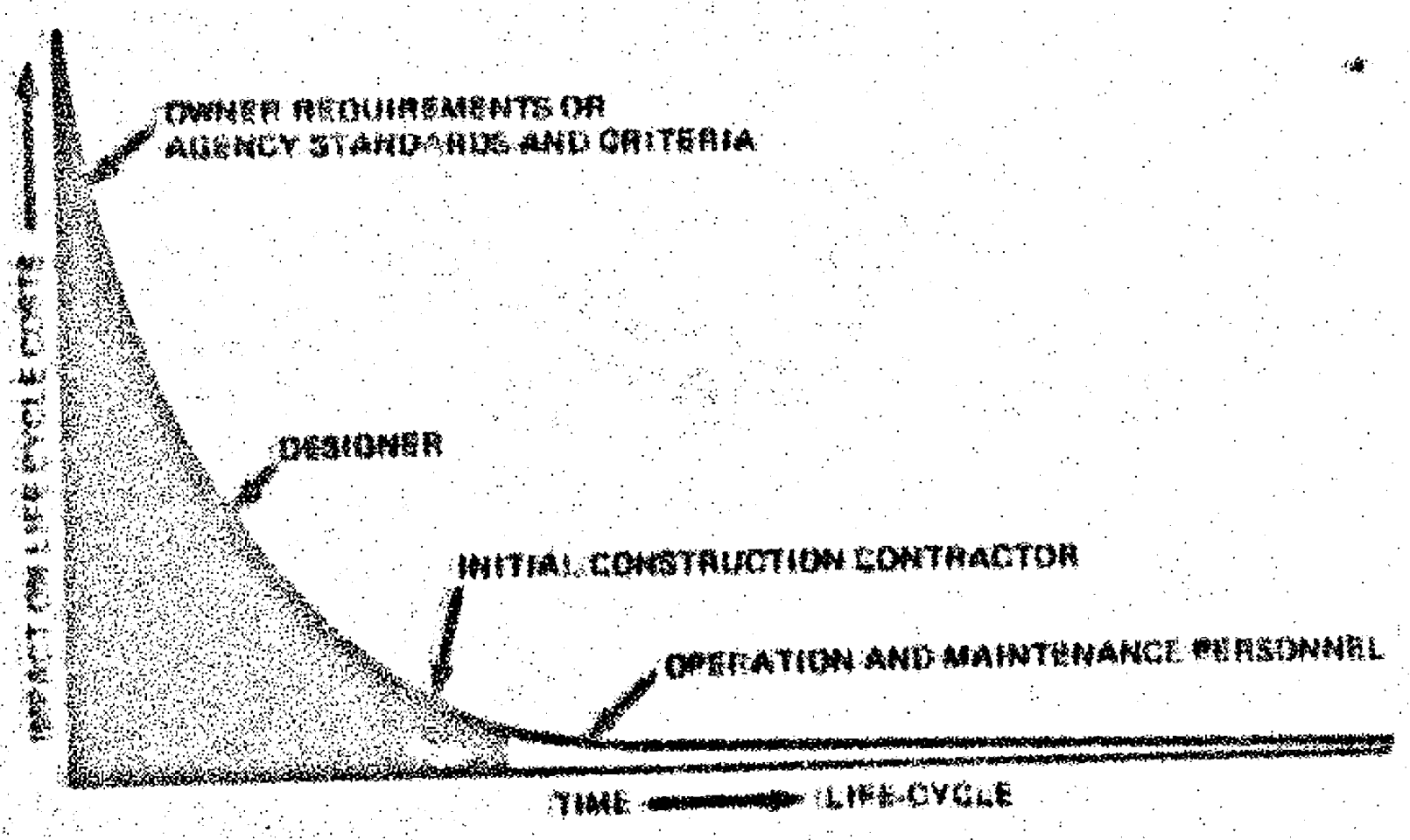


FIGURE 3.2. MAJOR DECISION MAKERS (PERSONS WITH IMPACT ON TOTAL COSTS) IN BUILDING LIFE-CYCLE COSTS.

1/Alphonse J. Dell'Isola, Value Engineering in the Construction Industry, p. 5.

ENERGY-EFFICIENT BUILDING DESIGN

Designing energy-efficient buildings is basic to the Nation's energy conservation effort. The Department of General Services, State of Florida, which has had an aggressive program aimed at new building designs, estimates 2/ that State buildings erected in the last 2 years consume about 55 percent less energy than those built before the passage of the State's energy law.

The American Institute of Architects and others estimate that the built environment of the United States accounts for one-third of the Nation's annual energy consumption. The institute also estimates that the energy demands of the new buildings could have been reduced by up to 80 percent if they had been initially designed to be energy efficient, whereas retrofitting an existing building will yield only an estimated 10 to 50 percent reduction in energy demand. Thus while the returns from retrofitting are significant, the returns from energy-efficient designs are far greater. 3/

In 1974 the General Services Administration 4/ estimated that about 14 percent of the total energy used annually in the continental United States was used by commercial buildings. It also estimated that this represented an equivalent of 5.47 million barrels of oil a day. A reduction of only 20 percent would save an equivalent of 1.09 million barrels of oil a day.

Energy-efficient design is a first step toward lowering life-cycle operating costs. Full life-cycle costing will be an extremely complex design consideration; many

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2/"Energy Legislation Panel Discussion," transcript of 1976 APEC Annual Meeting, comments by Thomas A. Sechler, Administrator, Department of General Services, Engineering Section, State of Florida, APEC Journal (Forward 1977), pp. 6-13.

3/Energy Steering Committee, "A Nation of Energy Efficient Buildings by 1990," The American Institute of Architects, n.d., p. 3.

4/Public Building Service, "Energy Conservation Design Guidelines for Office Buildings," General Services Administration, January 1974, p. 4-1.

material and design choices will almost undoubtedly need to be analyzed by computer. An energy study to evaluate three alternative heating, cooling, and ventilating systems may require as many as 6.5 billion calculations. 5/ Still, such a study by itself will not ensure an energy-efficient design. As pointed out earlier, the other subsystems of the building must all be taken into account.

USE OF COMPUTERS IN BUILDING DESIGN

The concept of computer-aided building design has been around since at least the early 1960s. Yet, nearly two decades later, in spite of a great deal of research and resources being devoted to its development, CABD is still not in common use nor does an integrated generalized CABD system exist. Nevertheless, many effective computer applications have been developed, both in academia and industry, which have made the transition from research into practice and are being used by building designers. Numerous application programs exist which perform many of the functions which are required for CABD. Generally, however, these programs are not being used in an integrated CABD environment.

Energy analysis of a building has become a highly specialized process which is following a similar path of development as structural analysis and, in a management sense, is at an immature stage. There are a number of energy analysis programs, 6/ with those most highly rated and used by the professionals generally being proprietary and used on a lease or royalty type basis. However, the number of programs is relatively small, considering the economic and institutional concerns and the resulting directions of future analysis requirements of all buildings. In part this reflects the relative newness of energy analysis interests coupled with the high cost and time required for program development. This state of existence is similar to that of structural analysis programs in the early 1960s.

5/Westinghouse Electric Corporation, "Computer Programs for Evaluation of Heating and Air Conditioning Systems."

6/Cuba, J. F., "Bibliography on Available Computer Programs in the General Area of Heating, Refrigerating, Air Conditioning and Ventilating," American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1975.

I the structural analysis area, however, three main development paths took place that pushed the area toward maturity. Under the aegis of an academic institution, private and public institutions combined resources to develop analysis processes and software (such as in the ICES development); public agencies (such as the National Science Foundation) sponsored generic research in areas of question; and mission-oriented agencies (such as National Aeronautics and Space Administration (NASA)) sponsored program development for specialized industry usage which later became available for use in other industries.

At the time of these developments, with the then state of development of hardware and software systems, a generalized, but uniform, input format had not been developed that would provide for future "plug compatibility" so that one input format would satisfy the input requirements of all structural analysis programs or for integration with other discipline-oriented programs that might precede the structural analysis program. Similarly, solution algorithms, and resulting output data and their formats, were not standardized or legislated so that the results of one program would, again, be plug-compatible with another or for integration with following programs. If the logic of plug-compatibility is extended into the program's internal operations of data manipulation and solution algorithms, the result is obvious: the resulting programs will not only provide duplicate results but will in fact be duplicate programs.

Engineers' Use of Computers

Engineers have been using the computer since the early 1950s, when structural engineers began applying the computer to structural analysis problems. Over the years, a great number of computer programs, of all types have been written for building design engineering applications. Yet, the computer's role in the design process has changed very little. It is still used primarily to solve mathematical engineering analysis problems, much the same as it was used in the 1950s. Use of the computer where the full potential of the interactions of man, software, and hardware systems are realized has not yet been achieved.

Architects' Use of Computers

On the other hand, the computer has rarely been applied to architectural design. "Many [architectural design] offices

(if not most) have terminals to time-sharing services that provide mechanical, structural, and accounting facilities of a trivial but important nature. * * * [However] Almost no offices have actively tried to augment their design practice with computer aids." 7/ Architects are generally not knowledgeable about CABD and have not made an effort to learn about this technology.

Engineering applications of computer aids, often consisting of mathematical design analysis, have been more easily adapted to the computer than architectural applications, which are more heuristic in nature and require a computer treatment that is being researched more slowly.

Past Promises Unfulfilled

The 1960s has been called "the period of ideas." 8/ Numerous ideas were put forth on how the computer could revolutionize building design practices. A tremendous amount of enthusiasm and excitement was created by the attractive promises made by early proponents of CABD. Several educational institutions--Pennsylvania State University, the Massachusetts Institute of Technology, the University of Illinois, and the University of California at Berkeley, to name just a few--were active in research on computer technology for the building industry. Many conferences were held to share ideas and research results. Everyone--universities, professional groups, and private firms--sponsored conferences or seminars.

Early proponents of CABD frequently made promises creating great expectations among the design professions. For example, one researcher in 1967 predicted that "... by the year 1975 when automation-aided techniques will be employed by building designers to assist their design decisionmaking efforts, comprehensive analyses of alternate design solutions will be routine procedure of the building envelope selection process." 9/ As late as 1971

7/Nicholas Negroponte, "Introduction," Reflections on Computer Aids to Design and Architecture, 1975, p. 7.

8/David Sides, "Notes on Computers and Architecture," Reflections on Computer Aids, p. 127.

9/Donald E. Dougald, "The Development of a Data Storage and Retrieval System for Building Envelope Design Information," p. 1.

another writer wrote that "By 1975, the majority of medium-to-large architectural firms will be using the computer to solve design problems on a day-to-day basis." 10/

A well-publicized project at Pennsylvania State University called MODCON (Man Machine System for the Optimum Design and Construction of Buildings) was one of the efforts in the forefront in the 1960s. The project promised to develop a system which would "allow the architect, engineer and others to sit down together and quickly conceive, design and specify a building on the basis of total performance criteria." 11/ The hope was to "eventually tie the industry together, force disciplines to integrate, make all available computational data immediately available and give professionals more time to be creative." 12/

It is obvious that these and other promises and prophesies have not yet been fulfilled.

Enthusiasm for CABD Wanes

Our study showed that architects, and, to some extent, engineers, have been disillusioned and discouraged by past failures and by overselling of computer potential, and some, by their personal experiences with the computer. In the late 1960s, the enthusiasm for CABD had diminished and conferences on such computer applications offered less and less.

Nevertheless, interest in CABD continues and there is some research and development. To quote Murray Milne, of the University of California at Los Angeles,

> "Much exciting and important work remains to be done. The study of design methods has moved into a new, more mature, and less self-conscious phase. Fewer people are working on much more complex problems and are making much less noise." 13/

10/William R. Miller, "Computers in Architecture," Datamation (Sept. 15, 1971), p. 26.

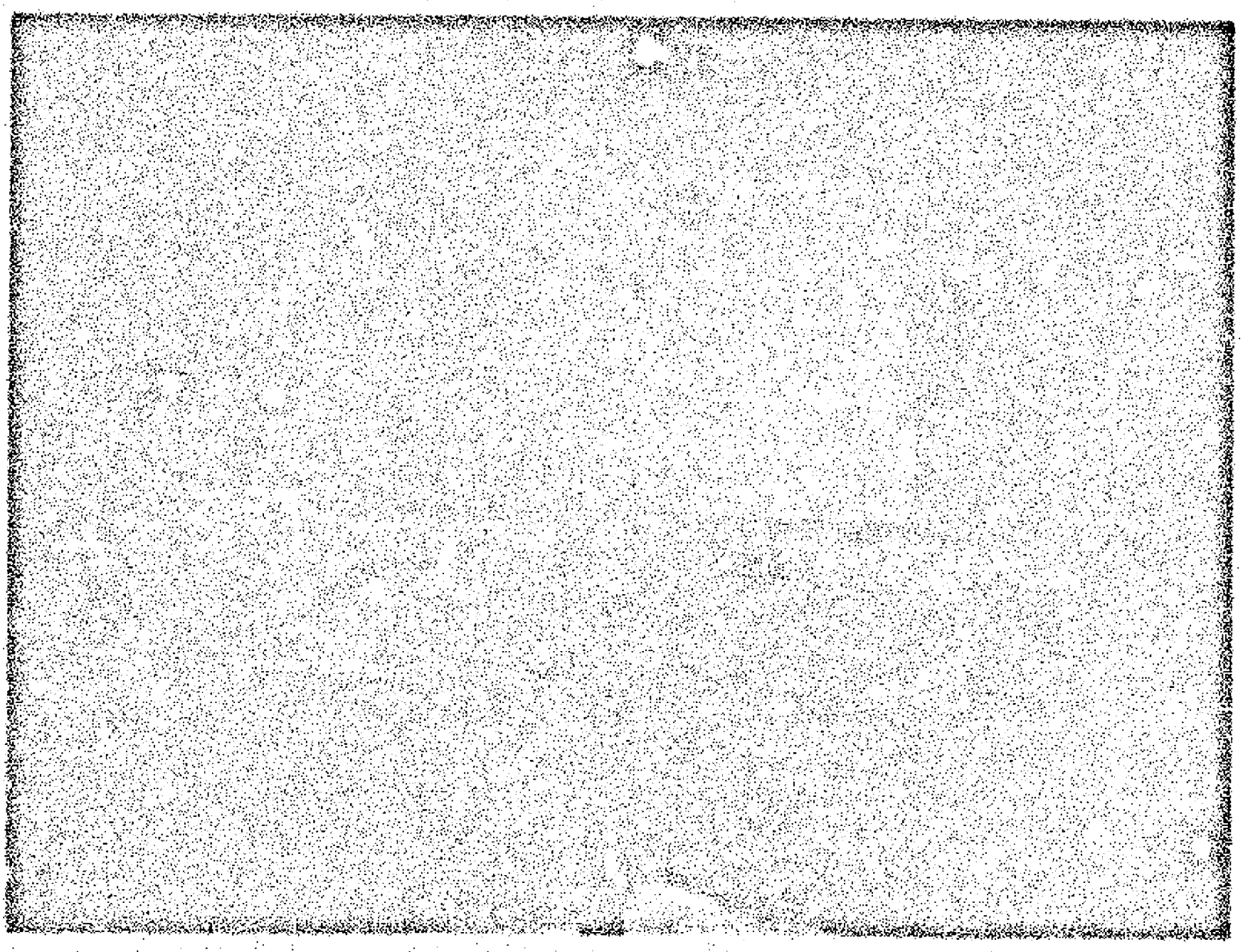
11/"Gifford Albright: Prophet for the New Computer World of MODCON," Engineering News-Record (July 18, 1968), p. 28.

12/Ibid.

13/Murray Milne, "Whatever Became of Design Methodology?" Reflections on Computer Aids, p. 36.

LOOKING AHEAD

The information arising from this study suggests there may be a potential for continued CAED-type developments and refinements and for growing sophisitication in both the software and hardware components, such as the use of lasers in graphics equipment. (See fig. 3.3.) Likely to receive particular emphasis are (1) data base structures, with the related options for integrations and refinements of applications and procedures, (2) development of graphics capabilities, (3) continuation of the rapidly increasing sophistication marking hardware development, and (4) improvements to man/machine interfaces, reducing the cost of hardware.



(Courtesy of Laser-Scan Limited)

Figure 3-3. Large-screen interactive laser display/plotter.

Data Bases and Systems Integration Issues

In simplistic terms, a program application, relating as it ordinarily does to one part of the overall design, requires for execution: (1) certain pertinent data, (2) a set of instructions expressed in a language compatible to the operator and computer, and (3) the necessary computational equipment, including input-output devices. The actions to create an operable program can, therefore, consist of selections from among: (1) many files of data, (2) many instructions and languages, and (3) many computing-equipment specifications.

When files of data are logically organized for input, retrieval, and manipulation, they are usually referred to as a data base. With or without inclusion of application programs, when a data base is common to several disciplines, allowing multiple types of applications, it is often referred to as a common or integrated data base. However, the concepts and physical forms that data bases and integrated data bases should take for use in CABD-type environments are matters of further research and development at this time. In fact, the directions that such research and, particularly, development should take are not matters of complete agreement.

There are, for example, people who are predominantly interested in developing the theories and concepts of data representation, geometrical descriptions and data storage and retrieval which, when viewed for application, will result in a single stored set of data. Thus the common or integrated data base, which is sometimes referred to as a building description system, is suggested by some researchers as the central feature and focus of an integrated computer-aided building design system. There is a rapidly growing acceptance of this approach (especially within the last year).

On the other hand, practitioners have historically favored a more evolutionary approach, with the gradual linking of application programs by direct data transfer, of only required data, from one program to another and usually without the creation of a master data base. In part, this approach appears to have been based on limited funding availability for development and limited or costly access to large computers with massive storage peripherals for application. The practitioners have also been highly concerned that CABD systems might not properly respond to how the architectural and engineering disciplines interplay with each other, as well as to how each discipline performs its own functions. However, this approach has failed to link programs from such diverse application areas as architectural, structural, mechanical, and electrical.

Regardless of the approach, the requirements, compositions and manipulations of data, and data files and data bases, combined with the requirements for the specific functions of the building design disciplines and the information flow between these disciplines, make the subject of an integrated computer-aided design system an intricate one. Some of the other issues which have been articulated as requiring resolution to provide for the orderly development and implementation of an integrated CADD system are:

--In describing a building, what information is actually project-specific information versus what is general or standard?

--What data should be explicitly represented in a data file or data base versus what can be implicitly represented so that the specifics can be determined, and how should the constructive data be transformed to specific?

--A glossary of technical terms and associated geometrical descriptions, defining building zones, assemblies, modules, and components is needed to provide for consistency as well as for data structure development.

--What technical, economic, graphic, and labeling attributes should be assigned to an object, and what attributes should be directly related and stored versus indirectly related and stored elsewhere?

--How to handle the maintenance of data consistency during updates and changes.

--The problems of how to allow any route to be followed in the design sequence.

--In looking at geometric objects, how general or "primitive," versus how specific, should the object be, particularly for how the architect works with objects? What is the basic set of primitives and how do they relate to the kind of structure the architect can make with them?

--Should standard details be referenced and explicitly stored or should there be a procedure to draw the specifically applicable detail in explicit form?

--The data base structure should be such that the generic sets of physical, functional, spatial, connection, and flow relationships of a set of objects are determinable.

--A coding scheme for the primary geometric description, based on either some mathematical or ad hoc scheme, is required that will accommodate levels of complexity and variability of modules and components.

--What are the data base and program requirements to accommodate, in its storage and manipulation, data in differing base units for a society in a physical transition state where, at any one time, some components may have undergone a "hard," actual conversion to a basic module based on a metric dimension, while other components may be only "softly," just dimensionally, converted?

--What system and application program documentation standards should be followed, since none has been as yet forthcoming from the appropriate standards type of organization?

--Some miscellaneous, but nevertheless important, issues concern levels of security and access of the process, as well as data and the ability to flag or reference data sources.

Solving these and other issues and questions will require combinations of (1) pure research, (2) applied research and development, and (3) the setting of standards by the appropriate professional and standard-setting bodies associated with the building design and construction process.

Other associated concerns are the first costs of developing and inputting both the generic and project specific data into the system, the general system's maintenance costs, and the costs of keeping the appropriate data up-to-date. In general, it would not seem practical for one design firm to ordinarily carry the expense burden of performing these maintenance functions. However, the sharing of data bases and related maintenance costs between design firms could be assembled into a variety of plans once the overall system framework, standards, and programming have been accomplished.

The single largest operating expense of an unintegrated computer-aided design system is perhaps the cost of preparing

input data. Each designer using computer-aided methods, whether architect or engineer, ordinarily would have to encode or digitize the graphic design output that precedes his function, and consequently, costs mount as well as the opportunity for erroneous data. The most cost-effective system would avoid this multiple digitizing of information.

At least some professional designers may well prefer to access their own sources and satisfy their own needs for information. Thus, use of current and correct data would continue as the professional responsibility of the individual designer. The increasing availability of low-cost hardware--minicomputers, cassette storage, and other storage devices--can provide the means of giving designers access to a personal data base.

Absence of a common general data base, however, need not block integration of designer efforts. For example, assume that a project's data file is to remain as the repository for design work as it is produced by computer-aided methods during the design period. Also, assume that lateral communications and coordination among the designers on a project have been facilitated by an information flow system so that information is exchanged in accordance with a designer's needs. Access to the project file could be provided for, possibly through a project file manager, in satisfaction of any designer's needs during the design period. Then, upon completion of the work, the project file again would serve as the basis for many of the project design documents. The key here is a compatible system for architectural and engineering designers rather than a common data base. Thus, the communication between the building design participants is thru and via a system which replaces the now unsystemitized verbal and document (drawings, sketches, letters, and memos) forms of communication. Additionally, the system provides the participants with instantaneous and consistent information of each other's design proposals and results.

It is not the purpose of this study to focus on a particular integrated, or partially integrated, system. There are possibly as many arrangements as there are varying designer-working relationships. Systems, however, should promote good design team relationships if they are to be effective. It may well be that, ultimately, if computer aids are to be cost effective, effectiveness will arise out of the closest relationships among design participants.

CHAPTER 4

POTENTIAL ADVANTAGES OF COMPUTER-AIDED BUILDING DESIGN

CABD techniques hold potential advantages over traditional, manual design methods. They offer speed, accuracy, and versatility. They may enable the designer to do things which were impossible using manual methods. Integrated CABD could be effective in melding the separate components of the design team into a creative, cohesive, and coordinated group. Although integrated systems are not common, especially in the United States, they do exist, at least in rudimentary form, in some countries. Stand-alone applications, whose savings potentials are far less than those of integrated systems, are demonstrating that computer aids can be cost effective in practice.

DEFINITION OF A COMPUTER-AIDED BUILDING DESIGN SYSTEM

An ideal computer-aided building design system is one which (1) integrates the designer(s) and computer into a more effective problem-solving team and (2) offers the possibility for integrated multidiscipline team work. An integrated CABD system would be one which melds the various design disciplines in such a way that the building can be viewed as a whole system instead of as many individual or independent systems or subsystems.

OBJECTIVES OF COMPUTER-AIDED BUILDING DESIGN

Major objectives of developing a CABD system are to minimize the repetition of input required during the design process and to facilitate instantaneous, precise data transfer among the design disciplines. By minimizing input requirements through transfer between disciplines, productivity and design efficiency could be increased. Additionally, in an effective CABD system, mundane, time-consuming tasks are assigned to the computer, freeing the designer to concentrate on the creative aspects of design.

While CABD systems may produce quality designs in terms of building performance, they will not guarantee "great architecture." By the same token, they will not prevent "great architecture." As illustrated in figure 4-1, a computer can be programmed to draw aesthetically-pleasing building designs. The King's College Chapel drawing demonstrates that the computer could be used in this kind of architectural design. CABD systems are simply tools which designers could have at their disposal. The

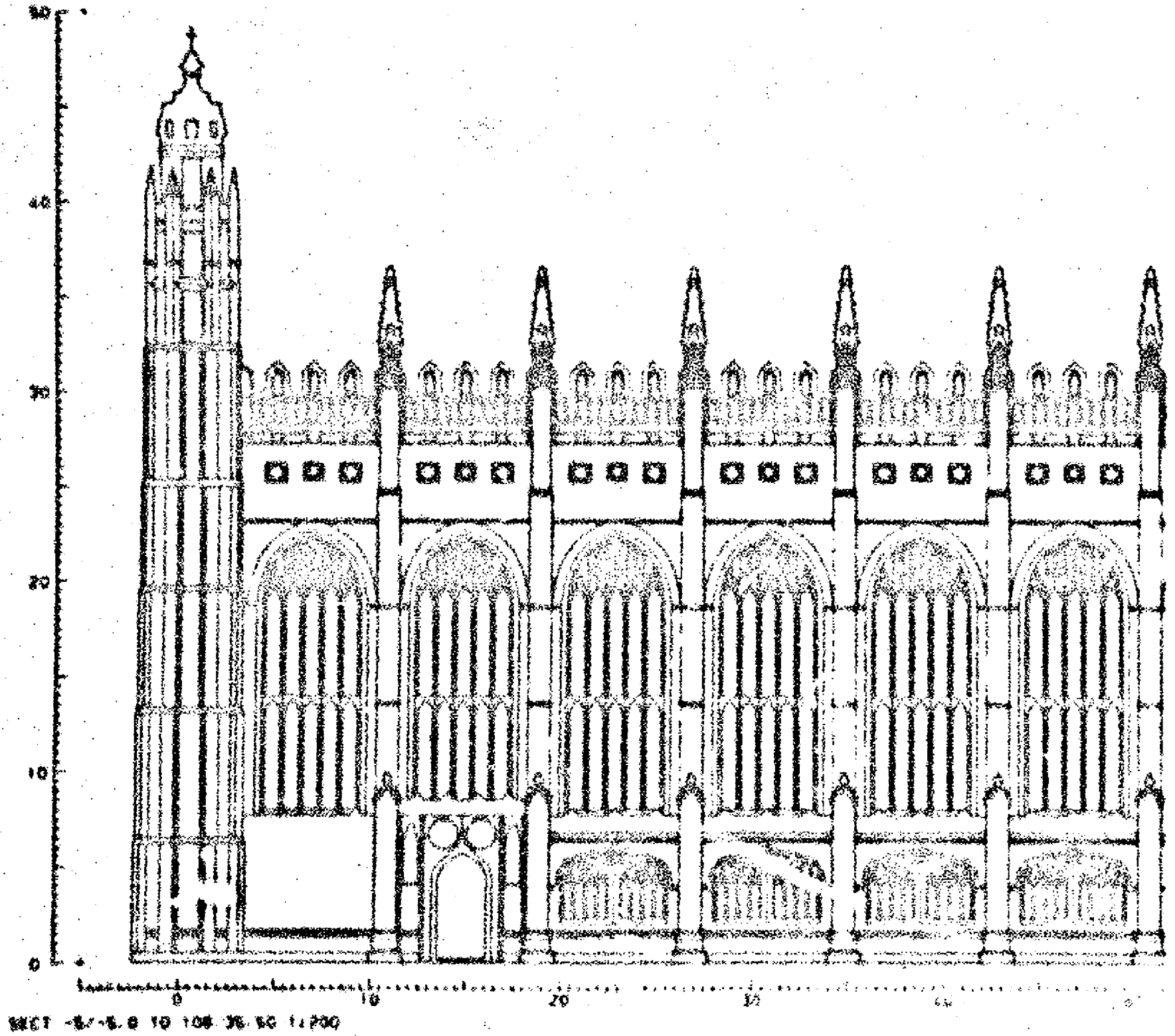
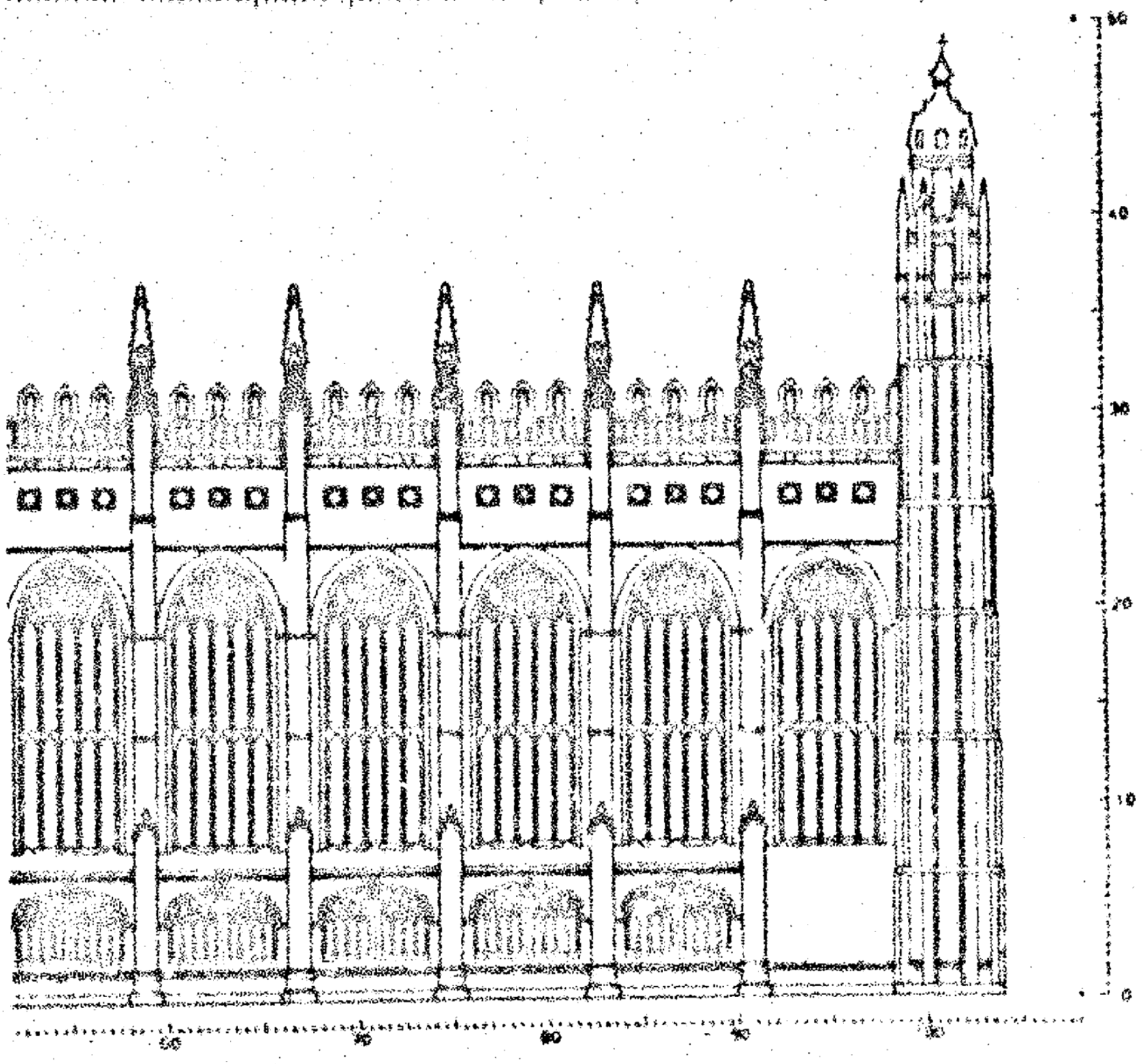


FIGURE 4-1.

COMPUTER-GENERATED SCALE DRAWING OF KINGS COLLEGE CHAPEL



(Courtesy of William Mitchell and
Applied Research of Cambridge Limited)

creation of great architecture would still rest in the creative ability of the architect, not in the computer, which can only do what it is programmed to do and therefore is not a creative entity. Creative work, creative ideas, and aesthetic tastes are the forces behind the designer exploiting a CAAD system's capability. The use of computer techniques has the potential for enhancing the performance of design, data generation, and data manipulation tasks and permits the designer to respond much faster and more economically than heretofore.

POTENTIAL PRODUCTIVITY GAINS

An integrated CAAD system could affect the productivity of the building industry in many ways. Such a system, in theory, should

--permit the rapid study of design alternatives to provide a high-quality building;

--provide a tool to evaluate options when project costs must be reduced;

--permit a complete evaluation and incorporation of energy conservation and environmental considerations during the design process, enabling design of buildings more predictive of energy efficiency and conservation of materials and the environment;

--provide completed designs and drawings containing fewer errors and without the inconsistencies of manual methods;

--provide a systematic process to determine and eliminate interferences between building subsystems and components through an iterative redesign process;

--provide a means of reproducing construction instructions--specifications and drawings--quickly and accurately;

--provide cost savings or good dollar value for expenditures because designers would have the ability to consider and evaluate more alternatives, and eliminate gross overdesign; and

--control the total design process and limit the number of unexpected conditions or surprises in building construction and operation.

Integrated systems are not common in the United States at this time; consequently, actual experience from which to evaluate the potential is not available. Where systems are being used, cost comparisons are made more difficult by the facts that (1) no two design projects are exactly alike and (2) no one, except possibly in an academic environment, develops a design simultaneously using both manual and computer-aided methods. Nevertheless, the British, who have several large-scale CADD systems for use in the design of certain types of public buildings--such as hospitals, housing, and post offices--may they have experienced a minimum of 5-percent savings in construction costs on projects designed with CADD systems. On one British hospital project, the capability to consider multiple alternative op''ons permitted a savings of 26 percent--over the national standard costs--of the total construction costs.

A major benefit from integrated systems, regardless of the type of building or the construction site, would be " . . . That in each project all information would be recorded in one place and in one form. This ensures that designers work on the same version of a project, and whenever the computer is instructed to produce drawings, schedules, . . . [or other documents] they are entirely consistent with each other, being produced from one set of data." 1/

A major source of savings generated by integrated systems would be the need for each individual designer to input the building description and other data each time it is needed to perform a function. In the absence of experience, there is no way to determine what the actual savings would be, but they could be substantial.

With the development of effective integrated systems, the designer could consider the building as a total system, rather than each subsystem as an independent entity. This would permit the checking of a design for system and spatial interferences, resulting in related savings in time and construction costs, and facilitate maximum optimization of energy efficiency.

1/Applied Research of Cambridge (Canada) Ltd., "Feasibility Study for Computer-Aided Design Systems for Ontario Housing Corporation," June 1976, para. 2.2.2.

REASON IS NECESSARY BUT NOT SUFFICIENT

In February 1977, Aart Bijl of the University of Edinburgh presented a paper 1/ discussing the experience of implementing CABD applications within a user environment. Some of his comments are pertinent and applicable to the situation in the United States. In the paper, Bijl concludes that:

> "Differences in perception of user practice, among research workers and practitioners, present problems for the research worker's explicit models and subsequent programs which are intended to interact with those practices. In the absence of shared models between researchers and practitioners, it is not possible to rely on reasoned argument alone to gain user acceptance of CAD applications. In our experience, research workers have to acquire new understanding of the implicit and obscure nature of design activity and must evoke a new empathy with practitioners. This will be accompanied by new demands for advances in perceptive and adoptive capabilities of computer programs."

He further states that:

> "In order to develop the necessary experience and insight into the affects [sic] of computing on the activity of people, CAD applications have to be used by practitioners, not used on behalf of practitioners but operated within user organizations. It is not until the user feels that he owns an application, is free to change and extend it, that any mismatch between a model esbedded in software and the user's own practices become evident."

PAST AND PRESENT EXPERIENCES WITH STAND-ALONE PROGRAMS

We were able to locate some estimates of savings achieved by designers using stand-alone computer programs. No attempt was made to validate any of the following statements of benefits or savings. They are presented in order to provide some indicator of the potentials of CABD systems and increased use of computers in building design in relation to dollar savings and productivity increases.

1/Aart Bijl, "Reason Is Necessary But not Sufficient," University of Edinburgh, February 1977.

Significant benefits and substantial savings have reportedly been obtained by using the computer for analysis work as opposed to manual calculations. The Automated Procedures of Engineering Consultants group (APEC) frequently publishes statements by members on their experiences using computers. Following are examples of statements appearing in a 1976 issue of the APEC Journal. 3/

--A Chattanooga, Tennessee, firm reported, "We estimate that the costs using ... [computer] programs compared to hand calculations were respectively $250 vs. $2,000 for HVAC [heating, ventilating and air conditioning], and $15 vs. $1,250 for lighting. Even though manual calculations would have cost so much more, the data they would have produced would not have been anywhere near as accurate ...."

--An Omaha, Nebraska, firm reported, "We thought .... [computer] programs were for the large jobs only. Not true! Regardless of job size, the programs are a great safeguard against design errors. Not only does each program produce far more information than is practicable to calculate by hand, it produces it in a uniform format and at a very comfortable cost."

A firm which tested the ARK-2 architectural design system, one of the few existing applications of the computer to architecture, concluded that, in time, productivity could be increased by a factor of 5.75. However, the more significant benefits were intangible. For example:

--The total design process could become a continuous activity rather than a series of short segments for all concerned.

--The ability to generate and keep drawings up to date in areas of rapid change should allow better, more accurate, up-to-date drawings.

--Because of the ease and speed with which accurate, to-scale, rough layouts can be generated, the designer can use optimization techniques on multiple alternatives in less time than it generally takes to generate one layout.

3/APEC Journal, vol. XI, no. 2 (Forward 1976), pp. 10-11.

--The ability to overlay drawings on the screen will facilitate quicker, more thorough reviews by eliminating the present methods of manually comparing drawings in blueprint form.

Automated drafting has been a timesaver. (See fig. 4-2.) In the preparation of working drawings, especially complicated, high-detail drawings and drawings wherein repetition is a factor, there have been cases where savings are significant. Users of automated drafting systems told us that the ratio of hours required for manual drafting versus machine plotting varied from about 3 to 1 to as much 60 to 1. As indicated on page 11, a major part of the design fee is allocated to preparing drawings. The use of computer-aided techniques can and does produce significant savings, and the quality of computer drawings is comparable to those manually prepared.



(Courtesy of Auto-trol Corp.)

Figure 4-2. Interactive Design and Drafting System.

A limited number of applications has produced greater benefits. One large structural engineering firm estimated that, using computer-aided techniques, the design for a 109,000-square-foot building resulted in a total savings of 23 percent, including fees, materials, contract charges, and all capital costs. A significant part of the savings occurred because computer-aided techniques permitted rapid consideration of designs that would, alternately, employ steel, poured-in-place concrete, and prestressed concrete. The design choice considered market price differentials and the construction time that each material and method required.

In another case, an architectural firm told us that, for a $15-million construction job, it would ordinarily use 15 designers. However, using computer aids tailored to architecture, the same amount of design work could be done much more quickly with only three designers.

Savings have not been limited to large, complex problems. One documented instance showed relatively significant savings resulting when the computer was used to solve a rather mundane analysis problem (data generation for structural finite element analysis). The computer run time was two minutes, with a run setup time of 8 staff-hours. The equivalent manual effort would be about 80 staff-hours.

A number of the firms pointed out that the computer has allowed designers to use design concepts which could not or would not have been attempted using manual methods. One example is the "mini-tube" or "tubular" design concept which was used to add structural stiffness to the 23-story Town Center Office Building in Rockville, Maryland. (See fig. 4-3.) The structural engineer on the project stated that new computer technology, coupled with arc welding, made it possible to take advantage of the increased strength and rigidity of highly indeterminate structures. He said, "Without computers, our mini-tube could not have been designed." 4/ Other examples of designs made possible by computer technology are Chicago's behemoth Sears Tower and the dome of the New Orleans, Louisiana, Superdome sports arena.

4/ "'Mini-tube' Concept Stiffens Frame of 23-Story Building," Building Design and Construction (June 1976), pp. 60-61.



(Courtesy of Soratio Allison - Robert L. Meyers, Structural Engineers)

Figure 4-3. Minitube concept. A design not possible without the computer; midbay columns were added during the design of the Town Center Building, Rockville, Md., to create an 11-foot uniform column spacing.

One firm pointed out that although computers have virtually an unlimited scope of application in the engineering design process, the efforts to date have only scratched the surface.

SPILLOVER BENEFITS

If CABD systems prove to be successful, the benefits to be derived would not be confined to CABD itself. Both construction management and the cost-estimating activities might benefit from the availability of a project's computerized data file which would include all of the building description information and which could facilitate retrieval of information, as needed and in the format needed.

Furthermore, a computer output tape with the as-built drawings of a building could facilitate both the management of that building and any future remodeling or rehabilitation of the building. General Services Administration officials advised us that the cost of developing as-built drawings for some of the old Federal buildings being remodeled sometimes costs more than designing a new building. If facility managers had access to computerized as-built drawings showing walls, service utilities, and the like, they could more rapidly and efficiently plan the utilization of space while, at the same time, keeping remodeling requirements to a minimum.

PRACTICALITY OF COMPUTER-AIDED BUILDING DESIGN

In 1972 APEC demonstrated the practicality of a CABD system. Its annual meeting in San Antonio, Texas, that year had the theme, "From Site to Sight in Two Days by Computer." During the conference, a design team, composed of individuals from several different firms representing each of the design disciplines, actually designed a 21-story hypothetical building using computer-aided techniques. Each designer used the computer aids then available to demonstrate how the computer could be used as a professional design tool. The design activities demonstrated included architectural studies, structural design, electrical distribution, piping design, equipment selection, elevator studies, and others. The design was accomplished in both steel and reinforced concrete. The demonstration simulated the real world design process, since integrated CABD systems were not then and are only now becoming available in the United States.

ASEC is convinced that CABD is a practical objective. Since 1970, ASEC has been supporting a modest effort to develop an integrated CABD system for its members, who are primarily mechanical and electrical engineers. It has succeeded in linking or integrating some programs so that the output from one program can be used as the input for another program. The potential savings in this step are significant. Not only does it eliminate the time-consuming job of preparing the input for the second program, but it prevents costly reruns that result when a mistake occurs in the preparation of the input.

Foreign Support of Computer-Aided Design

CABD has been recognized and is in various stages of development around the world. CABD activities are occurring in many countries--Czechoslovakia, Germany, the United Kingdom, France, Israel, Japan, Australia, and Canada, to name a few. The German Government has invested substantial sums of money in the development of computer applications. For example, for the period 1976-79, it has budgeted nearly $260 million for support of computer applications, including an estimated $30-$40 million earmarked for computer-aided design. Foreign activities are summarized in appendix II.

CHAPTER I

USE OF COMPUTERS BY BUILDING DESIGNERS IN THE UNITED STATES

Of the architectural and engineering application computer programs that exist, in both the public and private domain, we are told that there are actually only a relatively few which are commonly used by practicing architects and engineers. Incomplete program documentation, computer hardware differences, and computer language differences appear to be the primary causes of this situation. Also, practitioners tell us that determining the existence, source, and availability of a program is a major problem. As a result, there are many versions of programs resolving the hardware and language issues and there are many essencially duplicate programs.

USE IN BUILDING DESIGN

Existing programs generally perform a single function for a specific discipline. Additionally, most execute analysis functions; that is, performing generally recognized engineering routines based on scientific calculations. Only a limited number of programs--and most of these are proprietary--fulfill other design realization functions. Consequently, although computer aids are used to some extent by many engineering offices, and to a much lesser extent by architectural offices, these uses are applied to the building design process in a sporadic, even though planned, manner during the analysis-type processes of design.

While many computer programs have been developed, relatively few are for design. There is no agreement among designers on why this situation exists. Many believe that some building design processes, especially those in architecture, are more akin to art than science and, consequently, do not lend themselves to being easily converted to a mathematical form which computers can readily handle. Others, while agreeing in theory, believe there is a lot of science involved in architecture and that many more architectural design processes could be performed or aided by the computer than is now the case.

The design process, even that for architectural design, contains repetitive and noncreative steps involving activities such as data manipulation which could be effectively done by the computer. While the computer has not been employed in all possible tasks, the range of functions for which useful programs have been developed is impressive. Appendix III contains a representative listing of available applications.

ACCEPTANCE OF THE COMPUTER AS A DESIGN TOOL

The extensiveness of the available program applications list is somewhat misleading. Few architectural design firms utilize the computer at all: "*** go into 99 percent of the [architectural] offices in the United States and you will find the computer is not a factor in routine architectural services." 1/ Likewise, engineers do not use the computer as much as the list might imply. A 1974 survey of American Society of Mechanical Engineers members found that nearly 77 percent of the engineers surveyed, regardless of their educational background, seldom or never used the computer. 2/ Also the Society for Computer Applications in Engineering, Planning, and Architecture (CEPA) 3/ stated, in an October 1975 report, "Of the 264,000 civil engineers who are in practice today, only 33 percent (88,000) use computers." 4/ We do not know whether the engineers who concentrate on building design work use the computer more or less than these figures indicate. However, our study indicated that a substantial number of civil engineers engaged in building design work do not use computers in any significant volume of their work.

While architects and engineers are associated design professionals, there is understandably a difference in the way each profession conducts its design work. The designs they individually produce are basically different. However, the design of almost any building structure of more than minimum size and complexity will be the work of both architects and engineers. The design profession reflects this joint effort, at times, in firms comprised of both architects and engineers. Other design firms, comprised of only architects or engineers, obtain the additional professional design service they need on a consulting or contract basis.

AVAILABILITY OF COMPUTER AIDS TO DESIGN

To our knowledge there are no integrated building design systems available to designers in the United States at this

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1/David Sides, "Notes on Computers and Architecture," Reflections on Computer Aids, 1975, p. 131.

2/A. B. Soni and L. Torfoson, "Design Technology Transfer, p. 99.

3/Formerly the Civil Engineering Programming Application Group.

4/Civil Engineering Programming Applications, "A Proposal for a National Institute for Computers in Engineering," p. 15.

time, with the exception of an integrated system developed in Great Britain and being marketed and supported in the United States. By integrated design systems, we mean systems composed of many application programs that are able to turn output from one program into input for another. "The objective of this approach is that the designer inputs the minimum information which is logically expanded and reused by the computer as the designer requests various calculations and other manipulations of design data." 5/

Computer hardware systems used for design-related activities are numerous. Some are packaged systems marketed as a design system (fig. 5-1), while others are assembled using equipment of various manufacturers. Any design system capable of performing a full spectrum of design activities will have certain items of equipment, as shown in fig. 5-2. As would be expected, design systems found in the design community differ, depending on size, purpose, funding, and so on, of the design work to be undertaken, as well as on the different emphasis of the architectural and engineering professions and the organization's commitment to computer-aided design.

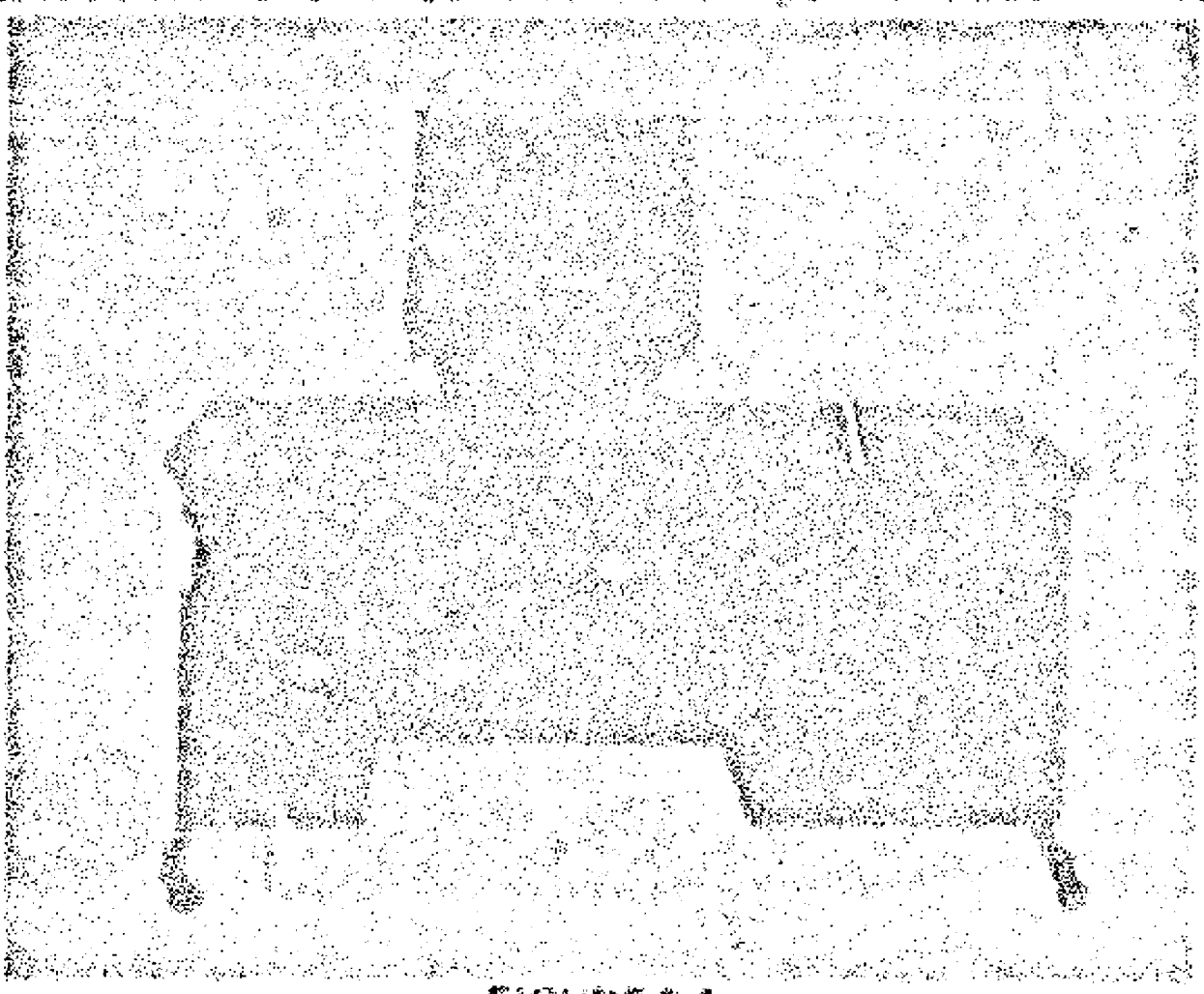


FIGURE 5-1
INTERACTIVE GRAPHICS SYSTEM. THIS SYTEM HAS MERGED TWO GRAPHICS TECHNOLOGIES TO CREATE A TECHNOLOGICAL FIRST, COMBINING SOFTWARE, HARDWARE, AND FIRMWARE TOGETHER AS AN INTEGRATED PACKAGE. ("FIRMWARE" IS THE USE OF CARTRIDGE OR CASSETTE PROGRAMED MEMORY.)
(Courtesy of Tektronix, Inc.)

5/Applied Research of Cambridge (Canada) Ltd., "Feasibility Study for Computer-Aided Design Systems for Ontario Housing Corporation," para. 2.2.2.



(Courtesy of the Computervision Corp.)

Figure 5-2. Design system including (left to right) (1) design console with large-screen CRT, telewriter, and electronic sketch pad, (2) large flatbed plotter/digitizer, (3) 14-million word disk drive, and (4) minicomputer with magnetic tape drive.

CAAD-type applications in the United States can be found in academia, design offices, Federal agencies, service bureaus, and user groups. During our study, as evidenced by appendix I, we visited organizations belonging to each of these categories to discuss CAAD and observe their use of the computer in their design functions.

GENERAL OBSERVATIONS

Academia

In the past, the large computer was most common in educational institutions, with the engineering, mathematics, and science departments being dominant users. However, academia is in a transitional period with a trend towards minicomputers and time-sharing systems--often used in an interdisciplinary, universitywide fashion (fig. 5-3). This means the engineering and architectural departments often must compete with the other departments of the university for use of the computer.

Academia CAAD-related developments are not directed to professional architectural or engineering use to any great extent. Still, a large amount of the CAAD software in use today evolved from academic research, and more of it supports engineering than architectural concepts. What is found at educational institutions is applications being used (1) as teaching tools in schools of design and in basic undergraduate curriculums and (2) for research on CAAD-type system components such as data bases, graphic input-output, and the like.

We observed that at schools where some computer exposure is given, the computers frequently were either old or very large. Comparatively few schools have minicomputers for engineering software development and use, although the trend is in this direction. Most minicomputers in academia appear to be used in laboratories for such things as physical data acquisition, as well as for computer hardware study and experimentation.

Academia has many computer-related problems. This is particularly true in engineering education, where the computer has a much larger role than in architecture in the current curriculum at most schools. We were told that, frequently, architectural students get no exposure to the computer and its usage during their education. However, this is not to imply that engineering students get adequate exposure to the computer, because we are told this is not



FIGURE 5-3

A MINICOMPUTER SYSTEM WITH CONCURRENT BATCH AND MULTI-TERMINAL OPERATION CAPABILITIES

the case for many. One cause of this inadequate exposure is that, at most educational institutions, computer systems are saturated. The reason given was that educational institutions generally operate time-sharing computer systems to serve all activities in the institution. Departments are often allocated limited blocks of time and/or limited blocks of computer resources for their students' use. As a result, students do not get to utilize the computer in their educational training to the desirable extent.

The switch from the larger computers to minicomputers has left many engineering faculty members without application software to use in conjunction with their courses. Generally, minicomputer manufacturers do not have and are not developing engineering education or application software. This forces faculty members to locate or develop their own programs. We were told that it is frequently difficult for the departments to obtain the funding support necessary for internal development of needed programs, or for even the procurement of needed programs available elsewhere. Often, a temporary solution is found by implementing software originally developed on the second-generation computers of the 1960s. These programs are historically small, one-function analysis applications written in a simple, though now outdated, version of FORTRAN. In such cases, the students will not be exposed to the current application software.

Thus, the programs used for instructional purposes are frequently old, out of date, and not representative of the programs a study will find in practice. More importantly, perhaps, professional practice has outpaced academia's financial ability to keep abreast in the applied research and development areas. The move to time-sharing systems has not only created a shortage of needed graphics terminals within the engineering and architectural departmental areas, but they also do not usually have available the peripheral equipment, such as vector graphic terminals (fig. 5-4), digitizers (fig. 5-5), and plotters (fig. 5-6) that they need to give the students knowledge of and experience using real-world computer-aided techniques.

Design-Construct Firms

The large design-construct firms also rely on the larger computers. These firms have made what we believe to be the largest expenditures for the most complete and sophisticated computer-aided design application in the private sector. Much of the expense has gone into the development and acquisition of extensive computer program libraries. However, we

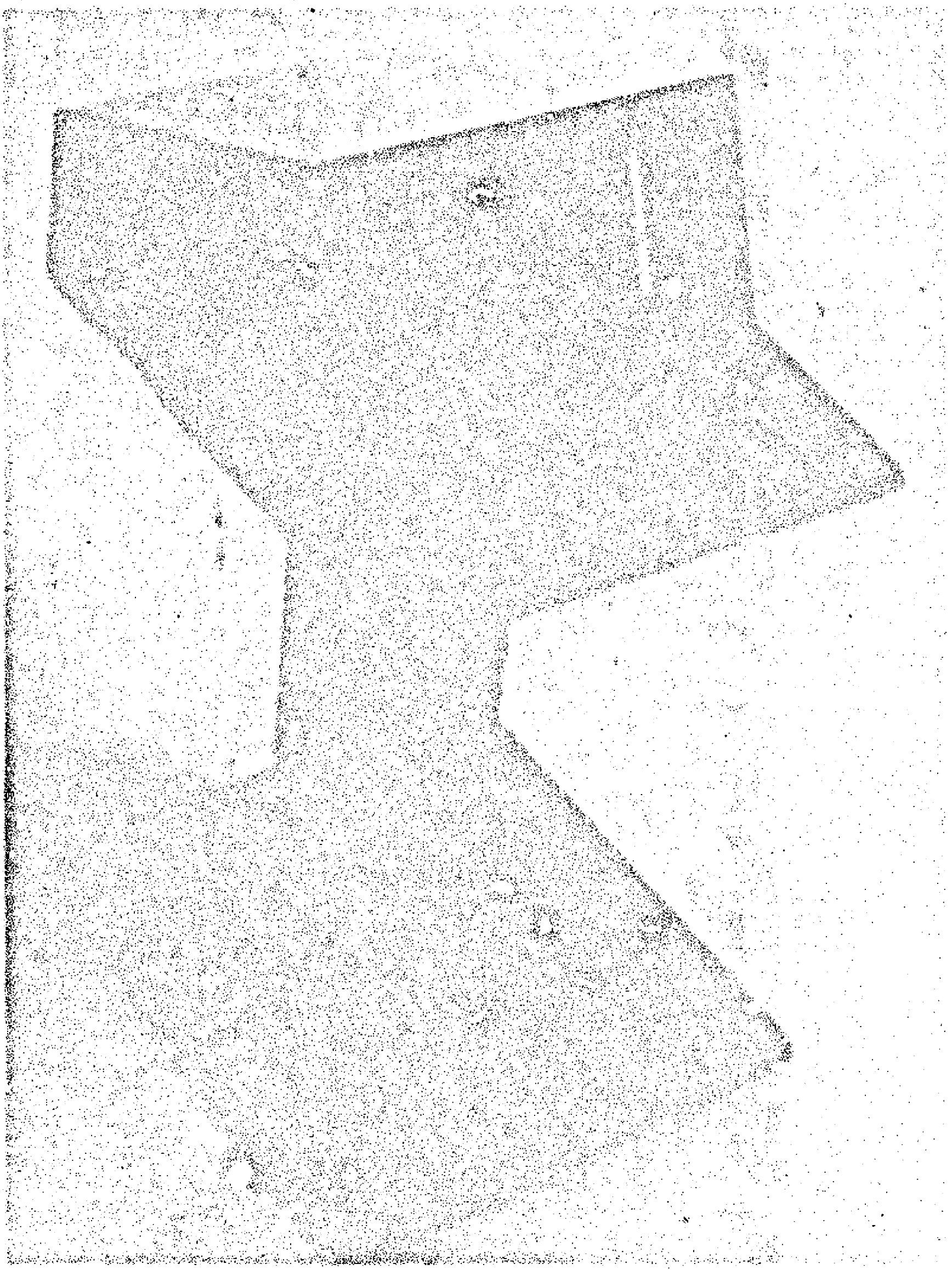


Figure 5-8. Graphics Terminal. (Courtesy of Tektronix, Inc.)



Figure 5-5. Data Digitizer. (Courtesy of Summagraphics Corps.)



(Courtesy of California Computer Products, Inc.)

Figure 5-6. Vertical Plotter.

were not made aware of any integrated CAED systems being developed or used by any of these firms. Our study suggests that a number of design-construct firms have expertise and technology involving computers. This expertise and technology is generally proprietary and not available for rapid diffusion throughout the industry.

Design Firms

There are also some architectural and engineering firms, both large and small, which have committed themselves to computer usage, generally with one of the numerous smaller or minicomputers (fig. 5-7). The degree of commitment varies from firm to firm, without regard to size. Committed firms are frequently members of one or more cooperative users' group and/or utilize the services of one of the many existing service bureaus.

Most of the application software being used by design firms has been developed internally by the firm or obtained from other design firms. Although the Federal Government possesses a large number of application programs, it is not a major source of programs for design firms. Designers contacted during the study told us that one reason for firms not using Government programs was the difficulty firms have in locating Federal programs and in obtaining a program once it is located. Another reason they cited was the cost involved in acquiring a Federal program. For example, the Computer Software Management Information Center in Georgia, which distributes programs for NASA and the Department of Defense, charges prices for the programs it receives, copies, and distributes. While we did not study the prices, we received a number of assertions that the prices are too high for general use by many firms and individuals. We were told that these prices also prevent general use by academia and, thereby, prevent universities from acting as technology transfer mechanisms. Some Federal agencies do not distribute or sell their programs.

Some design firms, primarily engineering, have made substantial investments in automated drafting systems. The computer selected by many of these firms is the smaller minicomputer which has evolved to the point that it rivals, and sometimes exceeds, the power, capability, and economy of the older large computers.

Service Bureaus

Computer services are offered or marketed by many companies--or service bureaus--throughout the country. Service bureaus typically offer a library of computer programs



(Courtesy of Prime Computer, Inc.)

Figure 5-7. Minicomputer system featuring a 1-million byte main memory, central processor, 392K byte disk storage, and an 8-million byte memory extender unit.

through time-sharing or batch-processing services over telephone line networks, as well as other related computer services. Increasingly, graphics programs suitable for design work are being offered. Some bureaus will go so far as to help the user prepare his input data. Bureaus generally maintain up-to-date programs and from time to time enhance programs, sometimes converting them for use on additional types of computer hardware. They do not, as a matter of practice, maintain, validate, or enhance programs for use other than as a part of their services.

Bureaus acquire software through internal development and from trade associations, industrial firms, software developers, and Government sources. Programs are also acquired from foreign sources; such sources appear to be increasingly important. In the past, academia was a major source of software, but we were told that it has diminished in importance.

Earlier, we stated that there are few true building design programs available. One of those programs which has been developed with design capabilities is available through a service bureau. The program reportedly can design the structural subsystem of an entire 30- or 40-story building, in concrete or steel, complete in one pass with one set of data input in less than 10 minutes.

A fairly recent development has been the appearance of service bureaus which offer only automated drafting services (fig. 5-8). These operations are either totally independent or, sometimes, the computer operation of a design firm which has been spun off into a separate subsidiary.

Cooperative Users' Groups

There are a number of cooperative groups which provide engineering application computer programs, exclusive of time-sharing services. There are basically three types of groups:

--Groups of individuals or organizations which use the same kind of computer. These are frequently set up by the manufacturer of the computer.

--Groups organized for users of a particular package of programs. The ICES (Integrated Civil Engineering System) Users Group is an example.

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(Courtesy of California Computer Products, Inc.)

Figure 5-8. High-performance drafting system with large flatbed plotter and controller--the type of equipment frequently used by firms providing automated drafting services.

—The last type is a group of computer users who have joined together to exchange programs and information relating to computer usage problems. Examples of groups in this category are (1) APEC (Automated Procedures for Engineering Consultants, Inc.), which is also involved in developing new programs, and (2) CEPA (Society for Computer Applications in Engineering, Planning and Architecture).

User groups vary widely in their methods of operation and in the extent to which they maintain and support the programs available to their members. Programs available through such groups are primarily for engineering and business/management applications. There are no similar user groups, to our knowledge, supporting architectural application programs.

CHAPTER 6

FEDERAL COMPUTER-AIDED BUILDING DESIGN AND RELATED ACTIVITIES

Opportunities for the use of CABD and CABD-type techniques, except in a review mode, are somewhat limited within the Federal Government. Agencies generally contract out most design work (75-80 percent) to private architects and engineers.

COMPUTER-AIDED DESIGN PROJECTS

There are a number of Federal Government agencies working on computer-aided design projects relating to their specific missions. One of these, the Army Corps of Engineers' Computer-Aided Engineering and Architectural Design System (CAEADS) project, is for military construction projects. Two others--the Navy's Computer-Aided Ship Design and Construction (CASDAC) project and NASA's Integrated Programs for Aerospace Vehicle Design (IPAD) project--could possibly be adapted for building designer use.

Computer-Aided Engineering and Architectural Design System

The Army Corps of Engineers is active in the development of CABD. Their CAEADS project stems primarily from the Corps' desire to use CABD on its internally designed military projects, to use the computer to make penetrating reviews and analyses of about 80 percent of its military design work done by private architects and engineers, and to provide an integrating tool for use by the private architects and engineers designing its military construction projects. At the time our study report was being prepared, there were no plans to extend this to the civil works functions of the Corps.

The system is currently being developed by the Corps' Construction Engineering Research Laboratory (CERL) under the sponsorship of the Office of the Chief of Engineers. It is to be an integrated set of computerized tools to assist the programmer, planner, and designer of construction projects. In many cases, the Corps visualized these tools to supplant present manual methodology. In other cases, the Corps believes, current processes will be replaced by new ones. The objective of CAEADS is to improve the quality of design and reduce costs.

Although several years of preliminary planning and exploratory research have gone into CAEADS, it is still in its infancy. CAEADS as now envisioned includes (1) the integration of management control-type functions, such as project generation and the evaluation and authorization processes, all of which are unique to the Corps and (2) an integrated CABD-type system, as discussed in this report. Also incorporated are project cost estimations at various levels of project development, cross-checks with the Corps' guide specifications, automated project specifications, and automated drafting.

Current efforts have been primarily concerned with the conceptual design of CAEADS, a detailed plan for its development and for resolution of 3-dimensional data base issues. CAEADS was the only ongoing, funded, integrated CABD system development project found in the United States during our investigation. The CABD project of APEC is dependent upon the inclusion of new programs as they are developed; the programs are not necessarily based on the creation of CABD. However, the development of CAEADS has been retarded due to low and fluctuating funding levels, and, at this time, its future is uncertain.

Integrated Programs for Aerospace Vehicle Design (IPAD)

This is a NASA-sponsored project to develop an integrated computer-aided design system for the aerospace industry. While IPAD is being developed for the aerospace industry, some experts have told us that concepts, and possibly the system itself, could be adapted for use in the building industry. "IPAD is to be a prototype computer-aided design software system to provide company-wide access to design information and will be incrementally developed on two different computers with extensive user involvement throughout [system] definition, design, and software checkout." 1/ The project, started in 1972-73, is scheduled for completion in 1981. The aerospace industry has been involved from the beginning through reviews and critiques and through early evaluation of incremental capabilities. It is estimated the project will cost $11 million to develop the system to a first-level capability.

1/Robert E. Fulton and Susan J. Voight, "Computer-Aided Design and Computer Science Technology," p.2.

At the very beginning of the project, NASA contracted with two separate aerospace companies to do independent feasibility studies for an IPAD system. These studies were extensive, covering many diversified considerations, as shown in figure 6-1. 2/ Many of these considerations apply to building design as well as aerospace design.

One of NASA's mission objectives is to provide the aerospace community with advanced technology for aerospace design. With this objective in mind, NASA concentrates on high-risk, high-payoff projects. Generally, these are projects which the industry wants but is unable to undertake itself, in spite of the potential benefits.

2/General Dynamics/Convair Aerospace Division, "Feasibility Study of an Integrated Program for Aerospace Vehicle Design (IPAD) System," vol. 1, p. 2.

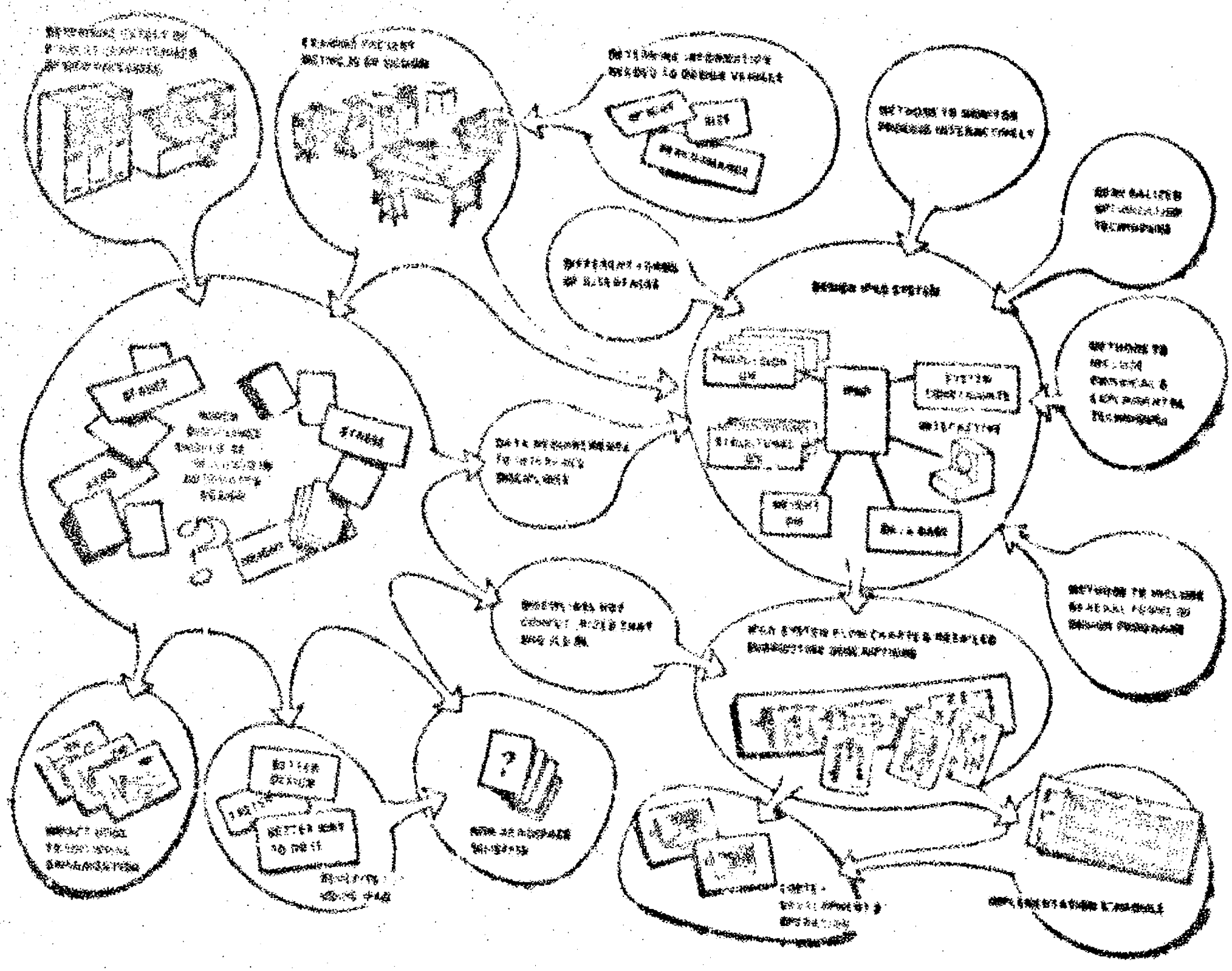


Figure 6.1. IPAD Study Flow Chart

IPAD is intended to be a tool to improve the efficiency and effectiveness of designers and technical staffs and the coordination of design and manufacturing technologies. 3/ Its software will augment, not replace, existing software systems used by aerospace companies. As currently visualized (fig. 6-2), IPAD will consist of

—executive software to control user-directed processes through interactive interfaces with a large number of terminals in simultaneous use;

—a large number of utility software packages for routine information manipulation and display functions; and

—data management software for efficiently storing, tracking, protecting, and retrieving data on multiple storage devices. 4/

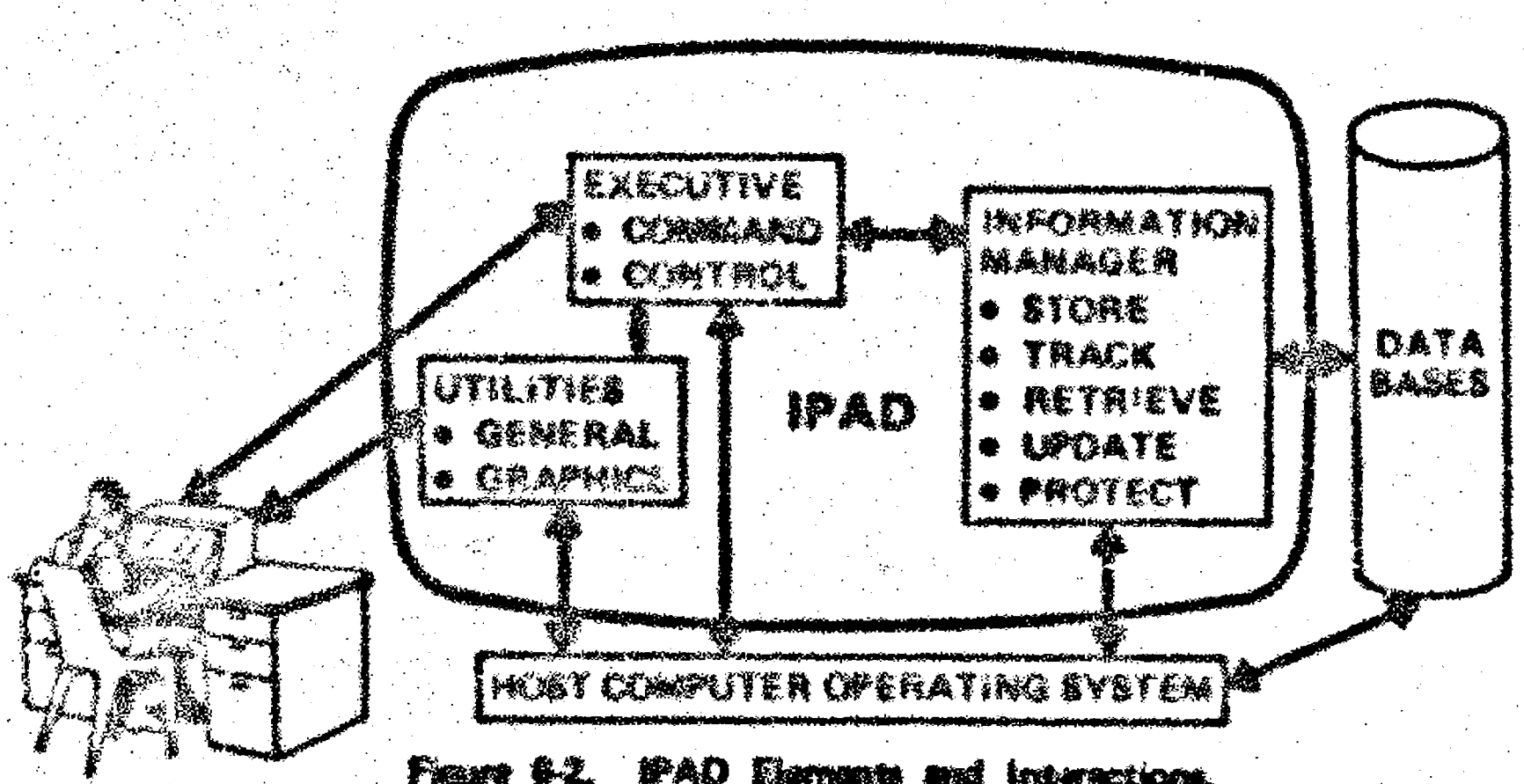


Figure 6-2. IPAD Elements and Interactions.

3/NASA Langley Research Center, "IPAD Prospectus," pp. 1-2.

4/Ibid., p. 2.

Analysis and design programs are not part of IPAD, but must be provided by the user. These could be existing and future proprietary programs or those in the public domain. The developers emphasize that IPAD is not automated design and will not constrain design methods. 5/

If IPAD's general arrangement is kept, the technology used would appear to be extendible to other disciplines such as building design. However, at least at this point, IPAD's computer hardware and software requirements appear to be too extensive for direct transfer to the construction industry. On the other hand, IPAD does create a model which, on a reduced scale, might be transferable.

Computer-Aided Ship Design and Construction

The Navy has been putting 1 to 2 million dollars annually since 1965 into the support of CASDAC as a research project, because one of the Navy's perceived missions is to provide the Nation's shipbuilders with advanced technology.

Maximum user involvement is sought by the Navy through opinion surveys, advisory committees, and development contracts with the individual shipyards. Generally, the shipyards have accepted stand-alone programs and the small, incremental changes to their processes. But, they are not using the larger integrated systems.

The CASDAC project is a focal point, umbrella, and management office for computer aids to design and construction. Several programs and systems have or will be developed under the project, some of which are potentially transferable, at least in part, to the construction industry. Two of these, the Computer-Aided Design Environment (COMRADE) and the Integrated Ship Design System, are discussed briefly below.

Computer-Aided Design Environment

COMRADE, introduced in 1972, is a set of computer systems software with capabilities, not limited to ship design, that provide a framework for assembling and coordinating programs, data, and users into an integrated subsystem--quite similar to the objective of NASA's IPAD project. The three major components of COMRADE are the executive, the

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5/NASA Langley Research Center, "IPAD Prospectus," p. 2.

data management, and the design administration systems. These are tools with which integrated design systems can be constructed. 6/

In 1973 a paper presented at the National Computing Conference in New York illustrated the general nature of COMRADE by using building design, rather than ship design, for the purpose of demonstrating potential applications (fig. 6-3). The paper's author concluded that COMRADE

BUILDING DESIGN USING COMRADE

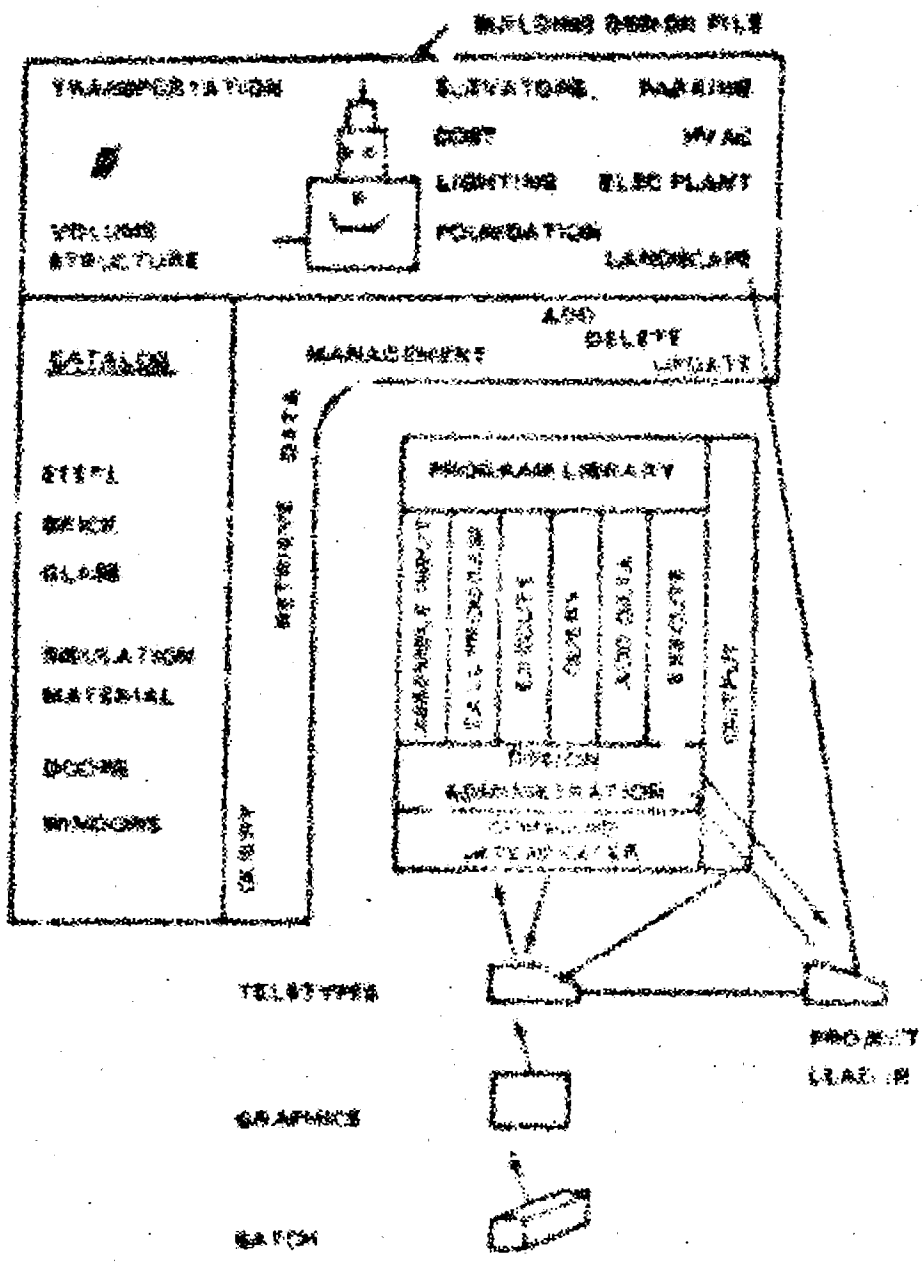


Figure 6-3. Building Design Using COMRADE.

6/Thomas R. Rhodes, "The Computer-Aided Design Environment Project (COMRADE)," American Federation of Information Processing Societies, vol. 42, pp. 319-324.

permits the development of an efficient man-machine team, with the man always in control of the design process. Communications between the various design disciplines are vastly improved since access to the design files at any time during the design process provides up-to-date information to designers. 7/

Integrated Ship Design System

This, like IPAD, is a prototype system, except that it is for ship-concept design (fig. 6-6). Its objective is to more rapidly synthesize a ship design and efficiently perform the engineering analyses and design calculations and to facilitate the exchange of information required by different disciplines involved in the ship's design. Operating under CONRADE, the system allows interaction between designers and the computer through the use of conversational teletype and graphics terminals. 8/

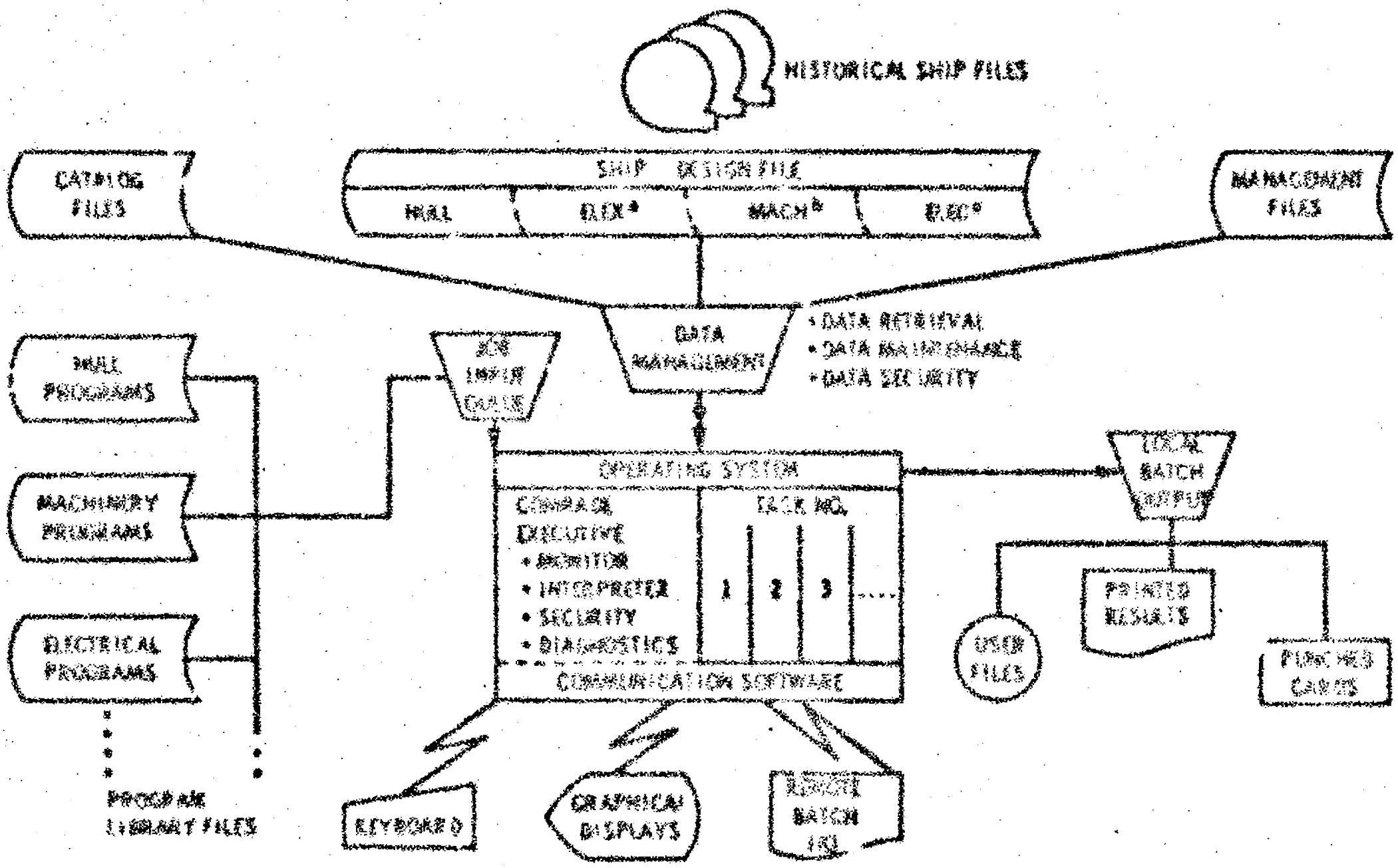
Ship designs and building designs have much in common. Each entails feasibility studies, conceptual design, preliminary design, and contract or detailed design. In each case, the major design decisions and all functional characteristics are determined during this process. Since the processes are quite similar, it is conceivable that the general nature of this system might be transferable to the building industry.

Current Status of CASDAC

By 1972 the Navy had demonstrated that CASDAC was a feasible approach and it was recommended to the Chief of Naval Operations that a development project be established. At that time, Navy officials estimated they would need about $40 million over an 8-year period to develop an operational system. Funding was approved to start the development project in fiscal year 1977. During the 4-year interim, CASDAC has proceeded on research funds. We were advised that no funds were authorized for fiscal year 1976 and that the future of the project is uncertain.

7/ Jack Brainin, "Use of CONRADE in Engineering Design," American Federation of Information Processing Societies, vol. 42, pp. 325-326.

8/ Jack Brainin, "Functional Description for the Integrated Ship Design System (ISDS)," Naval Ship Research and Development Center, Report 4651, April 1975.



Notes:

a - Electronics
b - Machinery
c - Electrical

Figure 6-4. Overview of the Integrated Ship Design System.

The estimated cost reduction or cost avoidance potential of the CASDAC programs could reach $155 million annually at the end of the 8-year development, according to Navy officials. Savings would start to accrue after the first year of development. The predicted cost savings generated by CASDAC are estimated to be 5 percent of the Navy's annual ship construction budget, or 15 percent of the portion of the budget dealing with new ship design and construction. In addition, there would be other related savings, such as maintenance, conversion, and repair cost reductions.

The project, while somewhat similar to the IPAD work at NASA, is broader than IPAD in that it covers both design and construction processes. Under established practice, the Navy is responsible for conceptual ship design, and the shipyard to whom the contract is awarded is responsible for the final design details and construction of the vessel. The CASDAC work would not disturb this allocation of responsibilities. It would cover it all, computer-aided design and construction, and would emphasize the partnership of the Navy and the private yards.

As previously stated, the cost of the program will be substantial over the next several years, and the Navy hopes to fund some of this cost through contracts with the shipyards. The plan is to couple CASDAC project application work with a shipbuilding contract. The work would be meshed into the CASDAC overall layout and the entire package would be available to all yards. The philosophy is that the Navy should pay for the work once, after which the cost-saving routines should be available to, and used by, all yards. The Government, in turn, should benefit from each use of the applications in any of the yards.

FEDERAL USE OF COMPUTER-AIDED BUILDING DESIGN-TYPE TECHNIQUES

One agency of the Federal Government makes use of a limited CABD-type system. During 1973-74, the Veterans Administration acquired a computer-aided architectural design system for its internal use. The agency has used the system, which has a limited CABD scope, in the development of perspectives and preliminary drawings for veterans hospitals (fig. 6-5).

Veterans Administration officials told us they have not been completely satisfied with the system. Agency officials are currently exploring ways to expand and enhance

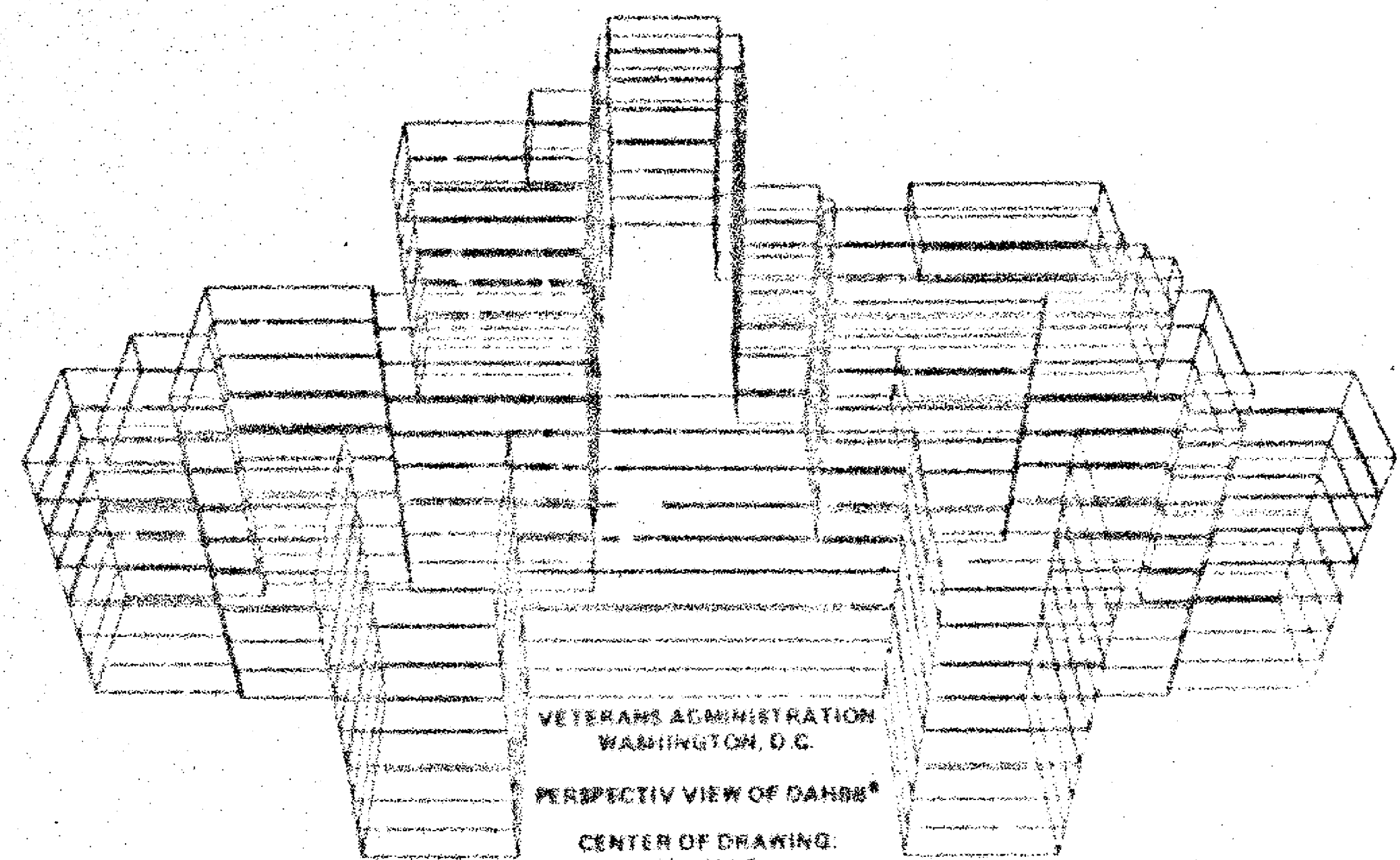


Figure 6.5. Example of the Veterans Administration's use of computer aids for hospital design.

Note * - Veterans Administration Hospital, Chicago South Side

the system's capability. Plans include continued use of the system, but primarily in the design review mode and as a tool to recommend changes in design proposals.

OTHER FEDERAL ACTIVITIES

Throughout the Government there are small projects to develop programs to perform certain functions, such as computerized specifications, energy analysis, and life-cycle cost calculations, which would be part of any CADD system. There is little or no coordination of most of these projects. For example, the General Services Administration, the Army Corps of Engineers, the Naval Facilities Engineering Command, NASA, and the Bureau of Reclamation were all computerizing their design and construction specifications. Two agencies--the Department of Health, Education, and Welfare and the Department of Energy--were not attempting to computerize their specifications because, in their opinion, such an action would not be cost effective. There are differing opinions among engineers and architects, as well as the Federal agencies, as to whether computerized specifications are cost effective.

National Bureau of Standards

The primary interests of the Bureau's Center for Building Technology are in setting standards for the industry to use. Center officials believe that the Bureau's role should be to focus on measurements, measuring quality, and setting standards for quality. The Bureau's Institute for Computer Sciences and Technology has similar views of focusing on setting of automated data processing standards. Which Institute within the Bureau that would be the focus for the setting of engineering application software standards, however, was not clear. These factors of automated data processing and application program standards are important in the eventual implementation of CADD in the United States; they were one of the first issues addressed in the European computer-aided design activities.

CHAPTER 7

FACTORS INHIBITING THE DEVELOPMENT OF COMPUTER-AIDED BUILDING DESIGN SYSTEMS

Integrated computer-aided building design systems do not seem to have a prominent place in design developments in the United States.

A wide variety of factors impact the development of CABD. The inhibitors range from the nature of the industry structure itself to disincentives to the use of computers.

STRUCTURE OF THE INDUSTRY

The organization of the building industry is fairly well summarized in a statement made in a 1976 report by Applied Research of Cambridge, Limited, a British firm:

> "The organization of the building industry is unique particularly in its separation of design from production and in its fragmentation into various professions, trades and manufacturing agencies. The industry is a complex accumulation of largely separate, but interlinked, practices, techniques and responsibilities. The major part of the industry relies on traditional methods both of organization and construction. These account for the major part of its workload. However, in various areas innovations are occurring. Normally they benefit a single interest in the industry, a particular profession or a particular construction process. It is only when an innovation can cut across the inter-interest boundaries that a change can overcome the fragmentary nature of the industry." 1/

Given the organizational structure, good communications and professional interaction would be necessary to the development of cost-effective integrated CABD systems. The problem was described by S. Daryanani in a 1970 National Bureau of Standards Symposium address. He made the following comments:

> "* * * the architect (as leader of the design team) has to depend on professional consultants in the engineering areas * * *".

1/ Applied Research of Cambridge, Limited, "Integrated Computer-Aided Building and the OXSYS Project," p. 2.

"This diversity of intellectual disciplines involved in the building design generally fragments the building team in several ways, the most important being the intellectual fragmentation. The architect does not appreciate the mechanical engineer's goal. The mechanical engineer does not care about the electrical engineer's objectives; and so on. The design profession is like a universe with several planets, each merrily in its own orbit.

"The most damaging consequence * * * is the problem of communications * * *.

"The lack of communication always results in suboptimization of design. Conceived without communication, the best structural design can force a suboptimal mechanical design. * * * The optimized building design is more a matter of communication than of linear programming.

"The last consequence of lack of communication is expensive duplication of effort. The same information is handled over and over again by different persons involved in the design process." 1/

There is no single organization within the building industry where matters of mutual interest such as CABD can be addressed. Recently, professional and trade associations, such as the National Construction Industry Council, have started holding joint meetings and have made attempts to form multi-interest associations to provide a single voice for the industry.

If there is a potential for the future of integrated CABD, the nature and disparity of the various groups necessary to its success suggest the need for a single focal point around which CABD can develop. In the last couple of years, at least, two new organizations have emerged which have the potential for assuming positions as central focal points for construction and its related activities. These are the National Institute of Building Sciences (NIBS) and the National Construction Industry Council.

1/S. Daryanani, "Computers and the Building Industry," Use of Computers for Environmental Engineering Related to Buildings, p. 788.

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National Institute of
Building Sciences

The Institute was created as part of the Housing and Community Development Act of 1974 because the Congress saw a need for a focal point for building science and technology. The act states

> "(A) that the lack of an authoritative national source * * * to advise both the public and private sectors . . . with respect to the use of building science and technology . . . imposes severe burdens upon all those who procure, design, construct, use, operate, maintain, and retire physical facilities, and frequently results in failure to take full advantage of new and useful developments in technology which could improve our living environment; * * * and (D) that the existence of a single authoritative nationally recognized institution to provide for the evaluation of new technology could facilitate introduction of such innovations and their acceptance at the Federal, State, and local levels." 1/

NIBS--which is to be representative of the various segments of the building community, of the various regions of the country, and of the consumers who might be affected by its actions--consists of not less than 15 nor more than 21 members appointed by the President, with the advice and consent of the Senate. For the purposes of balancing the public and private interests on the governing board, the legislation defines architects and engineers as public interest representatives. The Institute is designed to be self-supporting and eventually outside Government control. It will be a non-Government, nonprofit forum for all elements of the building industry. The Government provided $10 million in seed money to start NIBS and finance its activities during its first 2 years. After this initial funding, money will have to be generated from other sources, both public and private, such as grants and contracts.

The board of directors of NIBS has made it clear that it intends to make NIBS the nationally recognized authority on performance-oriented criteria for building construction and on building technology, codes and standards, and design innovation. Its intent also is to serve as referee between all industry sectors.

1/Public Law 93-383, Aug. 22, 1974 (12 U.S.C. 1701j-2).

In general, NIBS will be working for more uniformity in building codes and other regulatory processes and for methods to encourage innovation, with emphasis on performance criteria and standards. Indications are that NIBS is interested in advancing computer usage, and the computer will play a major role in the primary thrust of NIBS--building codes and standards.

National Construction Industry Council

The Council consists of national associations representing the professionals, managers, suppliers, and educators in construction. It is a relatively new organization, showing signs of progress towards becoming the industry's single voice. One of its current interests is the establishment of a Federal Office of Construction within the Federal Government. Several of the large professional associations of the design community are members, including the American Consulting Engineers Council and the American Society of Civil Engineers, as are some of the large construction associations, such as the Associated General Contractors of America and the American Subcontractors Association.

At the time of our study, we saw no indications that the Council would become directly involved in the development of new technologies for the industry. Still, it could serve as a valuable center for letting the industry's needs be known to NIBS and others who will be involved in technological developments.

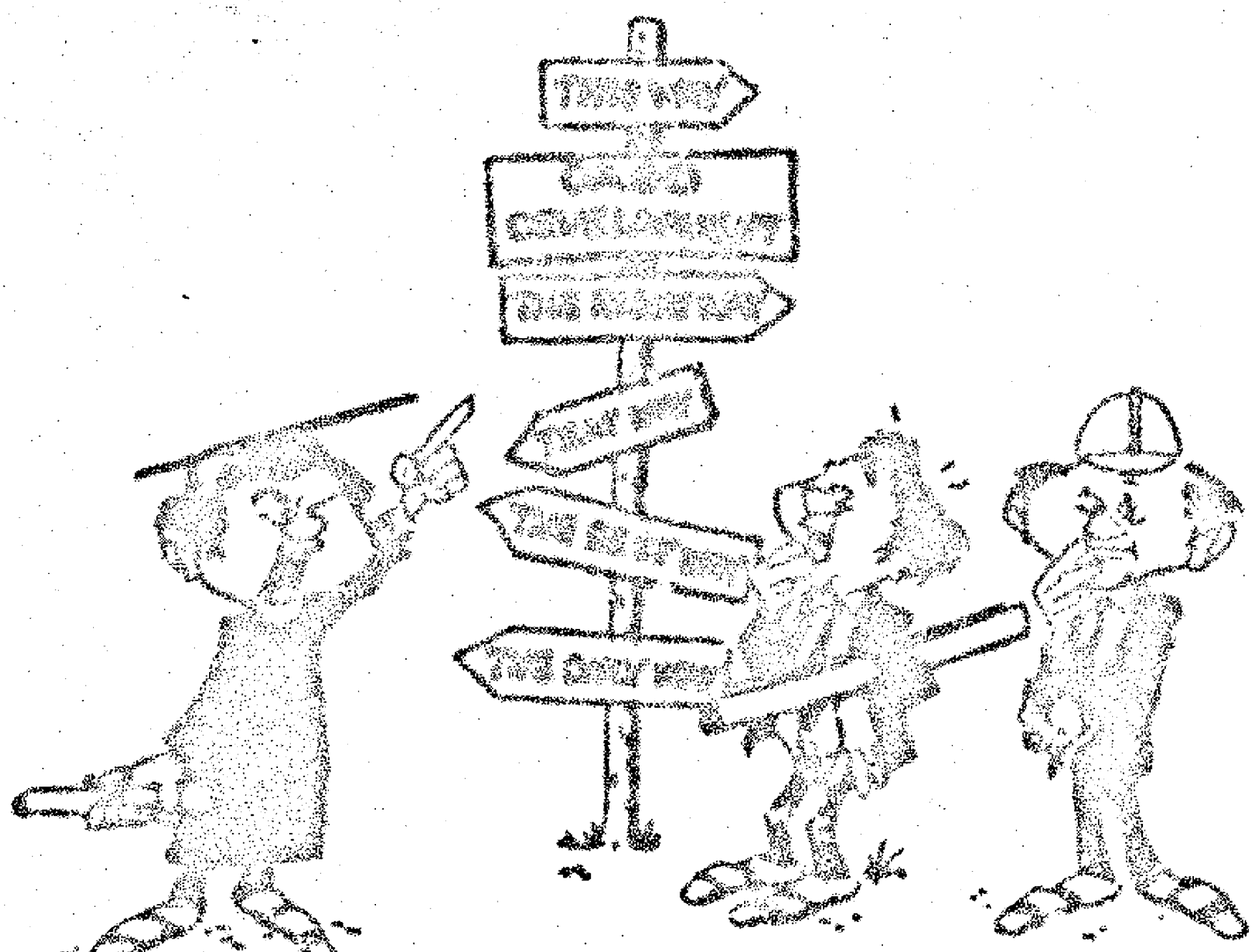
FLUCTUATING WORKLOAD

Another important factor is the fluctuating workload of the industry as a whole. Many industries are virtually assured of ongoing work over a period of several years--the building industry as a whole is not. The products of design firms are not generally of the type that can be held in inventory during slow periods.

SYSTEM DEFINITION

One problem facing the development of CABD is the lack of agreement among researchers and system developers on the requirements and scope of a CABD system. Nevertheless, there is an increasing body of opinion pointing towards integrated systems. This has been the course of computer-aided design work in other industries, such as in aircraft, shipbuilding and automobiles.

We were told that there have been relatively few design programs written and successfully applied in practice. Part of the problem appears to stem from a combination of (1) difficulties in defining design problems in a way which would make them susceptible to rigorous mathematical proof, (2) intraprofessional acceptance of heuristic design logics, and (3) lack of standards for engineering application software. Many designers have complained that most design programs, especially architectural applications, do not fulfill the needs of the designer.



STANDARDS

A major underlying factor inhibiting the development of CADD is the lack of applicable standards. For example, there are no standards for programing engineering application programs, there are no standards for documentation for such programs, and there are no standards for checking engineering calculations. As evidence that standards can be developed, the British, Australians, and Germans have developed standards for documentation of engineering application programs.

Currently, computer program development is unrestricted with regard to language, dialect, hardware and software environment, documentation, and maintenance. There are also no standards or requirements which must be followed to permit programs and systems to be easily transferred to other users and computers. Although some overlapping is necessary, the unrestricted development of programs has resulted in programs repeatedly being remanufactured with ensuing large wastes in manpower and money. Inadequate programs also result in inefficient usage and losses in confidence in computer-based techniques. 4/

"The extensive, uncontrolled, and unmonitored growth of civil engineering applications software has been such that the situation with regard to the usability and availability of this software is in a thoroughly chaotic state." 5/

This statement was made in 1972, but remains just as true today as demonstrated by the CEPA study of software issued in October 1975, 6/ which stated "A considerable number of computer programs exist today but vary widely with respect to quality and availability. An evaluation and culling process would be necessary to transform the bulk into an effective national resource."

4/Robert L. Schiffman, "Report on the Special Workshop on Engineering Software Coordination." p. 1-2.

5/Ibid., p. 2.

6/Civil Engineering Programing Applications, Inc., "A Proposal for a National Institute for Computers in Engineering," p. 6.

The CEPA study reported that it identified 7,394 civil engineering applications programs and systems. The study conservatively estimated the cost of preparing these largely duplicative programs was 6,650 staff-years of effort and $407 million. 7/

INDEPENDENCE OF THE VARIOUS DESIGN DISCIPLINES

Figure 7-1 represents how the decisions of the various building designers affect the total costs of an office building. Each discipline's decisions can and do affect the costs associated with each of the other disciplines. It is in the shaded areas where life-cycle cost problems occur. The amount of overlapping is constantly increasing as buildings become more complex.

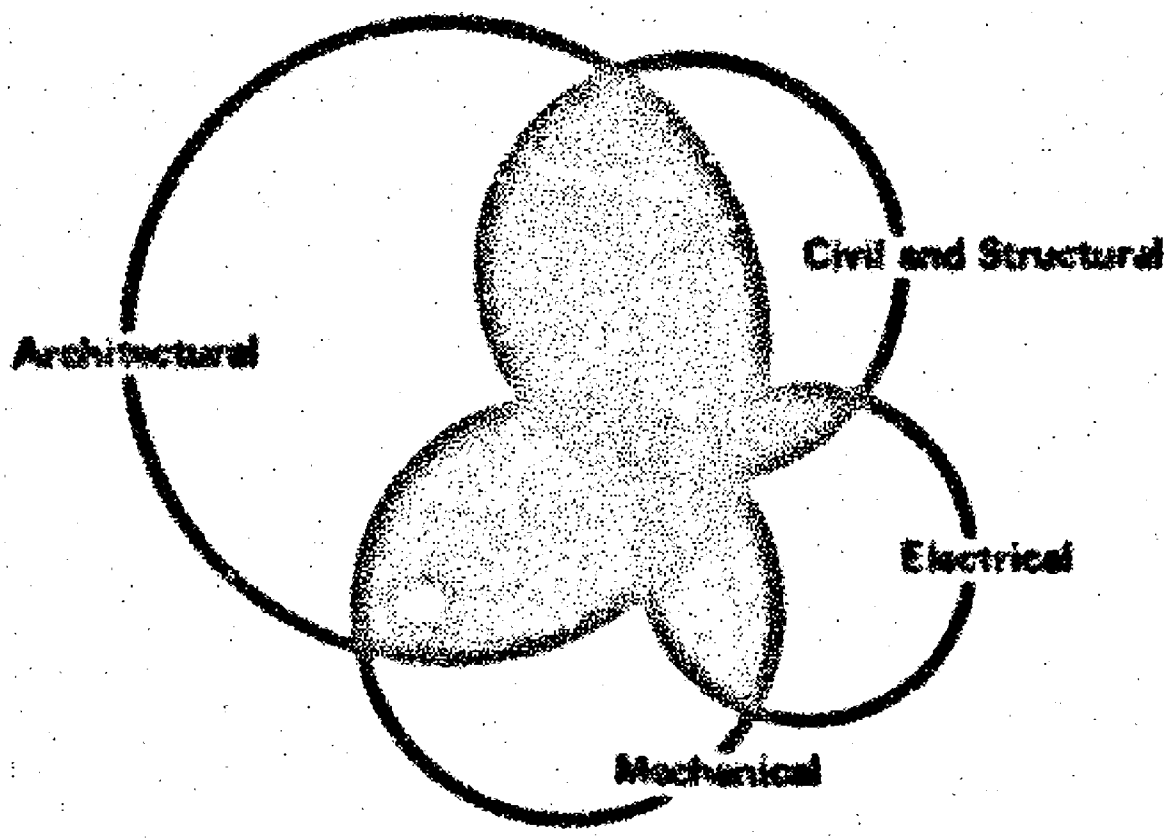


Figure 7-1. Effect of decisions by various disciplines on total building costs. Chart is based on typical commercial high-rise office building; effect will vary according to type of structure.8

7/Civil Engineering Programing Applications, Inc., "A Proposal for a National Institute for Computers in Engineering," p. 6.

8/Dell'Isola, Value Engineering in the Construction Industry, p. 14.

Following traditional building design practices, each discipline generally reviews its own requirements and establishes and modifies its particular criteria. As mentioned previously, this independent approach may not be conducive to the most economical building design in terms of life-cycle costs. Instead, individual disciplines have been devoted to evaluating the impact of those decisions on the total building system in terms of life-cycle costs. 9/

DISINCENTIVES TO USE OF COMPUTERS

Many of the firms we contacted during this study indicated that negotiations for design contracts, both public and private, tended to emphasize manpower time and material costs. Computers and all their related costs are considered as overhead. They said labor and material costs are generally accepted without question, but overhead gets close scrutiny and certain items are frequently rejected or subjected to negotiations.

The computer can make a tremendous impact on the operations of a design firm. In firms making extensive use of the computer as a tool in the design process, computer activities are no longer an incidental expense. Computer costs instead comprise a significant portion of the firm's operating costs. For years, designers have charged for their services based on manpower costs plus a multiplier for overhead and profit. Computer charges, which have no relationship to manpower costs, do not fit into this scheme.

The problem can be solved by simply replacing manpower costs with computer costs for the job performed. Computer costs are much more complicated than manpower costs--consequently, the problem is determining the proper charge for the job performed. Most owners want to pay the designer for only the computer costs related to the task in question. These direct costs are relatively low and do not cover such things as acquisition and development of computer software, computer system and software maintenance, education of operators, computer center management, and, frequently, the cost of the computer equipment. These indirect costs represent a tremendous investment.

9/ Palli Inola, Value Engineering in the Construction Industry, p. 14.

Firms told us when they used draftsmen for drawings, the manpower costs were rarely challenged regardless of the charge, but when automated drafting was used, the costs were frequently questioned. Also, when the computer is used for analysis work, the charges are scrutinized; yet, spending much more time manually to do the same job is rarely questioned. One firm told us that its experience with Federal agencies was that computer analysis done in-house was difficult to get approved and, when it was, no profit was permitted. But the same work done outside the firm was no problem, as agencies will pay the service bureau's complete bill, including the markup for profit.

This problem could have future significance, as life-cycle costs and energy analyses are starting to be required as part of the design work. Both of these analyses can be facilitated with the computer.

CHAPTER 9

COMPUTER-AIDED BUILDING DESIGN

IN THE UNITED STATES

THE FUTURE

If CABD is to be developed in the United States, it will take time, it will be an evolutionary process, and it will be quite expensive. NASA estimates its aerospace computer-aided project will cost at least $11 million to develop a first-level capability. The Navy estimates it will cost about $60 million to develop an operational computer-aided ship design system. By comparison, a number of architects and engineers tell us that a building design system could be more complex and costly than either of these projects.

Development by individual architect/engineering firms will be slow in view of the costs, and integration will probably take place after individual subsystems demonstrate their cost effectiveness. Each system would be proprietary, and, in the absence of standards, each system would be unique. Small firms will in all likelihood not be able to develop integrated systems and would have to lease proprietary systems, thus becoming competitively disadvantaged to the firms which developed the systems.

Before even this type of development could take place, some basic research is necessary to demonstrate the economic feasibility of the concept.

The Corps of Engineers, with its CADDS project, may ultimately develop a CABD system. But it is designed to meet Corps needs. Whether the Corps system would have commercially useful attributes seems at this point speculative.

In any event, the efforts in the public and the private sectors are not taking place in any structured environment that would make the results generally available to the design industry.

Thus, if CABD is to be developed, there is needed a focal point which should have the objective of fostering CABD development in such a way as to make the technology available to the design industry and yet enable the individual firms to retain their creativity and to develop such proprietary adaptations as each sees fit.

Logically, such a focal point at present would seem to be the National Institute of Building Sciences (NIBS). (See

p. 70 for a discussion of NIBS.) Given the NIBS charter to become self-sustaining after its first 2 years, the design-construction industry and users of its services would have to feel that CADD development merits their support.

Given the cooperative lethargy toward CADD of the American design-construction-user communities to date, an initial task of NIBS or other focal point would be to assess the state of the art in a much more detailed technical sense than we have in this staff study. The results and the pros and cons would then be publicized so that the nature and structure of private initiatives and interests in CADD can be determined.

Since the Federal Government is the largest single user of design-construction services, it has a direct interest in technology which improves design and construction, reduces energy use, and improves life-cycle costs.

In future studies of the Government's design and construction programs, we will evaluate the potential for improvements through computer aids.

There are many factors which have to be considered by both the public and private sectors in considering the future of CADD. Our study pinpointed some of these and we summarize them below.

Standards

The underlying problem impacting the further consideration and development of CADD has been the lack of appropriate standards. Numerous authorities pointed out during our study that there was a need for programing standards, documentation standards, standard nomenclature for building descriptions, and so forth. These same points are made repeatedly in technical papers, at conferences, and in special reports we have reviewed.

For standards to be developed, it would require the interest and active participation of the professional societies of all the design disciplines, the National Bureau of Standards, and the American National Standards Institute.

Definition of Design Needs

Numerous authorities contacted during our study made the point that the various design disciplines would have to communicate closely on what data each member of the team needs to make his or her design calculations and decisions.

Education

The educational process is a long, drawn-out one. It takes years for the effects of education to impact on practice. Consequently, the sooner that students are given adequate education in the capabilities of computers in design and their application, as well as in analysis, the sooner that the potential of computer techniques can be realized.

Exactly how education should function is a matter to be resolved by the academic community and the professional societies working jointly on the problem.

Research

Numerous American universities, research institutes, and private firms have researched and developed CAD-type applications and systems. Developing in Europe is a close association between the universities' engineering, architecture, and computer science facilities and the hardware developers and manufacturers, the software industry, and the designer-user. This association seems to be achieving solid results.

There is a need to study institutional relationships in the United States to determine how they can best interact within the framework of the American free enterprise system.

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LISTING OF PARTICIPANTS IN CADD STUDY

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Department of Commerce:
- National Bureau of Standards, Gaithersburg, Maryland
  - Institute for Computer Sciences and Technology
  - Institute for Applied Technology, Center for Building Technology

Department of Defense:
- Office of the Assistant Secretary of Defense for Installations and Logistics, Washington, D.C.
- Department of the Air Force:
  - Civil Engineers, Washington, D.C.
- Department of the Army:
  - Corps of Engineers:
    - Headquarters, Washington, D.C.
    - Construction Engineering Research Laboratory, Champaign, Illinois
    - Hydrologic Engineering Center, Davis, California
    - Waterways Experimental Station, Vicksburg, Mississippi
- Department of the Navy:
  - Naval Facilities Engineering Command:
    - Headquarters, Alexandria, Virginia
    - Facilities Systems Office, Port Hueneme, California
    - Civil Engineering Laboratory, Port Hueneme, California
  - Office of Naval Research, Arlington, Virginia
  - Naval Ship Engineering Center, Hyattsville, Maryland
  - Naval Ship Research and Development Center, Carderock, Maryland

Department of Health, Education, and Welfare:
- Headquarters, Washington, D.C.

Department of Housing and Urban Development:
- Headquarters, Washington, D.C.

Department of the Interior:
- Bureau of Reclamation, Denver, Colorado

Department of State:
- Headquarters, Washington, D.C.
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- U.S. Embassy, Paris, France
- U.S. Consulates, Frankfurt, Munich, and Stuttgart, West Germany
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Office of Federal Procurement Policy, Washington, D.C.
U.S. Postal Service:
Headquarters, Washington, D.C.
Veterans Administration:
Headquarters, Washington, D.C.

QUASI-GOVERNMENT ORGANIZATIONS

National Academy of Science:
National Research Council, Building Research Advisory Board, Washington, D.C.
Technology Assessment and Utilization Program
Federal Construction Council
National Institute of Building Sciences:
Headquarters, Washington, D.C.

INTERNATIONAL ORGANIZATIONS

European Economic Community, European Computer Program Institute, Ispra, Italy
International Council for Building Research, Studies and Documentation, Rotterdam, The Netherlands
North Atlantic Treaty Organization, Committee for the Challenges of Modern Society (U.S. Coordinator in the Department of State)
United Nations, Economic and Social Council, Economic Commission for Europe, Committee on Housing, Building and Planning (U.S. Coordinator in Department of Housing and Urban Development)

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National Computing Center, Manchester, England

PROFESSIONAL AND INDUSTRY ORGANIZATIONS AND ASSOCIATIONS

American Bar Association
    Model Procurement Code Project, Washington, D.C.
American Concrete Institute, Denver, Colorado
American Gas Association, Arlington, Virginia
American Institute of Architects:
    Headquarters, Washington, D.C.
    Research Corporation, Washington, D.C.
American Institute of Steel Construction, New York, New York
American Society of Civil Engineers, New York, New York
American Society of Heating, Refrigerating, and Air Conditioning Engineers, New York, New York
American Society of Mechanical Engineers, New York, New York
Association for Computer Aided Design Limited, Melbourne, Australia
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Centre Technique Industriel de la Construction Metallique, Puteaux, France
Civil Engineering Programming Applications, Inc., Rockville, Maryland
Comite Scientifique et Technique de l'Industrie du Chauffage, Service Information, Saint-Remy-Les-Cheureuses, France
Masonry Institute of Maryland, Baltimore, Maryland
National Building Federation, Paris, France
    Centre d'Assistance au Calcul Technique
    Centre d'Assistance Technique et de Documentation
National Construction Industry Council, Washington, D.C.
Portland Cement Association, Skokie, Illinois
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Society of Design Engineering and Development, West Germany

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Applied Graphics Corporation, Gaithersburg, Maryland
Applied Research of Cambridge (Canada) Limited, Toronto, Ontario, Canada
Applied Research of Cambridge Limited, Cambridge, England
Architects Collaborative, Boston, Massachusetts

Baker, Michael, Jr., of New York, Inc., New York, New York
Bank Building Corporation, St. Louis, Missouri
Bechtel Power, Los Angeles, California
Bechtel Power, San Francisco, California
Berger, Louis, and Associates, Inc., New York, New York
Blum, Herman, Consulting Engineers, Dallas, Texas
Brannen, Robert A., and Associates, Boston, Massachusetts
Braun, C. F., and Company, Alhambra, California

CADSYS Limited, Edmonton, Alberta, Canada
Camp Dresser and McKee, Inc., Boston, Massachusetts
Civil Design Systems, New York, New York
Common, Inc., Chicago, Illinois
Computdraft, Philadelphia, Pennsylvania
Computer Services, Inc., Chicago, Illinois
Computervision Corporation, Bedford, Massachusetts
Consoer, Townsend and Associates, Chicago, Illinois
Control Data Corporation, Minneapolis, Minnesota
Control Data Corporation, New York, New York
Coot, Planning and Management International, Inc., Washington, D.C.
Crissman and Solomon, Boston, Massachusetts

Daniel, Mann, Johnson and Mendenhall, Los Angeles, California
Day and Zimmerman, Inc., Philadelphia, Pennsylvania
Decision Graphics, Southboro, Massachusetts
Digital Equipment Corporation, Marlboro, Massachusetts

Ebasco Services, Inc., New York, New York
ECI Systems, Inc., Cambridge, Massachusetts
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Envirodesign, Boston, Massachusetts
Environmental Design and Research Center, Boston, Massachusetts

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Microkit Inc., Santa Monica, California
Monolithic Systems Corporation, Englewood, Colorado
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Princeton Electronic Products, Inc., North Brunswick, New Jersey
Summagraphics Corporation, Fairfield, Connecticut
Synercom Technology, Inc., Houston, Texas
Tektronix, Inc., Beaverton, Oregon
Varian Graphics, Palo Alto, California
Vector General, Inc., Woodland Hills, California
Versatec, Santa Clara, California
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SUMMARY OF COMPUTER-AIDED BUILDING DESIGN AND RELATED DEVELOPMENTS IN FOREIGN COUNTRIES

Numerous research and development projects throughout the world are concentrating on the use of computers for building design and related work. These efforts range from CABD system development to computer program documentation standards to interactive design tools. Foreign interest in developing CABD systems is very high, especially in West Germany, where there is an organized, coordinated, ongoing effort, sponsored by the Government.

During 1976, we visited several national and private CABD projects in France, the United Kingdom, and West Germany, and one Common Market activity in Italy. In addition, we learned about CABD efforts in Australia and Japan through correspondence and were told of work in countries not visited or contacted. The following is a summary of some of the efforts we observed or have been made aware of. The presentation is not a balanced treatment for each country. More depth is given in certain countries because information was readily available. Nevertheless, the discussion should give some image of what is going on outside the United States.

ECONOMIC COMMISSION FOR EUROPE

The United Nations, through the Economic Commission for Europe, has been actively interested in the application of computers in the building industry for at least 10 years. Commission emphasis has been on technological policy, not on development of application programs and systems. Policy is an important consideration in the development of integrated CABD systems because the major inhibitors we identified during our study were frequently policy and management problems rather than the lack of technology.

Commission efforts, while not directly aimed at the development of CABD, do address issues and the resolution of problems which impact on and, in some cases, inhibit the development of an integrated CABD system. Such efforts as harmonizing building standards and codes, and software documentation standards, we are told, are vital to CABD development.

The Commission's Committee on Housing, Building, and Planning has held international meetings to discuss computer

usage and to propose courses of international action. In 1972 the Committee completed an inquiry into the use of computers in the building industry. Its analysis of countries replies 1/ contained the following observations:

--Common use of computer programs was occurring in most countries where computers are widely used, but often in different ways.

--Integration of the work of the various disciplines was not occurring very often. The reason was partly due to difficulties in organizing, financing, and administering cross-discipline research and development and in implementing the results.

--Although widespread attempts were being made to develop systems, the work was almost entirely within the research stage. Most of this effort was Government sponsored or financed.

--Work towards a design system is largely concerned with industrialized building rather than traditional building, with a strong bias towards structural engineering.

--With the exception of two countries -- Canada and France -- the cost of developing data banks for construction was felt to be too high. Both Canada and France were developing data banks on building materials and components.

--As the use of computers expands within the building industry, the training needs of the industry become increasingly difficult to meet, especially in the area of sophisticated and complex management control systems.

Reports indicate that the Commission recognizes that substantial benefits could flow from integrated CABD, with major benefits being realized only after a comprehensive system has been developed and utilized. Its studies indicate that the major factors mitigating against wider

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1/Economic Commission for Europe, Committee on Housing, Building and Planning, Working Party on the Building Industry, " Computer Applications in the Building Industry." HBP/BUILD/94, June 27, 1972.

international use of common computer programs are the incompatibility of hardware and the differences in the form of the national standards and regulations. 2/ Also, design professionals everywhere have considerable difficulty locating available programs. On the other hand, existing programs are frequently duplicated because most are inadequately documented.

Country delegations participating in a September 1972 ad hoc meeting in London on the use of computers in the building industry 3/ concluded that:

--The above inhibiting factors point to the need for continuing international cooperation in order to accelerate progress towards the harmonization of standards and procedures, and

--The development of an international index of programs, standard rules for software documentation, and the wider dissemination of information on the use of computers should be encouraged.

Several Commission efforts are continuing under the auspices of the three standing working parties of the Committee on Housing, Building and Planning. 4/ The Committee has about 40 projects, several of which address issues such as:

--Harmonization of the technical content of building regulations.

--Promotion of international standardization in the building field.

--Use of computers in the building industry.

2/Economic Commission for Europe, Committee on Housing, Building and Planning, Working Party on the Building Industry. "Report," HBP/WP.2/AC.1/1, Oct. 19, 1972.

3/Ibid.

4/Economic Commission for Europe, Committee on Housing, Building and Planning. "Review of Work Accomplished or in Progress," HBP/R.46, Mar. 26, 1975.

--Policies related to research and development in the building industry.

One of the specific recommendations made during the London meeting was for participating countries to designate focal points for international cooperation on computer applications in the building industry. 5/ As of December 1975, 19 countries, including the United States, had designated focal points. An ad hoc meeting of these focal points was held in Paris, December 8-10, 1975. The United States representative did not attend. At this meeting, 6/ it was agreed, among other things, that:

--All international organizations known to be concerned with some aspects of computer applications in the building industry be requested to submit information on their activities.

--Bilateral contacts should be established between the focal point with a view to exchanging experience and documentation in areas of mutual interest.

--All focal points should prepare a brief description of the organizations, institutions, ministries and other bodies concerned with the use of computers in the building industry in their countries, including an explanation of how coordination on the national level is ensured in this field.

The report of the Paris meeting 7/ contained the following statement regarding the current situation on the use of computers in the building industry in different countries:

"All delegations taking the floor reported that considerable progress has been made in the application of computer techniques in the building industry in the past

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5/Economic Commission for Europe, Committee on Housing, Building and Planning, Working Party on the Building Industry. "Report," HBP/WP.2/AC.1/1, Oct. 19, 1972.

6/Economic Commission for Europe, Committee on Housing, Building and Planning, Working Party on the Building Industry. "Report," HBP/WP.2/AC.1/3, Feb. 20, 1976.

7/Ibid.

> years. In particular in the field of scientific and technical calculations a wide range of programmes now exist and computers are also being increasingly used as a means of facilitating information exchange and of improving management and organization in the industry. Systematic efforts are being made in most countries to co-ordinate existing programmes and know-how and to promote more effective utilization of existing programmes by the setting up of data banks and advisory services. In view of the high investments required fully to exploit the potential of the computer as a calculation, information and management tool in the building industry, it was clear that international co-operation and exchange of experiences would be beneficial in this field. 8/

The delegations recognized that if computer tools were to be more efficient and better adapted to the needs of the designers, the latter must express their needs more clearly than at present, in spite of the difficulty of this task. The problem of the high cost of working out assisted-design systems was underlined by several delegations.

COMMON MARKET ACTIVITIES

In Europe, as in the rest of the world, the use of computers has grown rapidly during the past decade or so. Hand in hand with this growth has been a proliferation of computer application programs. With software development cost spiraling, ways and means are being sought to keep these costs to a minimum. In this regard, the promotion of software sharing is now considered necessary by the Europeans.

During 1976, the Council of Ministers of the European Economic Commission, the Common Market, approved a proposal of its Data Processing Committee to study the use of computers as well as the management and data requirements of the construction industry. It was expected that, in early 1977, study contracts would be let to firms in several countries after the administration and financial arrangements had been developed by the Committee.

8/Economic Commission for Europe, Committee on Housing, Building and Planning, Working Party on the Building Industry. "Report," HBP/WP.2/AC.1/3, Feb. 20, 1976, p. 2.

European Computer Program Institute (EUROCOPI)

The Commission of the European Communities established EUROCOPI to provide Europeans with a single, efficient way of accessing computer programs--programs of all types. This program library was originally called the Computer Program Information Center when set up in 1971 at the European Communities' Joint Research Center, Ispra, Italy.

The long-range objective of this action was (1) to promote full European cooperation for a complete information service on scientific/technical software and (2) to improve program exchange. 9/ After 5 years of operation, EUROCOPI was well established. Although not functioning at full potential, it had, in the opinion of the Commission, proven the feasibility and usefulness of such an arrangement.

EUROCOPI has collected over 10,000 program abstracts from various fields, of which 3,000 have been placed into a computerized data base. A conversational information storage and retrieval system, known as SIMAS, has been developed and placed into operation. The system's capabilities include both batch and interactive time-sharing modes, and retrieval by remote terminals over telephone lines is possible. During 1975, the Institute distributed over 2,000 documents and 700 programs. At the end of 1975, the users of EUROCOPI services numbered about 540. About 150 of the users were non-Europeans, and, of these, 50-60 were from the United States.

EUROCOPI has a staff of 9--5 technical and 4 clerical persons. The Institute does not test or evaluate programs distributed but would like to develop some kind of an acceptance criteria, short of extensive testing and certification. Before distributing a program, it checks to see that the decks are complete and that the program will, in fact, run.

EUROCOPI is operated on a 4-year budget cycle supported by the Commission of the European Communities. In the past, the Commission funded the entire operation. Now, however, EUROCOPI is moving to a partly self-supporting

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9/European Computer Program Institute, "An Outline of the Scope and Activities of EUROCOPI."

service position. Starting in October 1975, it began charging for reproduction and mailing costs. The average fee charged is about $25.

Officials at EUROCOPI believe they have not yet achieved one of their long-range goals--to promote full European cooperation for a complete information service on scientific/technical software. The need for cooperation has continued to grow as more and more program library collections, information services, and user support activities have started in Europe.

European Consortium for Software Access and Information Transfer in Research and Teaching

It was out of the realization that a transfer mechanism was needed to open up these program libraries to all of Europe that this consortium was created. 10/ The situation exists that these libraries are regional or discipline oriented or are dependent on a particular computer. This limits their access and usefulness to only a small part of the European user community.

During 1975, EUROCOPI took some initiatives aimed at removing obstacles from data transfer. Out of these actions came the consortium. It was set up to provide a framework for cooperation and to enable a program of cooperative work to be carried out. The nucleus of the group is formed by EUROCOPI, the Program Library Unit of the University of Edinburgh, Scotland, and the GIZSOZ project in Bonn, West Germany. 11/

We were told that it appears the consortium will pursue an approach centered around standardization and implementation of computer-assisted user support aids and user education. Working groups have been set up to look at the following areas:

--program abstracts,

--standardization of program classification and indexing,

10/Giancarlo Gaggero, "The Goals and Organizational Objectives of ECSIR," European Computer Program Institute.

11/Ibid., p. 3.

--programing standards, and

--guidelines for program documentation.

European Informatics Network

This project is funded by the 18 member countries of the COST (Cooperative Scientifique et Technique) group. Its objective is to set up and run a computer network in Europe that would connect various computer centers (distributive process). Eight or nine countries are contributing directly in the effort. As of June 1976, five centers had been designated for implementing the network:

--Joint Research Center, Ispra, Italy, with an IBM computer.

--Polytechnic, Milan, Italy, with a UNIVAC computer.

--Polytechnic, Zurich, Switzerland, with a CDC computer.

--National Physical Laboratory, Teddington, England, with an ICL computer.

--Institut de Recherche d'Informatique et d'Automatique, Paris, France, with a CII computer.

The official we talked with expected centers to be designated in West Germany, Denmark, and the Netherlands in the future.

The technical specifications for the network have been defined. Mitra minicomputers will be used at each center to provide the interface. Protocols have been developed for communicating between operating systems. Software for implementing the protocols is being written.

The Commission of the European Communities has another project, called EURONET, to establish a European information network intended to provide access through a network of distributive data bases. We were told that one possible application of the European Information Network could be serving as the physical network for supporting EURONET. In addition, the network is slated to be linked with other networks. One of the problems is the number of different languages involved. As of May 1976, these were English, French, Italian, German, Danish, and Dutch. It was

expected that Norwegian, Portuguese, Spanish, and Greek would also be added.

FRANCE

In broad summary, we found France notable not only for the development of two particularly interesting computer-aided engineering design systems, but also for the steps being taken within the French building industry for generally facilitating development and application of computer-aided design. Foremost is the way in which the building industry is organized. And of equal interest is the growth of services to the industry in the form of technical assistance, a computer software library, and the ARIANE information retrieval system.

The Building Industry

Following World War II, an enormous rebuilding effort was necessary in France. The work could not be carried out by traditional means. Building, out of necessity, had to become industrialized, bringing deep changes to the industry. Craft specialization was no longer linked with building materials such as stone, concrete, wood or iron. Giving up craftsmen's methods also meant lessening individualism. Know-how secrets, carefully kept by craftsmen, were shared. Coordination among the different sectors of the building industry became advantageous, as did access to common interest information and research laboratories. 12/ The side effects of this coordination and mutual research are helping to facilitate the development of CABD.

The French building industry has created powerful research and technical assistance mechanisms. The industry invests millions of dollars annually for collective research benefiting hundreds of engineers, technicians, and academicians. The goal of its technical assistance is to place the technical, organization, and management tools in the hands of the contractor when and where he needs them.

12/Federation Nationale du Batiment, "L'Industrie Francaise du Batiment" (in English).

National Building Federation

Building industry assistance flows through the Federation, which assumes a number of roles under a single management. At least institutionally, it is highly organized, as indicated by its general structure, as shown in figure II-1. The organization includes technical/manufacturing/fabrication/contracting associations and unions, representing 45,000 firms.

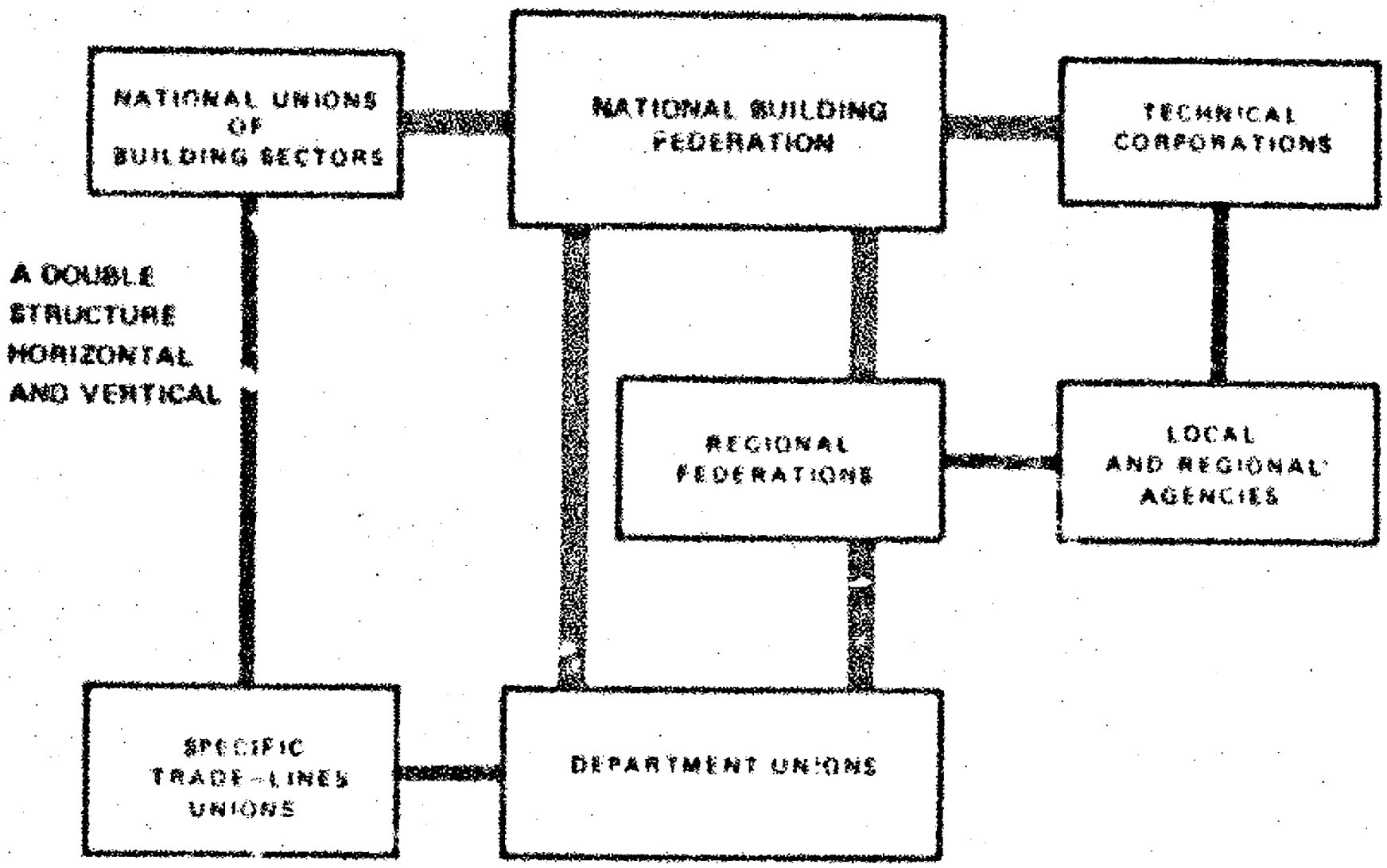


Figure II-1. Organization of the French building federation. 13/

In essence, the Federation is the "single voice" of the construction sector of the economy, which makes up one-third of the national production. The Federation ". . . can influence state expenditures, organize promotion, participate

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13/Federation Nationale du Batiment. "L'Industrie Francaise du Batiment" (in English), p. 7.

in surveys and define the National economic policy." 14/ Its dominating presence makes possible significant economic, social, and technical impacts on a national scale.

The activities of the Federation and its member associations and unions are primarily supported by an educational assessment levied on member firms based on their gross billings and/or payroll. Initially the assessment was four-tenths of one percent. Currently it is one percent, but over the next few years will climb to about two percent and then remain constant at that level. The very small firms do not pay the assessment. In any case, assessments on one-third of the national production represents a significant yearly appropriation.

The funds received by the Federation are used for a wide variety of services, including

--training of labor from the worker to the engineer (this includes the full support of an engineering university);

--a complete system of banking and assurance organizations for financing of construction loans and providing coverage for liability, fire, accident, and life insurance;

--research laboratories and product-testing laboratories for construction materials, components, subsystem, and processes; and

--technical assistance centers which provide product and standards information, computer hardware/software information, assistance and training.

Membership of the firms was said to be voluntary. However, there are subtle Government and non-Government, as well as cultural pressures, to join. The governmental "pressure," or inducement, starts with the fact that firms are legally required to spend a set amount on education and training of employees. If they do not, the unused moneys must be turned over to the Government. However, the payment of the educational assessment to the Federation fulfills this legal requirement.

14/Federation Nationale du Batiment, "L'Industrie Francaise du Batiment" (in English), p. 8.

We visited four organizations which were subordinate to the Federation and its technical center category. Of these, the Centre Technique Industriel de la Construction Metallique is supported through the Syndicate de la Construction Metallique de France, which is itself a member of the Federation; the other three, the Centre d'Assistance au Calcul Technique, the Centre d'Assistance Technique et de Documentation, and the Comite Scientifique et Technique de L'Industries du Chauffage, Service Information, are directly supported by the Federation. The technical assistance efforts by these organizations provide:

--Engineering software library functions, including dissemination of software and documentation, and computer program maintenance.

--Engineering software application service functions which include running of client problems, as well as programing of input and writing of new programs, if desired.

--Educational functions with respect to hardware and software, particularly centered about the use of engineering application software.

--Construction information library and retrieval functions, including information on construction products and procedures, manufacturers and fabricators, and, finally, governmental regulations and requirements.

ARIANE

This is a data base search and retrieval system developed by the Centre d'Assistance Technique et de Documentation for information on construction products, procedures, regulations, and specifications. Such a system is a very important element in computer-aided design application. The system was started in 1968-69 as a manual search system. In 1972, it was converted to a computerized system.

It consists of books, files, and a data base. Accessing the data base, which is stored in a computer, is by a pair of cathode ray tube terminals operated in an interactive mode. Searches can be made for three types of information--manufacturing, engineering, and regulations. In manufacturing, for example, inquiries can be made to

determine the addresses of companies manufacturing a specific product or the products made by a specific manufacturer. A deeper inquiry can be made to determine specific data about a specific product and a listing of alternative substitute products which could be used. The hierarchical search process enables the operator to determine, for example, the appropriate finish to use on a specific school wall--interior or exterior--and all the information needed on surface preparation, method of application, and building code requirements. In summary, AMIANE has a very flexible search system which is capable of providing both general and highly detailed information.

The system does not store in the computer the text of regulations and other data with lengthy narratives. Only a microfiche reference is stored. Using the reference code given in the data bank response, an operator can retrieve the microfiche and project it on a screen; hard copies can be made if desired. The people operating ARIANE had the attitude that using the computer as a storage file cabinet was inappropriate.

Information in the system is categorized, as mentioned above, into three general areas. Currently, the system does not have any information on the environment of construction. It has information on 75,000 brand name products, 7,500 manufacturers of building materials and 3,000 families of products. This represents 80 percent of all the building materials available in France. New entries are added to the system daily and entered into the computerized data base every Monday. The library of information consists of 700 microfiches, each with 192 views, 2 pages per view. This is about 300,000 pages of information, which is the equivalent of a 200-book (150 pages per book) library. The system is not limited by the size of the data base. Additional microfiche files can be added.

The computer used to operate ARIANE is capable of handling 200 terminals at once. However, only nine entry stations are currently used--one in Paris and eight others throughout the country. These nine handle about 200 questions each day from contractors and designers. At this time, no contractor or design office has a terminal tied into the system, but this would be possible.

The objective of the system is to solve problems, not merely to answer questions. That is, system operators

query callers to determine the real problem because the questions frequently asked first will not result in information needed to solve the problem. The callers frequently do not know what question to ask or how to ask it.

The services of ARIANE are available to all contractors and design offices for $240 a year. This permits each subscriber to make 50 requests of the system during the year.

The success of the above work can be judged from the plans for its continuance, both in development as well as in day-to-day services. Additionally, the Centre Technique Industriel de la Contruction Metallique has a proprietory version of the subsystem, TOPOLOGY, as part of ICES, which was originally developed at the Massachusetts Institute of Technology. It is marketing the subsystem in the United States, as well as in Europe, and plans to develop other subsystems.

Government Research

The one Government agency visited in France was the Institut de Recherche d'Informatique et d'Automatique, which does computer research into both hardware and software. It is supported by the Ministry of Industrial and Scientific Development through the Directorate for the Computer and Electronic Industry. Its mission is to perform theoretical research in the general area of computers. It also finances some outside research in addition to its internal efforts. A staff of five people administers the grant program, which is about $3 million a year. With this money, 10-15 researchers are supported at universities, outside research organizations, and occasionally in industry. The Institute is not working on CABD development. However, we noted some matters of interest which relate to the application of CABD.

The Institute has developed a general-purpose computer network, CYCLADES, which allows for the interconnection of a vast set of data processing resources: computers, terminals, and files. We were told that the network, not designed for a specific application or one type of computer, could be usable in an integrated CABD system. The network was placed into operation in January 1975, tying together 14 organizations using 10 different computers. In addition, the network is hooked up to the National Physical Laboratory, London, England. Although operational, work continues toward improving its performance. The main efforts are towards exploiting the computers at the various centers.

Design Programs

As is the common case throughout the world, engineers in France can obtain many analysis programs but only a few design programs. Two engineering programs of particular interest are TEQUILA and a reinforced concrete design program. TEQUILA is a program system for the analysis, design, and detailing (for fabrication) of "normal" steel buildings. "Normal" applies to perhaps 85 to 95 percent of all steel buildings. It is available in four languages (French, English, Spanish, and German) and in metric or English units. All detailing is performed in accordance with appropriate codes of practice. Our consultants advise us that this program appears to be quite advanced and that there does not appear to be a program of similar capability in the United States.

The TEQUILA system provides either printer plots or drawings, as appropriate, for the shop fabrication of steel sections. The steel sections may be hot-rolled, cold-rolled, built-up and/or composite. Member connections may be welded, riveted and/or bolted using the fixed and/or pinned concept. The required cutting from flat sheet, drilling, clipping, coping, and so forth, as well as assembly and erection drawings, is out-put by the system.

We did not receive detailed information on the reinforced concrete program but information that we obtained showed that it computes required reinforcing bars, checks to see that the bars can be placed without interference at connections to other members, and determines the formwork required. We were told that in the United States there are programs that perform some of these functions but none that follow through to the formwork computations.

The fact that these two programs perform the design function, a heuristic process, and continue through to construction or fabrication functions is of great interest.

UNITED KINGDOM

British CABD activities are relatively advanced and more directly in line with the subject of this study than are the French efforts. At the time of our visit, three interactive CABD systems had been developed and a fourth was under development. Impressive work had been done in three-dimensional color graphics and photomontages, and efforts were underway on data base management, information

retrieval systems, and standardization of computer program documentation.

Department of Environment
Sponsorship of CABD Efforts

The Department of Environment of the Government of the United Kingdom, which took over the functions of three antecedent Ministries--Housing and Local Government, Transportation, and Public Buildings and Works--in November 1970, has taken the lead in maintaining the Government's relations with the construction and building materials industry. It also acts as the focus in Government for a whole range of policy issues affecting the industry. Its Building Research Establishment provides a research backup to this work.

The Department has maintained a technological policy 15/ with regard to use of computers in the construction industry. As early as 1965 the Ministry of Public Buildings and Works recognized that the increasing use of computers required more coordination of effort if greater benefits were to be realized. It also saw significant potential for greater use of existing knowledge. 16/

Committee on the Application of Computers in the Construction Industry

The Ministry set up this committee in May 1966 with the following objectives:

> "To keep under review the present and potential applications of computers in the construction industry, taking account of experiences and trends in other industries; to identify areas in which there was a need for coordination of effort; to examine the need for action,

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15/An active policy of participation in and financial support of the development, transfer, and implementation of existing technology and the promotion of further technological advances.

16/National Consultative Council of the Building and Civil Engineering Industries, "Paper SC/CDC/P(75)2 - Review of the Current Situation (Amended)," Department of the Environment, London (May 1975).

secure the wider application of existing knowledge and the promotion of further advances; and to make recommendations."

To carry out committee functions, the following subcommittees were set up:

Computers in Structural Engineering, Computers in Construction of Buildings, Computer Use in Quantity Surveying, Computers in Services Engineering, and Architectural Applications.

Emerging from these subcommittees were two of the CABD systems developed in England--the General Engineering System (GENESYS) (Structural Engineering) and the Computer-aided Environmental Design Analysis and Realisation System (CEDAR) (Architectural Applications). 17/

System Development

An explosion of individual efforts, coupled with the foregoing committee efforts, resulted in several building design systems being developed in England, such as GENESYS, CEDAR, the Oxford System, HARNESS, and the Computer-Aided Rationalised Building System. According to British Government officials, none of these have been universally accepted. We discussed three of these systems with persons participating in their development.

GENESYS

The development of GENESYS, a general engineering system of computer programs for primarily structural and civil engineering, was started in 1967 under Government sponsorship. In October 1974 the Department of Industry, through the National Research Development Corporation, assumed the funding role for GENESYS. Genesys Limited, the developer, is now a wholly owned subsidiary of the corporation. The system was released publicly in 1972. Genesys officials told us that since then many problems associated with devopment, maintenance, and support have been identified and resolved. Over $2 million in public funds have gone into the development effort. The system is being maintained and further developed by Genesys Limited.

17/National Consultative Council of the Building and Civil Engineering Industries, "Paper SC/CEC/P(75)2 - Review of the Current Situation (Amended)," Department of the Environment, London (May 1975).

The system is virtually machine independent (portable), according to Genesys officals, and has been implemented for some 20 different types of computers at 70 computer centers worldwide. They claim that about 2 man-months of programing effort are all that is required to transfer the system to a new machine. The GENESYS subsystems are reported to be 100 percent portable and readily transfer from machine to machine. 18/

It is the policy of Genesys Limited to vary leasing charges for software. This means that a university or a small user will generally pay less than a large service bureau, which would pay less than a national industry. 19/

Genesys Limited officials said they would like to start selling GENESYS in the United States. To do this, they must first convert the GENESYS design programs, in particular the reinforced concrete program, to agree with U.S. codes and practices. They said this and other developments lie in the future, including the possible implementation of the system on minicomputers. Also, probably by the end of 1976, a graphics package was to be added to the system. (We do not know whether this goal was met.)

Officials at Genesys Limited told us that the goal of a complete CABD system has not been accomplished. GENESYS has quite a few of the parts, but there are still gaps in the total system. Currently, the system has no electrical or mechanical subsystems nor any environmental programs.

CEDAR

An interactive building design system, CEDAR uses graphics terminals connected to a remote time-sharing computer currently located at the Computer-Aided Design Centre, Cambridge, England. It is intended for the use of designers in the Department of Environment and in local government design offices. The department set up the

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18/Genesys Limited, "GENESYS," Genesys Limited, Loughborough, England (May 1976).

19/Ibid.

CEDAR project in 1969 to construct a limited pilot CABD system capable of being evaluated in use to provide experimental information on technical and economic performance. By 1973 the pilot system was completed and evaluated. 20/

The CEDAR pilot enables a designer using the SEAC (South Eastern Architects' Collaboration) building system (a component-based system) to proceed from an early sketch-plan showing the layout and dimensions of rooms through the design of a structural steel frame and external walls to the completion of production drawings and schedules. The designer, using a set of commands, can insert or delete components or initiate automatic processes for detailing a design or the analysis of a completed design. 21/

The system uses two types of files. Project files contain the complete set of data on the building design. Master files contain basic data about the building system which is not unique to a single project. The geometry package, used in the system, has proved reliable, according to reports. While it is simple and loosely structured, the developers believe it has generally proven satisfactory for the needs of a complex CABD system. 22/

In 1974 the Department of the Environment and the Royal College of Arts, London, conducted an experimental investigation of the performance of a CABD system, using CEDAR. 23/ Three architects were asked to design the most economical one-story frame for test buildings, using both manual and computer-aided methods alternately under controlled conditions. To our knowledge, this is the only controlled experiment on CABD ever done, anywhere.

20/J. R. Chalmers, et al., "Progress in the Development and Evaluation of CEDAR: A Computer-Aided Building Design System," Department of the Environment, London (August 1974).

21/Ibid.

22/J. Chalmers, et al., "Data Structures used in CEDAR--A Computer-Aided Building Design System," Department of the Environment, London (February 1974).

23/B.G.J. Thompson and J. Hughes, "An Experimental Investigation of the Performance of a Computer-Aided Building Design System," IFIP Congress 1974.

The study showed that CABD seems likely to save about 50 percent of frame design costs or about 1 percent of the frame capital costs. In addition, 7 to 8 percent savings could be made through redesign or multiple design iterations. The effects of design iterations on capital costs of the frame design reported in the study are shown in figure II-2. 24/

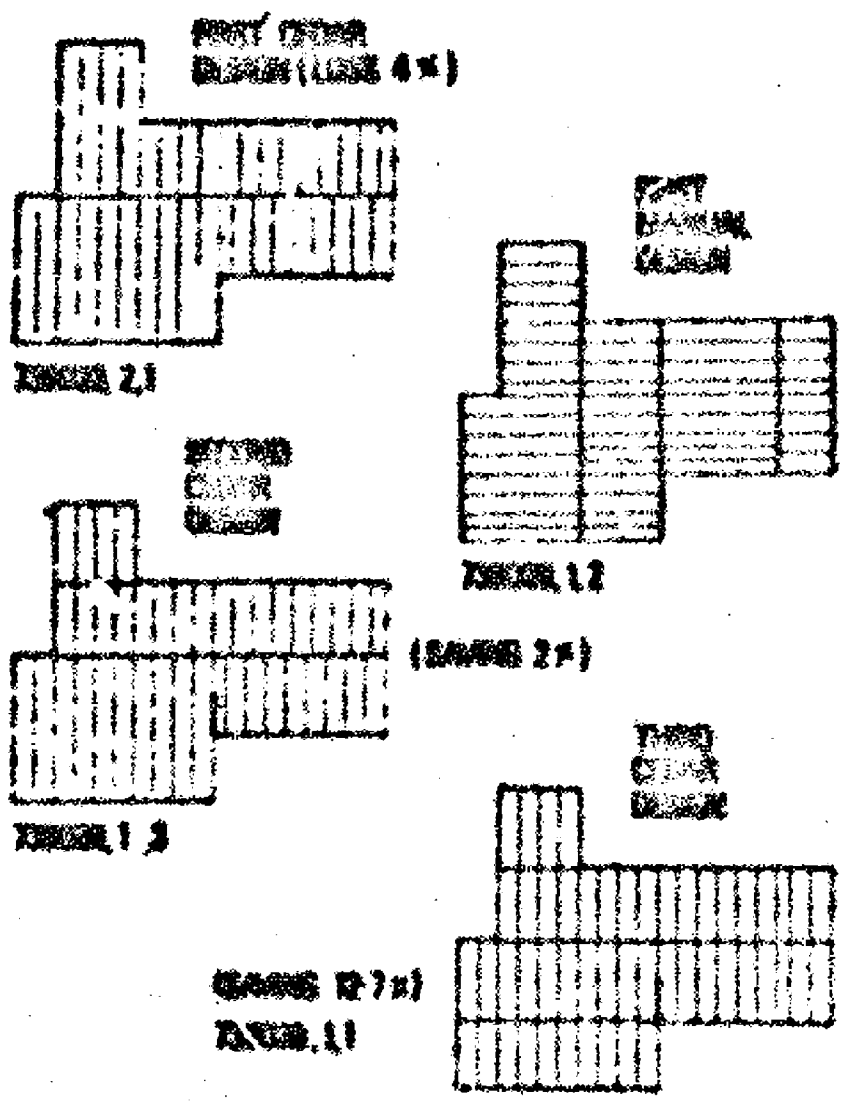


Figure II-2. Effect of multiple design iterations on capital costs of frame design.

24/B.G.J. Thompson and J. Hughes, "An Experimental Investigation of the Performance of a Computer-Aided Building Design System," IFIP Congress 1974, p. 775.

The experiment showed that, using the CABD system,

> "It was possible to produce a completed and costed frame in 1-1/2 - 2 hours compared with 8-12 weeks manually. It is possible for the designer to produce several versions of the frame and choose the one that suits him best. Trials showed that most savings were achieved in three iterations and averaged about 6 percent of capital cost of the frame." 25/

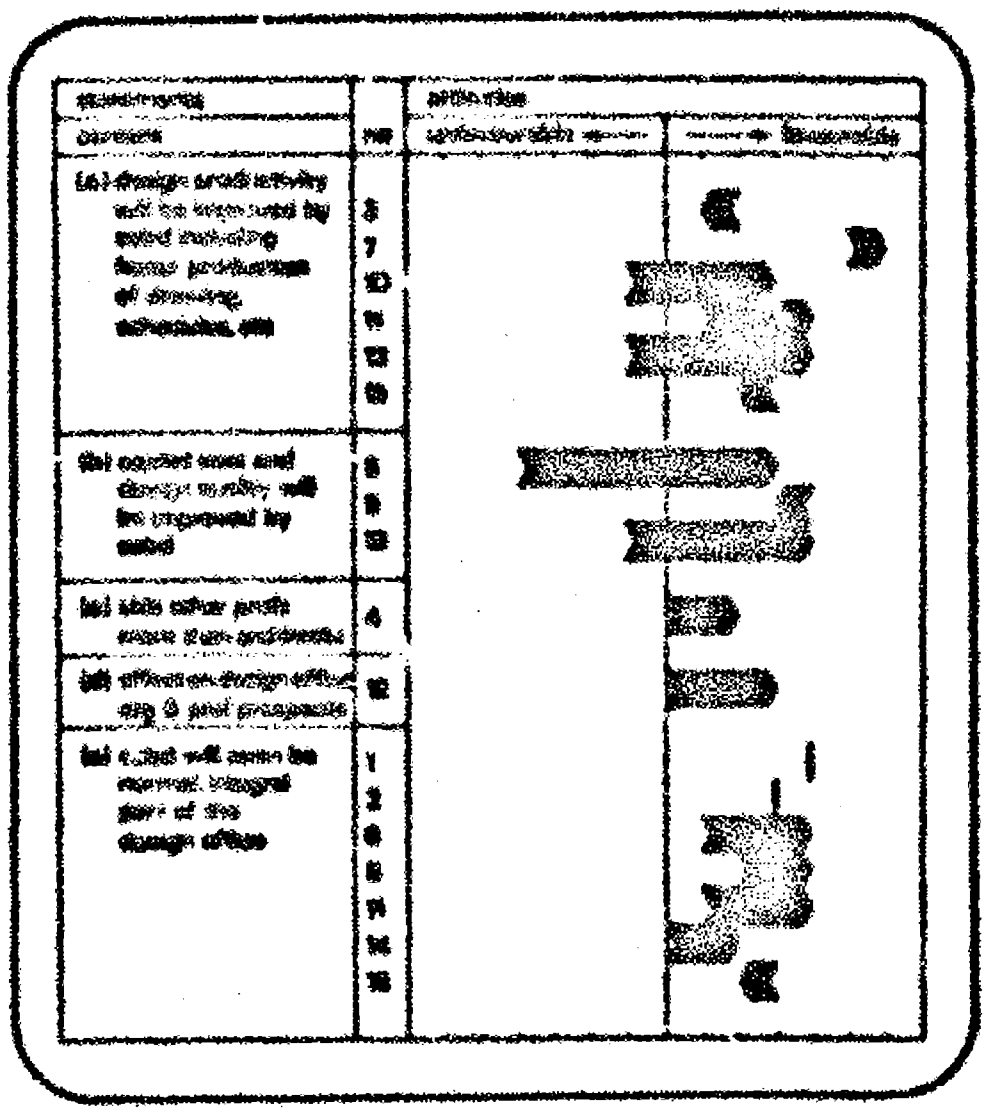


Figure II-3. Results of users' attitude survey. Users were asked to comment on a series of suggestions about CABD systems before and after use of CEDAR. Arrows show the change in attitude

25/J. R. Chalmers, "Computers and Designers," DOE Construction 14, p. 3.

The attitudes of the three architects towards CABD were determined both before and after the design exercise. Each was asked to respond to 16 questions, grouped in five categories. The statistical analysis of the responses, done by researchers, shown in figure II-3, indicated a more favorable attitude towards CABD after the experiment than before. 26/

CEDAR development is now proceeding toward a production system based on the ideas and experiences gained during the pilot project and evaluation. The initial applications will be the energy and environmental aspects of early design, but further early design applications are also envisioned. The aim is to develop a system with which designers can rapidly and accurately compare alternative building geometries and site layout for energy consumption and life-cycle costs. The department is considering placing a minicomputer at the workstations to improve the efficiency of the system.

The Oxford System

This is an integrated interactive CABD system for detail design of the Oxford Method for buildings. The Oxford Method, a well-established building method, was developed by the Oxford Regional Health Authority to meet the particular needs of its building program. The Health Authority states that

> "The fundamental concept of OXSYS is to replace the image of a building on paper with a readily accessible, easily manipulated image in a computer memory that can be analysed, evaluated, and modified. A visual display screen replaces the conventional drawing board for recording and amending design decisions. The great advantage is that every member of the team, even though they might be geographically separated from each other, is able to work with the same up-to-date version of the building image." 27/

Various input procedures setup the geometry which gradually assembles a progressively more detailed computerized model. Analysis programs provide designers with a variety

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26/B.G.J. Thompson and J. Hughes, op. cit., p. 776.

27/Oxford Regional Health Authority, "The Oxford Method," Oxford Regional Health Authority, Oxford, England.

of information such as area/volume relationships, heat gains and losses, and cost estimates. This information is available through the design process so that the designer can consider the cost and performance of alternative design solutions. When the model is complete, it is used to generate the drawings and schedules for the construction project.

We were advised that the system has been successfully used in production. Its success is largely based on very active user involvement in system design and development. Fifty percent of the design and development of the system was done by Oxford Regional Health Authority architects and engineers.

While the Oxford Method was developed primarily for hospitals and health care centers, it has been used in the United Kingdom for educational and office buildings. The method has been licensed for use in countries outside the United Kingdom.

Current Situation in Computer Application

In May 1975, the Standing Committee on Computing and Data Coordination of the National Consultative Council of the Building and Civil Engineering Industries, of the Department of the Environment, issued a report covering, among other things, the current status of development and applications undertaken by industry. 28/

Private firms, according to the report, had made extensive use of the computer and had developed programs or systems of their own. Most of this effort was in structural analysis, particularly finite element analysis. Service engineers (mechanical and electrical) and architects have been less active in program development.

A few contractors have developed design programs for use in their own design offices. Also, a few software houses have written programs specifically for design or management in the construction industry. These include Applied Research of Cambridge, which we visited, and Systems Programs Limited.

28/National Consultative Council of the Building and Civil Engineering Industries, op. cit.

Applied Research of Cambridge

The firm, formed in 1969 by architects, planners, and computer scientists, is a specialized software development organization. Applied Research had developed two major integrated computer-aided building systems--the Oxford System and HARNESS--and is currently developing a third. This latest systems effort is based on OXSYS and, although the context is similar, it has much more general objectives and wider application.

Applied Research of Cambridge is dedicated to the premise that "an integrated approach to a multi-function CABD system can help the design team through many stages of the design process and provide multiple benefits." 29/ The system being developed by Applied Research is, in our opinion, at the cutting edge of the state of the art in CABD today. The unique software infrastructure approach taken could be used as the foundation for many types of integrated system development. Applied Research is currently producing modular software for use in general CABD systems.

The structure of the system under development is formalized into three separate levels.

> "The first level, or Basic Operating System, is computer science oriented and is the realisation of the infrastructure itself. It is not oriented towards building problems in any way and can be employed in other areas of system design and implementation. The second level, the Basic Design System, is oriented towards computer-aided building functions in general. The third level, or Detailed Design System, is directed towards the particular characteristics of a specific method of building and can involve substantial complexity in the automation of design procedures." 30/

The software for this system, being developed on a PRIME 300, is written in standard FORTRAN. Except for the Basic Operating System, the system is transferable to other machines as written. As of June 1976, the project was half

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29/Applied Research of Cambridge Limited, "Applied Research of Cambridge: An Introduction," p. 6.

30/Applied Research of Cambridge Limited," Infrastructure Software for Integrated System Development," p. 7.

complete. The Basic Operating System was completed and working, and a substantial portion of the generalized, building-oriented section was complete. The new system was scheduled for completion in mid-1977.

Applied Research of Cambridge, like Geneeys Limited, is looking toward marketing its products and services in the United States and has already set up an office in the United States.

Design Office Consortium

The consortium is a Government-supported association for promoting the use of computers and associated techniques throughout the building design and construction industry. Its aim is to pool knowledge and experience in the use of computers and to develop computer usage. At the present time, the consortium is taking existing application software and evaluating it in order to be able to inform others of the program, and setting up a Software Development Commission to assess application software requirements. This latter effort helps induce government offices to fund and support software development.

British Department of the Environment officials told us that the technology transfer problem exists in England also. While the design community is often interested in research efforts at the universities, there are few mechanisms for transferring the research results into practical application. The establishment of the consortium is one attempt at tackling the transfer problem.

During 1977, the consortium issued its first program evaluation report. 31/ This report covers computer programs to aid the three-dimensional visualization of building designs and is the first of a series. The report evaluates programs suitable for public use and concentrates on the main aspects of the programs, based on user experience on design projects and on the costs and comments of the designers themselves. The programs selected were programs which were readily accessible in the United Kingdom, with support, and whose owners agreed to the evaluation.

31/ Design Consortium Office, "Computer Programs for Building Perspectives," Evaluation Report Number One, 1977.

Computer-Aided Design Centre

The centre is one of the results of the British Government's decision to promote computers in industry. About one-fourth of its budget is supported by the Government; the remainder comes from industry and research contracts. The centre requires industry to provide some of the support for all work--that is, joint development is required. In the past, this work was geared to the use of large computers. More recently, heavy use is being made of PRIME minicomputers.

The centre's interest in computer graphics focuses on GINO-F, a general-purpose computer graphics package, written in FORTRAN, originally developed at Cambridge University, England, and enhanced by the centre. In another effort, three-dimensional graphics and color are used to create photomontages. In the process, a precise, computer-drawn building, bridge or road that is being proposed is overlaid on a photograph of the area to show how the structure will actually appear in the proposed environment. The total presentation is an accurate perspective; not plan or elevation type views. Therefore, the result is useable to show review groups the planned project, as well as for technical review.

One of the centre's programs, GREYSCALES, interactively generates perspective views of a model and displays them as halftone pictures consisting of various gray levels on a refreshed display. This process gives depth and form to the shapes.

We were told of one interesting example of the use and impact on the architect. A design competition was being held in Italy on a university building. An architect, planning to enter this competition, sent the centre simple plans of the building, which were put into the computer. The architect then came to the centre and spent a day in front of the display tube and studied more than 30 perspectives of his design. At the end of the day he concluded that the design was not what he wanted. He went back to his office, redesigned the building and then had it put into the computer again. Unfortunately, the design competition was canceled, but this illustrates the impact that use of graphics had on the architect's proposed design.

The centre's setup for graphics and perspectives would not be economical in an individual architect's office. But a central location (service bureau) would seem to be feasible, especially where many perspectives are required. Centre

officials told us that architects tend to believe they can do their perspectives faster by hand. They said this may be true if input data is not readily available, but, if it is, the computer-aided methods win, especially if more than one perspective is to be drawn. One on one, manual versus computer, both methods might be equal, except the computer product would be much more accurate.

The centre is now moving its efforts into the general information-handling problem. A joint project, involving the centre, a company in the United Kingdom, and one in the Netherlands, looked at data base systems for pipes in chemical plants. Existing systems were evaluated; no new technology was developed. Two extremely powerful software tools were developed through the projects by ignoring the sophistications and frills of the existing systems and concentrating on what was necessary.

The first was a data base software system that provides a tool for the specialist. It provides facilities that permit programers to build a variety of data structures and to operate on them. The second was a language processor's software package, for use by systems builders. These tools have not yet been used to build any systems other than feasibility-type systems.

National Computing Centre (NCC)

The centre is a nonprofit organization stemming from the British Government's interest in the effective use of computers as a national resource. Formed in 1966 to service the computing community in general, it is jointly financed by industry, commerce, and government. NCC is an association of computer-using organizations, as well as manufacturers, service organizations, and others who do not use the computer themselves but have an interest in its applications.

The membership directs the work which should be done by NCC. Centre managers are employees of the association. The centre director, however, is appointed by the Secretary of State for Industry--normally under a 5-year personal services contract, not as a Government or centre employee. The centre is actually run by a council of 14, half of these elected by members and half nominated by the Government. NCC performs the following services:

"* * * gives information and advice; provides education and training; promotes standards and codes of practice; cooperates with, and co-ordinates the work of other organizations concerned with computers and their use." 32/

While NCC is not specifically involved in the development of CABD systems, some of its activities impact on the development and implementation of CABD.

Software Products Scheme

The Scheme was set up in 1973 by the Department of Industry to encourage the development and marketing of software products, in general, by providing loans for these activities. It is open to any United Kingdom software house or bureau. Private proposals, if accepted, can be supported up to 50 percent of allowable costs. Scheme-generated proposals, which are contracted out, are supported up to 75 percent of allowable costs, the contractor bearing the remaining cost in exchange for market rights. The allowable costs include development, expenses such as computer time, market studies, and, for a period of 1 year after launch of the product, sales costs.

The Scheme is concerned with the exploitation of software products. Therefore, projects are designed with commercial viability as a major objective. NCC had developed a format for proposals which includes the information needed for project proposal evaluation. 33/ The topics to be discussed in proposals are:

--Objectives: Statement of reason for development and summary of new techniques to be used.

--Environment: Background information, such as who will buy the program, existence of similar or analogous programs, and anticipated future trends which might affect the market for the program.

32/ National Computing Centre, "Membership."

33/ National Computing Centre, "Software Products Scheme."

--Technical: Specifications for end product.

--Marketing: Definition of exploitation of the program. Discussion should include such things as size of market, suggested price, potential sales, distribution methods, competitors, and maintenance and support services to be provided.

--Financial: Estimation of costs to develop and market versus predicted income from sales.

The British Government has given the Scheme 700,000 pounds (roughly $1.4 million) on which to operate. Successful projects are expected to repay the Scheme and contribute a small profit to keep the fund going. Since the firm and the Scheme share in the gross income in the same proportion as they share costs, both should break even at the same time.

Standards

On the development side of NCC, the Standards or Methods Group works on practices of those using computers and their management of computers. It publishes manuals, guidelines, and state-of-the-art reports. One of the things it is working on is better documentation standards. A consultant was hired to prepare a report on what documentation should be; his report defined documentation and described what documentation should not be. Then, using this information, a systems documentation manual was developed which has been adopted as the Government standard for documentation. It is a reference manual, a "tools, not rules" book. Over 6,500 copies of the manual have been distributed.

One recent effort in the area of documentation standards development is of direct interest in its approach and in its general applicability to technical application software. NCC went to the British Institution of Civil Engineers (ICE) to find out what services NCC could perform. Out of this came the need for technical application software documentation standards, and a joint NCC/ICE Documentation Committee and a 14-member advisory panel were set up by the Joint Committee on the Use and Development of Computers in the Civil Engineering Industry. This joint committee meets under the auspices of ICE, the Association of Consulting Engineers, and the Federation of Civil Engineering Contractors.

The results of this effort to date have been an interim report and a draft of a two-volume documentation manual: Standards for the Content of Documentation and Guidelines for the Format and Control of Documentation. The manual relates not only to what a program does, but also why documentation is considered important because of general liability concerns relating to the distribution, selling, and use of technical application programs.

FEDERAL REPUBLIC OF GERMANY

In West Germany the development of CABD is probably more planned than in any other country. The approach there, which will probably produce at least one integrated CABD system, is flexible enough to conceivably result in several such systems. The Government has established a national technological policy and is financially supporting computer-aided design development. There are some purely private efforts but most are at least partially supported by the German Government.

Traditionally, strong support of technology has been an integral part of the total policy of the Federal and State Governments of the Federal Republic of Germany. "The Federal government considers basic research at industrial laboratories and government-financed establishments as an entity requiring close cooperation, coordination, and national direction." 34/

In the 1960s the West German Government embarked on a program to aid the development of the data processing industry in West Germany. Several people told us that the initial goal was to assist the computer industry (primarily Siemens, the German computer manufacturer) to gain a competitive position against foreign competition (primarily the American computer giant, IBM). The first program spanned 5 years, 1966-70. The second program, 1975-75, also was primarily geared to aiding hardware--but the assistance was split between large and smaller hardware manufacturers--and software developments began to be supported also (both system and application software). The goal of the third--and possibly the last--program, 1976-79, is to have a computer industry based in West Germany which is viable, competitive, and independent of Government aid. Support of software development is continuing with unchanged intensity. In the 4-year third program, about 562 million deutsche marks (roughly $258 million) will be allocated to applications of data processing.

34/U.S. Department of Commerce, "Technology Enhancement Programs in Five Foreign Countries," p. 123.

Gesellschaft fur Kernforschung (GFK)

GFK, located at the Karlsruhe Nuclear Research Center, is the West German Government's project manager for computer-aided design. It does not directly engage in development, but acts only as the administrator of funds and coordinator of program development, for the Ministry of Research and Technology. GFK had its origins in a 1972 study, 35/ under the Government's second data processing program. The study looked into computer-aided design in civil engineering from the users' point of view.

The results of this study included not only a list of programs needed by architects and civil engineers, but also an "activity requirement matrix" which conceptually showed where program development emphasis needed to be placed in order to attain integrated computer-aided design systems along function lines, such as housing, industrial, health, leisure, educational, and commercial construction. This led to the concept of horizontal integration of programs which is based on the attainment of integrated computer-aided design systems, ranging from initial concept and planning through fabrication/manufacture/construction to financial accounting, for a particular class of design-construction activity. Therefore, rather than develop a steel or reinforced-concrete design program, for example, that could be applied to the "universe" or all design-construction classifications, which would be considered vertical integration, the approach taken in horizontal integration would be to develop a program specifically tailored for each of the design-construction classifications.

The previously noted study thus set the framework for the future and set the criterion by stating the aim of future development, "* * * that most of the programs were to become subsystems of an integrated civil engineering information system." 36/ Finally, a proposal was made for the project-management and funding to achieve these goals.

The Government decided to locate GFK at the Nuclear Research Center because the center already had a large administrative base and the Government did not want to set up a new agency or organization for the sole purpose of

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35/G. Lang-Lendorff, "STUDIE für de Forderung im Bereich, 'Rechnerunterstutztes Entwickeln und Konstruieren im bauwesen'."

36/Ibid., summary.

administering the computer-aided design portion of the Data Processing Program. Also, the center is a neutral institution outside both the computer industry and academia. A staff of less than a dozen people administer all aspects of the computer-aided design effort, which includes teleprocessing man-machine interface, graphics, civil engineering, shipbuilding, electronics, and so forth.

The project selection process is involved, including reviews and analysis at the Ministry of Research and Technology as well as other Federal ministries. Also, several advisory councils must pass judgment on the projects. Finally, panels of experts are called in to evaluate the proposals and make the final selection. Although somewhat cumbersome, the Germans believe that this procedure assures to the greatest degree possible that there will be little duplicatior in research work and also that the projects selected will stand the best chance of being successful in terms of applying research and technology in practice. One of the overridir philosophies of the program is that the research and development will be completely practical in nature. We were told that the West German Government will not support "science for science's sake" projects under this program; the end result is expected to be an application for use in industry.

In June 1976, GFK was supporting 100 projects relating to civil engineering. Ten of these projects were in the universities--financed 100 percent by the program. The other 90 were in industry--financed 50 percent by the program and 50 percent by industry.

GFK continues to review CABD and CABD-type systems and approaches, and hardware-software needs and interactions both in Germany and in other countries to provide continual guidance for its project management functions. A Computer-Aided Design Workshop in 1975 37/ was an indepth review of GENESYS from the United Kingdom and the IST and REGENT systems developed in West Germany. An executive summary of an extensive, eight-volume, 1975 study of the state of the art and the tendencies of computer-aided design development in the United States is reported in a 1976 publication. 38/ This study encompassed computer-aided design and computer-aided manufacturing activities in all the major metal-, chemical-, and electronic-based industries and in the architectural and engineering disciplines.

37/Gesellschaft fur Kernforschung mbH, Karlsruhe, "Integrierte Programmsysteme," KFK-CAD 2.

38/Diebold Deutschland GmbH, "Rechnerunterstutztes Entwickeln und Konstruieren in den USA," KFK-CAD 7.

GFK has identified missing links and other areas of need within CABD, 39/ where CABD is broadly defined to encompass all the major discipline-oriented design classifications, and has given high priority to projects which address these needs. We were told that other projects, although not excluded from the GFK program, have much lower priority when competing for funding.

The current trend is to give funding to consortiums made up of university research groups, software engineering groups (usually a software firm) and users. All project proposals are reviewed by a working group, of which GFK has ten. Each group covers a special field, such as steel construction, soil mechanics, and so forth. They are made up of 10 to 20 members each, of which half are programers and developers and the other half are users. A system analysis must be performed for each proposed project and the developers are required to develop a development/maintenance/marketing plan. This plan must include the name and agreement made with the firm who will do the maintenance, testing, and marketing of the product after the development. The development stage includes 6 months or so for program debugging, which is supported by the project grant. About 30 percent of the grant is generally spent in this "using phase."

The director of the computer-aided program told us that GFK is a believer in stringent standards; those established required documentation, including manuals. The standards are aimed at minimizing software portability and documentation problems. System analysis, including preliminary users' manuals, are required before the system programs are actually written. Consequently, the developer must think through the process first if he is to minimize transferability problems. The group is also concerned about ongoing program maintenance and wants to set up a monitoring organization. It would like to transfer programs or license them to bureaus to keep them up to date. The goal is to set up a feedback mechanism to make programs more usable.

Architectural research project

This project at the Technical College of Darmstadt is aimed at fulfilling the needs of the architect. The research team hopes to develop a system, including both hardware and software, in which the computer hardware becomes the architect's hands and the software his directions.

39/G. Lang-Lendorff, "CAD-Richtlinien" (CAD Standards), KFK-CAD 6.

The immediate goal of the project is to develop programs to create basic forms and to manipulate these forms so the architect can experiment with the structure. Architects generally like to work with their designs because this process stimulates ideas and probably leads to better design. Dr. Emde, the project team leader, believes that if the architect could and would experiment with the computer, he would gain confidence and experience and be able to see the computer as a useful tool.

The researchers are aiming at the development of a package for architects--hardware and software--costing $50,000. The hardware for their proposed system would include a minicomputer, two disk drives (one fixed and one changeable), tape drive, plotter (50" x 64" table), display tube, and digitizing tablet. 40/

Verein Deutsche Ingenieur

In addition to the Government-sponsored work in Germany, there are activities within the engineering profession, this organization being one example. The Verein Deutsche Ingenieur, a German association of mechanical engineers, has set up a committee on data processing in engineering which is developing eight guidelines for computer usage. These guidelines will have a legal standing comparable to those published by the American Institute of Steel Construction or the American Concrete Institute. The committee's objectives are:

--To demonstrate to engineering management and professional engineers how computers can help perform design tasks better, faster, and more economically.

--To show how engineering problems which defied exact solutions by conventional methods due to their size and complexity can now successfully be solved by new techniques using computers.

--To inform computer systems personnel concisely and systematically of the possibilities for rationalization of the product design and development process the computer offers.

--To make the engineering educator aware of future demands on engineering skills and guide him in the design of his curricula.

40/Helmut Emde, et al., "Mathematische Grundlagen für das Rechnerunterstutzte Konstruieren und Darstellen von Architekturobjekten."

Many of those we contacted during the study believe this last objective is extremely important and an often overlooked element in the advancement of new technologies in engineerng and architecture. They said that educational institutions must stay abreast of state-of-the-art techniques being used in practice if they hope to fulfill the needs of the profession by equipping young engineers and architects with the basic tools and knowledge they will need to make the transition from school to work.

Enhancement of ICES

Messerschmitt-Boelkow-Blohm (MBB) has been interested in ICES since 1968. During 1975, MBB and the ICES Users Group in the United States signed a maintenance agreement calling for MBB to enhance and maintain the ICES Basic System, STRUDL II, and TABLE II. In July 1976, the ICES Users Group announced 41/ the release of the new MBB version of the ICES Basic System, STRUDL II, TOPOLOGY I, and TABLE II. We learned that MBB sought this contract because it agrees with the ICES philosophy and wanted to organize a well-documented program library and standardize the programing.

The public domain version of the ICES Basic System, distributed by the ICES Users Group, had not been maintained for at least 7 years and needed to be updated. As the result of individual enhancements and error corrections, a multiplicity of versions were resulting which forced the ICES Users Group to develop a coordinated standard version maintained by a maintenance contractor.

The MBB goal was to develop a basic system which was hardware dependent with all subsystems being hardware independent. This has been accomplished. This makes the system more portable, as only the basic system would have to be rewritten in order to introduce the system on a new machine. As a result, MBB has implemented ICES on the Siemens computer; an action which was also part of its agreement with the ICES Users Group. The basic system, as rewritten, takes over data management and other activities, such as matrix inversions, in order to use the computer for problem-independent functions. Therefore, the subsystems, which are problem-solving oriented and written in FORTRAN, do not now include hardware dependent characteristics and can be easily transferred to other computers.

41/ICES Journal, vol. VIII, no. 2 (July 1976).

In addition to the maintenance of certain programs for the ICES Users Group, MBB maintains the ICES subsystems programs it has in its own library. These include Urban COGO, SEPOL, LEASE, ROADS, and a new subsystem called DGM for processing digital terrain models. At the time of our visit MBB hoped to expand its contract with the ICES Users Group to include these subsystems in its maintenance role. MBB also has the documentation for three subsystems (GRAPHICS, STATS, and SPEC) which it has obtained from the Ministry of Works, New Zealand. Coincidentally, in November 1976, the ICES Users Group requested proposals for the maintenance of several of these subsystems.

All of the programs in the MBB ICES version have complete documentation. We were told that some new subsystems are to be introduced in the future, as well as some modifications that are to be made to existing programs.

MBB believes that the total ICES package is too large for one company to maintain. It would like to see a conglomerate of up to 10 companies, worldwide, set up to maintain the system and develop new subsystems. Also, it would like to see distribution of the source code restricted to prevent unqualified users from tampering with the system. MBB's position is that it is dangerous to allow inexperienced people (users) to make changes in the system; it believes that source codes should be only in the hands of those having full and adequate knowledge of the system.

MBB would like to begin some work on other major systems, such as NASTRAN, but does not have the finances. It plans to approach GFK, but obtaining the financing will be difficult unless the market potential and willingness of others to support the effort can be shown.

Other Activities

One software developer we visited was thinking about developing a CABD package deal with hardware, software, and engineering support, including training, all included in the package. Viewed as a CABD tool, it wanted the package to be modular so that users would not have to buy the whole package with all the peripherals at one time. This firm had participated in several of the Data Processing Program projects.

CANADA

The Canadians have also recognized that the design of modern buildings has become so complex, due to energy and

life-cycle cost considerations, that it is difficult to achieve good designs through traditional means. They see the computer as an avenue to better designs and to substantial savings in both money and energy. Since 1971-74, the Department of Public Works of Canada has been supporting a CAAD development project.

The objective of the project is to produce better, more economical buildings, considering total life-cycle costs. "When completed, the project is expected to include one or more computer centers with a substantial array of hardware, a nation-wide communications system, well developed capabilities in the areas of conversational computer use and interactive graphics, application software in all the major disciplines involved in building design and construction, and strong technical support for the software." 4/

The project approach is giving full recognition to the multidisciplinary nature of building design. Architects and civil, mechanical, and electrical engineers are all involved in the development of CAAD applications in their own areas of expertise.

The Department of Public Works emphasizes that, while it is furnishing financing and leadership, it solicits the needs of the private design community and strongly encourages its help in evolving a product that will serve the private designer and the department.

The department, in assuming the role of leadership, anticipates a system that develops at an evolutionary pace with the interest and participation of the private design and university sectors. This effort, it is anticipated, will be a prototype system subject to steady development and improvement until it reaches a level that encourages enlargement and dispersion.

The Canadians are not attempting, at this stage of the project, to link the work of the different disciplines into a fully integrated computer-aided design system for buildings. The first step toward integration will be the development of a common computer-based human interface system, through which data files generated by one discipline can be easily accessed by other members of the design team.

4/ F. Hamilton Wright, "Computer-Aided Design at the Department of Public Works of Canada," p. 1.

A basic tenet is that the communications system and data bases developed must allow the consultant using the system to use a computer of his own choosing.

In Canada, as in the United States, the great majority of the Government's design work is performed by the private designer. The project is being developed, we are informed, to aid these designers and to aid the Government as a consequence of the quality of the product it receives. It is anticipated that both private and Government designers will utilize the system in a coordinated way in search of building designs that optimize performance in life-cycle costs.

The Canadian Government has come to the conclusion that "WHILE THE PROCESS IS THE PROBLEM, THE BENEFIT FROM CAD WILL BE DERIVED FROM THE PRODUCT. [Their emphasis.] The incentive must come from the owners who benefit the most and they should shoulder the development costs." 43/ Conservatively, the Department of Public Works estimates that a mere 2-percent savings in life-cycle costs will at least equal the cost of the whole design process.

AUSTRALIA

The state of the art of CADD is believed to be well advanced in Australia. However, the Australians are totally dependent on hardware from other countries and rely extensively on computer software developed by foreign countries. This creates some complications, particularly with regard to building codes and their interpretation.

The Association for Computer Aided Design Limited

This association was formed in 1970 as the "Association for the Computer Aided Design of Structures" by a small group of enthusiastic structural engineers representing contracting, consulting, government and academic organizations who recognized the benefits that they would receive if the experience and knowledge of the individual, in the use of computers as a structural design aid, could be gathered together and shared by all. The scope of the association's interest has, over time, been broadened to encompass geotechnics, mechanical engineering, civil engineering, architecture, and planning, in addition to structural engineering.

43/ Andrew K. Dymyati, "A Computer Drafting Machine," Bell Canada, Vol. , No. 1 (January 1981), p. 12

The aims of the group are to:

--promote interest and increase professional competence in the use of computers as a design aid,

--improve the capability and capacity of its members to use computers in their professional work,

--rationalize available programs and systems and initiate the specification and development of new programs,

--provide means for checking and testing programs and systems,

--encourage acceptance of programs checked by the association and standards and policy documents produced by the association, and

--promote discussion and exchange of experience in computing systems and design aids.

The 140 members of the association include 5 from outside Australia. About half the membership are designers and consultants, 16 percent represent contractors and the building industry, 17 percent are from government, and 17 percent from academia and research establishments. Consequently, the group has a broad base of interests. Being a nonprofit, self-help organization, the bulk of its work is carried out on a voluntary basis by the members, with funding obtained by membership subscription.

We were advised that computer-aided design methods are used regularly by all association members. While the membership does not include all design offices, it does represent the major offices in Australia. All the members have individually convinced themselves that computer aids are economically viable. The group believes that the major factor inhibiting the development of computer-aided design in Australia is the lack of acceptance due to a lack of understanding of computer-aided design techniques.

In August 1974, the association published a recommended standard for documentation and checking of computer-aided engineering calculations. 44/ This document has received general acceptance by the profession in Australia and is in

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44/The Association of Computer Aided Design, Policy Document 74/1, "Recommended Standard for Documentation and Checking of Computer Aided Engineering Calculations."

fact now a mandatory requirement for computer-aided design to satisfy the Victorian State Uniform Building Regulations.

This policy statement sets forth recommendations on standards of documentation and checking of engineering calculations carried out with the aid of computers, with particular reference to structural engineering. It points out the need to check computer programs, discusses possible sources of error arising from their use, and highlights procedures necessary in order to adequately check computations and programs. It also suggests standards for professional presentation of computer output. The standards are applicable to design engineers, as well as those engineers responsible for checking designs.

JAPAN

In lieu of a visit to Japan, we corresponded with Japanese authorities on computer-aided design who supplied up-to-date information for our use.

In terms of numbers of computers in use, Japan is second to the United States. In the context of computer-aided design, engineering applications came into use 10 years and more ago, and today most Japanese engineering firms use computers, either their own machines or machines accessed through time-sharing arrangements.

As in the United States, structural programs and applications are in the majority, and the architectural processes have not been thoroughly exploited. This architectural lag is attributed to (1) the architectural design process being somewhat inexact, (2) the cost of computer graphics being high, and (3) the attitude of architects towards computers.

Despite these hurdles, there is said to be a strong and growing demand for the development of refined CAD systems. There is current interest in integrating the existing systems and applications developed for the individual fields of engineering with new and improved design processes and applications. This objective is said to be much discussed among practicing Japanese architects and engineers.

Computerizing of drafting and other routine design work has been developed mainly by building design companies. More sophisticated applications and integrated design systems are expected to be developed by research workers in Japanese colleges and universities.

The trend being what it is, future development seems assured. However, as in the United States, problems to be dealt with center around systems integration and common data base issues, achieving facilitated modes of communication between man and computer, and the continued and further emergence of low cost hardware.

The Japanese have also developed computer-aided techniques in fields other than buildings. Knowledgeable individuals in the United States advised us that the Japanese use of computer-aided design in shipbuilding is far superior to the United States and well developed.

THE NETHERLANDS

We did not visit the Netherlands, but a great deal of activity appears to be going on there. References to work in this small country frequently appear in the literature. One development of interest to ICES users is discussed below.

The Shell Benelux Computing Center in The Hague has written a very useful tool for users of ICES. ICES, not being a conventional program system, tends to resist the more usual debugging techniques. The center developed A User's Guide to Debugging ICES Dumps. Generally the information necessary to debug an ICES dump is scattered over diverse sources. This manual endeavors to combine the facts in a single publication, designed to meet the requirements of ICES users, and includes information gleaned by experiment and practical experience at the center, where ICES has been operational for several years. At the time we prepared our report, this manual was not distributed in the United States, but was only available from the European ICES Distribution Agency at Ispra, Italy. 43/

Other activities which appear frequently in the literature are Delft University of Technology and the Dutch Association for the Development of Civil Engineering Techniques based on Analog and Digital Computers, called CIAD. Unfortunately, we were unable to visit the two activities.

OTHER COUNTRIES

In addition to the countries discussed above, we have become aware of CAD-related activities in Scotland, Finland, Czechoslovakia, Belgium, Norway, Hungary, Austria, Italy and Israel. At least five countries have established national

43/"A User's Guide to Debugging ICES Dumps," ICES Journal, vol. VIII, no. 3 (November 1976), p. 92.

centers for computer applications in the construction industry. These are Bulgaria, Hungary, Czechoslovakia, Rosania, and the Netherlands.

At an ad hoc meeting on the use of computers in the building industry 46/ in London in September 1972, it was reported that,

> "Work on systems for building design is generally related to a particular type of building or to particular industrialized building systems; the problems of developing an open system for building design are beyond the existing [1972] state of the art to solve but in Bulgaria programs are being linked to form an integrated design system and a system for construction." 47/

In a preceding summary and analysis of country replies to the Economic Commission for Europe's inquiry on the use of computers in the building industry, 48/ it was noted that an Integrated Building Design system had been developed in Finland which computes all the structural elements of a reinforced concrete building and estimates quantities of concrete, reinforcement, and formwork. This report also defined a system of programs to be a "suite" of related programs, each of which can be used individually, but which taken together integrate two or more functions. Based on this system definition, the summary noted that in the Ukraine and Rosania there are operational systems designed on a modular basis in which each new program is developed as an independent module which can then be included in the set of programs by any of the users of the system. It also noted that in the USSR a system of building design (AChOC) was being planned. AChOC is to optimize design decisions and to automate the design process, securing the best division of functions between man and machine. AChOC probably will operate via a network of automated design centers.

46/Working Party on the Building Industry, Committee on Housing, Building and Planning, Economic Commission for Europe.

47/HBP/WP.2/AC.1/1, Oct. 19, 1972.

48/HBP/BUILD/94, June 27, 1972.

IBM EUROPEAN ACTIVITIES

In Europe, IBM has been active in the computer program area. Since 'unbundling' in the United States, IBM has virtually terminated all application programing efforts in this country. The following are examples of some of IBM's European projects.

IBM Data Centre Services, Poeldonker, Netherlands

The centre made a study of the impact of interactive ICES mainly on the use of the STRUDL subsystem. The report, "ICES under TSO," by Wouter Bloss, et al., discusses the demands arising from interactive ICES for subsystem development and programing, as well as how these are realized in STRUDL. Finally, it discusses what could be new in ICES development.

IBM France Data Center Services, Paris, France

IBM France has been using, maintaining, and developing the ICES system and the STRUDL subsystem since 1970. Some of the main developments have been:

--concerning the ICES system

-usage of the H-level of FORTRAN,

-messages to the operator's console during the execution,

-minibus capability to save problems, and

-plotter output (4 kinds of plotter devices, plus standard plotter interface).

--concerning the STRUDL subsystem

-graphical outputs on plotting machines:

-perspective and planes of all or a part of the structure,

-member forces and force envelopes plotted on each member of on the plotted structure,

-principal stresses plotted at nodes and centroids for plane finite element, and

-deformed structures

-under static or dynamic loading conditions, and

-normal modes.

IBM Germany, Manufacturing Industry Center, Munich, West Germany

IBM announced, at the Fifteenth ICES Users Group Conference in London, England, September 25-26, 1975, a version of ICES STRUDL II as an IBM Special Program. The program corresponds to the last IBM France version. The set of programs, which IBM released, includes major developments concerning the ICES system itself, as well as the STRUDL subsystem. The program has been or will be announced in the following countries: Spain, Germany, the Netherlands, Belgium, Italy, Sweden, France, Austria, Turkey, the United Kingdom, Iran, and Japan, but not the United States.

APPENDIX III

REPRESENTATIVE LISTING OF AVAILABLE TYPES OF COMPUTER PROGRAMS FOR DESIGN APPLICATIONS

Initial phase

Feasibility study	Economic feasibility analysis Cash flow analysis Depreciation Amortization Land evaluation Investment analysis Housing type mix analysis Census data analysis Density maps Grid maps
Programing	Problem structuring Activity data analysis Space need projection Accommodation schedule production Circulation analysis Cluster and bubble diagram generation

Sketch design phase

Site planning	Site mapping Slope analysis Drainage analysis Cut and fill analysis View analysis Accessibility analysis Overlay mapping analyses Site plan synthesis Soil stability analysis Water surface profile
Schematic design synthesis	Floor plan layout Three-dimensional spatial synthesis

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Performance and cost analysis of proposals	Checking for compliance with the brief Circulation analysis Preliminary analysis Preliminary structural computations Heat gain computations Heat loss computations Insulation and shadow pattern analyses Natural lighting computations Artificial lighting computations Sound transmission computations Reverberation time computations Space frame analysis Dynamic analysis Truss analysis Beam analysis Plate and shell analysis Column analysis Wall analysis Heating and cooling loads Wet stand pipe analysis Waste and vent analysis Energy consumption analysis Electrical lighting optimization Electrical short circuit analysis Elevator simulation Acoustical analysis Preliminary cost estimation
Presentation	Plotting sketch plans, elevations, sections Plotting perspectives

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Production documents phase

Detail design	Building products data retrieval Automated detailing Structural member selection and sizing Mechanical and electrical system detail design Duct, pipe, and electrical network layout Equipment selection Electrical feeder sizing
Costing	Generation of bills of quantities Pricing of bills of quantities Cost analyses
Production	Generation of schedules Generation of specifications Plotting of working drawings

Construction supervision phase

	Network analysis Precedence diagramming Project cost control

Management functions

	Job costing Time and payroll functions Invoicing Project control Personnel systems Project performance reporting

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