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This report presents the findings and papers developed at the Workshop on Advanced Technology for Building Design and Engineering held in August 1983. The workshop addresses the long-term implications of advanced technologies, especially computers and electronics in general, on the process of building design, production and management. The report contains working papers on the use of advanced technologies in the representation, organization and integration of building-related data, and discusses barriers and incentives to advancing the state of the art. General findings of the workshop are presented, as well as the texts of two keynote addresses on new computer technologies and trends in the use of computers in architectural and engineering design.

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A Report from

The Workshop on Advanced Technology for Building Design and Engineering

August 1983

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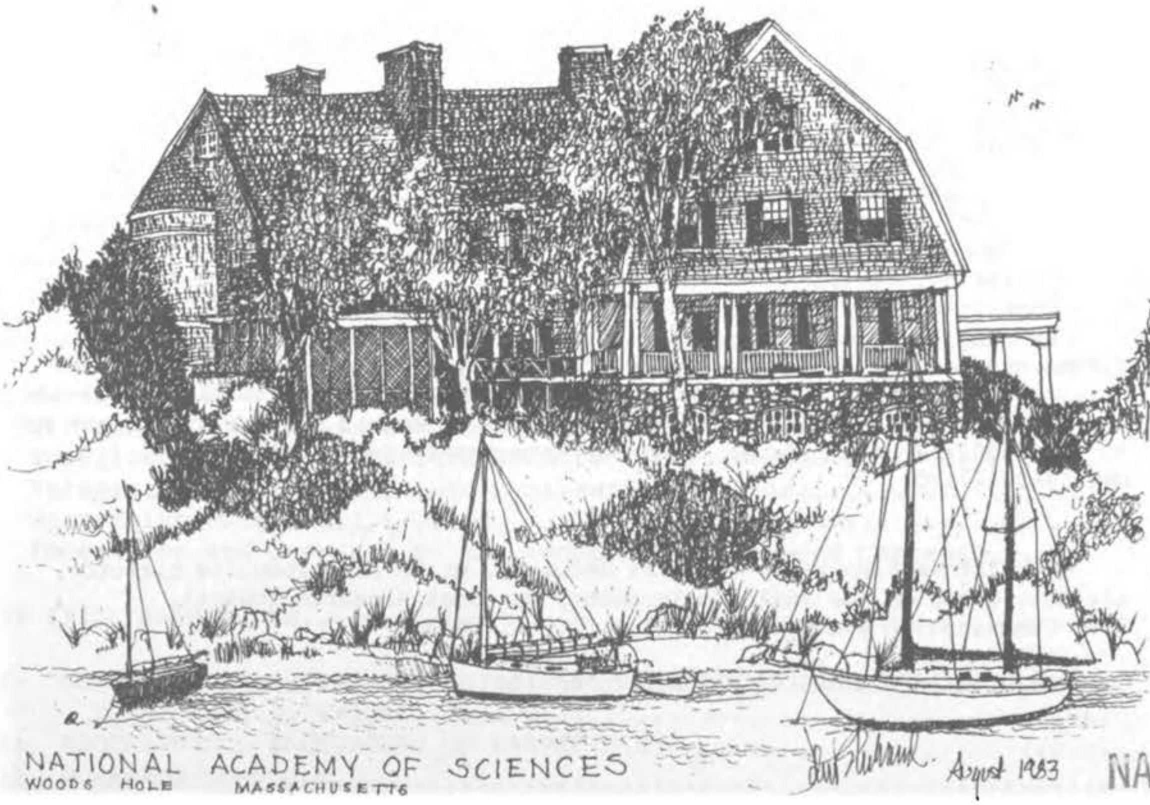

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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CONTENTS

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OVERVIEW

INTRODUCTION

Advances in technology often outpace the integration of such advances into practice. The first horseless carriages had replicas of horse's heads mounted on their fronts; the first television sets were housed in cathedral radio cabinets; the first refrigerators were designed like ice boxes. In each case the technology was adapted to existing products until it evolved into a design and function of its own.

Computer and electronic technologies are currently being adapted to the existing methods of designing, producing and managing buildings. Participants at the Workshop on Advanced Technology for Building Design and Engineering were asked to rethink the building process given the likely advances in computer-based technologies. The purpose of the workshop was to develop a long-range assessment of how advanced electronic technologies will affect future building design, production and management. The emphasis of the workshop was on the conceptual framework for how advanced technologies could lend themselves to design approaches not now possible with existing manual methods.

The product of this workshop, encapsulated in this report, is meant to assist those in public agencies responsible for long-range planning of construction programs. The report addresses the use of advanced technologies in the representation, organization and integration of building-related data, and discusses barriers and incentives to advancing the state of the art. The workshop was supported by the member agencies of the Federal Construction Council, which consists of 14 federal agencies that design, build, or manage public facilities.

Because the workshop consisted of separate working groups (each issued a report), no attempt has been made in this document to eliminate duplication of information. Working groups tended to hold parallel discussions on a number of subjects from slightly different perspectives. This report includes the full reports from all workshop working groups.

ORGANIZATION OF THE WORKSHOP

Twenty-nine invited participants attended the workshop that was held at the National Academy of Sciences' Study Center in Woods Hole, Massachusetts from August 21-26, 1983. In order to provide a wide spectrum of thought and experience, three types of individuals were invited: (1) those from the building industry familiar with the use of computers in the building process, (2) those from the computer industry responsible for product development, and (3) those familiar with the concepts and vocabularies of each other group. This latter group served as an interface group during the workshop. Architecture, engineering and computer sciences were the primary disciplines represented. Participants came from federal agencies, universities, architecture and engineering firms, research organizations and computer manufacturers. Biographical sketches of participants are presented in Appendix II.

The workshop opened with two keynote addresses by Denos Gazis and Charles Eastman. Mr. Gazis, from the IBM Research Center, presented a forecast of computer technologies that may have an impact on the design and construction of buildings. Mr. Eastman, president of Formative Technologies in Pittsburgh, discussed trends in computer usage in architecture and engineering practices focusing on the development of building models in electronic form. The keynote addresses are found in chapters one and two.

Participants divided into four daytime working groups. The subjects of these working groups were: (1) building description and representation, (2) data-base design and management, (3) data integration considerations, and (4) computer-aided building and the potential for linkages between computer-aided design and computer-aided manufacturing (CAD/CAM).

Participants spent the first two days in their working groups discussing a series of issues developed for each group. The ideas generated from these free-wheeling discussions were synthesized into an outline of a paper on the third day. The fourth day was devoted to writing a summary of the group's findings. On the final day, reports of the four working groups were presented for consideration and discussion by all participants. The workshop chairman, James Burrows, met with group leaders during the week to coordinate the four groups' activities. The reports from these working groups are found in chapters three through six.

During the evening hours different combinations of participants met in seven working groups to discuss incentives and barriers to the advancement of the state of the art of computer technology in the building industry. The subjects of the seven evening working groups were: (1) university research, (2) government research and development, (3) private industry research and development, (4) integration of concepts into architectural practice, (5) integration of concepts into engineering practice, (6) university programs, and (7) incentives and barriers to the adoption of advanced concepts.

Several of the groups with overlapping topics decided to merge. Evening group discussions were followed by a writing session and presentation to the full workshop on the last night. The reports from these groups are found in chapter seven. An agenda for the entire workshop is found in Appendix III.

GENERAL FINDINGS

The workshop chairman and other participants were asked to record some general findings of the workshop. These findings, while not conclusions of the whole, indicate some areas of agreement among the various working groups. Some were articulated at the workshop itself; others were formulated afterwards. The general findings are:

- The process of designing, producing and operating buildings is fragmented among numerous participants in the life cycle of the building. As a result, much valuable data associated with the process of building and operating a building are lost during a project's life span.
- Computer technology is currently used in a limited way for some design, analysis and management applications in the building process, but an integrated approach to collecting all of the data about a building project has not yet been economical or practical. However, the use of advanced computer technologies among those in the building industry is increasingly becoming evident. Computer technology will be applied more fully to create integrated building models when it is cost effective to do so. Changes in the collection and use of building data will be driven by the availability and economic incentives to use it.
- Computer technology has the potential for improving the building process by making it possible to develop complex building models that describe the project and that preserve valuable data in useful forms. This application will improve the building process and make it easier to operate buildings. In addition to project-specific data generated during the design and building processes, general data about regulations, codes, building and engineering practices could be automated.
- While many legal, regulatory, institutional, and educational issues must be addressed in achieving the building model, computer technology is expected to become available to make it feasible. Technical barriers are expected to be overcome. These include common data descriptions, interface and interchange standards, and suitable programming languages. Within the next 15 to 20 years unlimited computer capability and unlimited data storage capacity should exist.

- The legal, regulatory, institutional, and educational issues are likely to be more significant barriers to achieving the integrated building model than a lack of technology. New organizational structures may emerge to manage the building life cycle.
- The building industry is slow to change and has shown little inclination to fund long-term research and development. In order to stimulate change, innovative research and educational partnerships will be needed. The federal government can be a leader in specifying and funding advanced technology applications in the building process.
- The long-term effects of applying advanced technology to the building process could be beneficial. Use of computer technology could lead to better linkages and interactions between the major players in the process and reduce the segmentation between the parts.

PART I

PRESENTATIONS

1

COMPUTER TECHNOLOGY

Denos C. Gazis
Assistant Director, Semiconductor Science and Technology
IBM Research Center, Yorktown Heights, New York

The objective function of any effort intended to advance the use of technology in building design and engineering should be to provide a fit environment for all. It should also provide the owner and occupants with the opportunity for choice. The role of the designer and engineer, which can be supplemented and extended through the use of computer-aided design and computer-aided manufacturing (CAD/CAM), is to make the opportunity for choice a reality within the constraints of health, safety and the common welfare requirements. Electronic technology now available for these purposes and technologies still in the development stage are described below.

There has been an evolution from the vacuum tube systems of the early days (the "first generation systems" of the 1940s) to the chip. Each movement has been accompanied by a reduction in the size of the components and the power required to operate them. If the present computer systems were still based on vacuum tubes, they would be the size of the Houston Astrodome and require the Gulf of Mexico to cool them. An IBM personal computer now has about as much computing power as the entire IBM Research Division had in 1960.

Digital technology is driven by four goals: make it smaller, faster, with more functional capacity, and for lower cost. The two polar directions for electronic computation development are: (1) microcomputer technology, which is moving with space as the limiting factor, and (2) mainframe technology, which is moving with power as the limiting factor.

Mainframes tend to be built of simple but fast chips while microcomputer technology is moving toward development of relatively slower but ever more complex chips. Circuits on some of the fast chips now operate at nanosecond speeds but will be almost 10 times faster by the end of the decade. (There are as many nanoseconds in a second as there are seconds in 30 years.) The dimensions of components seem to be capable of being reduced in size by one-half every three to four years. In the case of memory chips, we will soon have a chip with a memory capacity of one million bits, and by the early 1990s, we will have them with four-million-bit capacity. High-resolution lithography will soon produce lines that are as thin as one-half micron (for chip production). But silicon technology will also reach a technical limit and may be superseded by galium arsenide (GaAs). The Josephson effect, that provides extremely fast switching speeds (about 10 picoseconds), and very low power consumption offers another possible alternative beyond silicon for high-performance processors.

But what does all of this mean to the development of CAD/CAM for design and engineering? It means that there is essentially no constraint with respect to computing power. A few years ago computer facility managers felt that they needed to keep their systems totally occupied 24 hours a day to gain maximum advantage from the large investment made in the systems. But this attitude has begun to vanish with the advent of the personal computer. We will soon be able to think about computer power the same way as we now think of horsepower in automobiles--it is there when we need it, but we don't need to use it constantly to justify ownership. We can begin to think more about the conservation of human effort in complex problem solving and can forget about the optimization of computer use.

As computer technology moves in these directions, it is often the case that it is the characteristics of the human user--our size, our physiological capabilities, and our psychological responses--that begin to limit any further reductions in size or shape of the computer hardware, particularly the input and output devices that we use. Thus, the development of input/output devices is increasingly being driven by ergonomic considerations.

A number of emerging computer-related technologies may also have an impact on the design and engineering of new buildings (e.g., how buildings are used). Teleconferencing will provide not only a direct substitute for transportation, but also an added interaction capability, a "live" connection between remote locations. Telephone message facilities will allow storage of audio messages that can be edited and modified by the sender before being transmitted (in a store-and-forward fashion). Speech recognition capability as well as speech communications with hardware will be possible soon. "Expert systems" will permit the use of computer capacity to improve and extend the education and professional capability of the user or to provide consultation for new, unfamiliar tasks. Robotics will change product manufacturing capability as well as field assembly processes and, consequently, design alternatives. Simulation of product performance in order to test various parameters before actual production will permit the testing of various levels of building performance as part of diagnostic procedures. Three-dimensional modeling will facilitate architectural design and permit reliable "views from the inside" of a building with fast turnaround after design changes.

Technology is presenting us with a powerful set of tools for improving our built environment. It is up to us to put these tools to good use.

2

TRENDS IN THE USE OF COMPUTERS IN ARCHITECTURAL AND ENGINEERING DESIGN

Charles M. Eastman
President, Formative Technologies, Inc.
Pittsburgh, Pennsylvania

Some trends on the availability of computing capability seem clear: (1) it will continue to be ever cheaper, (2) everyone in the business of building will have computer capability, (3) there will be an increasing use of networks and telecommunications, (4) the amount of effort required to enter data for drawings or specifications into a system will continue to decline, and (5) photographs and actual drawings will be capable of being input to more advanced systems without laborious processes.

Building Product Use

Computers will be a vital part of the process of building product distribution as parts descriptions, specifications, and details begin to appear in machine-readable form--a "Sweets Catalog" in electronic form. This will likely include the use of expert systems for specifications writing, especially in those areas of specifications that are based on special knowledge or high-technology products. Encoded part descriptions make it possible to select products for use in buildings based on their desired performance characteristics rather than brand name, and to specify products that are known to be in inventory on a regional basis for a specific building site. These are important opportunities for designers and contractors.

This same capability will provide the producers and distributors of building products with information that will more easily allow them to find where the market opportunities are on a geographical basis and to arrange their regional distributions and sales efforts accordingly. It also is likely to mean that producers will be competing more on the basis of the performance characteristics of their products than on their past reputation or favored status.

Construction Documents

Construction information that is provided today by working drawings generally is not a well-organized guide for the actual construction of a building. Construction information takes a different form in vertically integrated design/build firms, where conventions are not as important. Some alternatives being introduced through computer-aided design (CAD) processes are the provision of a bill of materials for the building that can be used for ordering supplies, the provision of suggested pallet layouts on the building site, and the combination of detailed drawings with construction schedules so that the details needed at a certain point in the schedule are made available.

Computer models of buildings may eliminate the use of drawings as the information of record in a building project. These capabilities at the contractor level will allow the automatic production of drawings on demand from a data-base model of the building project. When this occurs, new issues and opportunities arise with regard to liability factors and automated code checking.

Tools for Developing Intelligent Building Models

There are many technical challenges to realizing intelligent building modeling systems. Some new tools are available that will make the job easier: logic-oriented languages (e.g., Smalltalk and Prolog) combined with data-base management, and abstract data types of the kind required for engineering systems that can embed integrity constraints. Data-base organizations for managing integrity using hierarchical transactions are useful. They allow partial integrity and controlled propagation of constraints.

Automated design can be based on the use of "shape grammars" and other pattern-embedding techniques. This includes the use of automated detailing from data files of details as well as automatic remodeling of design decisions at a later date (e.g., bathrooms and kitchens). Architectural aesthetics are then built upon systematic evaluation of formal systems of composition, and the designer is allowed to deal with higher levels of complexity in possible solutions.

Building Design as a Project or as Maintenance of the Environment

Architecture could become a continuous process over the life of a building--adapting and re-adapting the space and equipment to the changing needs of the client. This suggests facilities management--not the design of a single project--as the basis for all future work. Facilities management defines the need for remodeling or new construction and the performances required. This defines a project that, when built, becomes part of the facility management process.

Building Performance

CAD also allows modeling of building phenomena in the process of testing design alternatives. Among the factors that can be dealt with in this way are acoustic conditions, circulation patterns (including emergency evacuation), user activities (although "activity languages" are still needed), thermal cycle of materials after they are installed in buildings, air flow and circulation within and outside the building, and design trade offs and their impact on construction processes. Each of these, and others, can be iteratively applied, followed by design revisions, so as to allow efficient search for higher performing designs.

Building Models

There is a simplistic view of a building model as a three-dimensional model of the building elements, the functional attributes associated with each element, and the construction details that surround the elements. Such a model potentially allows the automatic production of drawings. A little work still is needed on the placement of notes on the drawings, on dimensioning, and on perimeter boundaries, but I expect to see complete automation of drawings within eight years. It also allows the automatic checking of interferences and provides the data for analysis programs. For example, building performance can be modeled by iterative hill-climbing techniques, or design rules could be checked. Carnegie-Mellon University and the University of Michigan have such systems under development, and there are a few commercial systems on the market.

Such computer models have some serious limitations, especially in attempting to make a recording of a complete design. Such models generally do not easily support revisions such as the moving of a wall or changing a mechanical duct run. For example, when moving a wall it is necessary to adjust abutting wall connections, adjust door and window placements, update affected details, adjust any covered structural or piping elements, adjust space calculations, adjust energy, acoustical, and lighting requirements, and adjust the bill of materials. These updates can now be made automatically, but to do so is only slightly faster than manual changes because the means to do the updating are not well developed. Each element in the three-dimensional layout must be resized, relocated, and tested piece by piece.

Needed are more advanced systems incorporating deterministic rules that define how one change affects other changes. A good example of such a rule is: Given the change of a window in a facade, automatically adjust the detailing around it, automatically recalculate the new energy loads for the room it encloses, and resize the duct or energy delivery to the room if required.

Several techniques from artificial intelligence research provide tools that could serve as general mechanisms for embedding such knowledge in building models such as logic programming languages (Prolog) and object-oriented languages (Smalltalk).

PART II

STUDY GROUP RESULTS

BUILDING DESCRIPTION AND REPRESENTATION

The group studying building description and representation consisted of: Charles M. Eastman, Formative Technologies, Inc.; John O. Houston, Grafcon Corporation; Mary Oliverson (chairman), Applied Research of Cambridge, Inc.; Edward Popko, IBM; Neville Powers, Applicon/ Schlumberger; and Fred Stahl, National Bureau of Standards. It was asked to explore how graphics technology will develop during the next 10 years and what it may provide as a "medium" for building designers. Originally the group's subject was "building description and graphic representation" but it decided at the onset of discussions to broaden the topic to encompass all types of representation including voice and holography. A summary of the group's deliberations is presented below.

INTRODUCTION

In a climate of national economic growth, the demand for building stock --new buildings, enlarged facilities and renovated space--dramatically increases. The same economic growth increases the demand for labor, materials, and equipment, and increases both the initial cost of a facility and the long-term maintenance cost. The growth industries that emerge from such periods often find themselves within a shifting and uncertain economic climate.

Buildings are often speculative investments. Owners attempt to predict the demands for office space, hotel rooms, housing, and so forth. Although these investment risks often result in large profits, they also contribute to an uncertain climate within the industry. When over-building occurs as a result of incorrect predictions, the volume of construction in a city may drop dramatically.

Buildings are expensive, long lasting, and difficult to change. Their inception and initial planning generally take place in an environment with low information content and with few data to guide the choices. When prices are rising in conjunction with the economic climate that increases the demand for buildings, the costs of being wrong in the planning stage can be very great. Because buildings are long-term investments, it is often necessary that the space remain flexible and capable of being adapted to changing needs or growth.

The increased complexity of client needs, the long-term economics of design and maintenance, and the competition between architect, engineering, and construction (A/E/C) groups to expand their roles has led to fundamental changes in the entire industry.

Professional A/E/C services have expanded and, in some cases, overlapped into services traditionally associated with other professional groups. There is greater interdependency among the A/E/C professionals, cooperation takes place over longer time periods, and more professional boundaries are crossed. Today's industry is shifting from a narrow and highly segmented building production association toward a widely based and semi-integrated array of "cradle to grave" services and products. A/E/C-client industry relationships are longer lasting, more comprehensive in scope, and higher in capitalization than ever before.

Recent advances in computer technology have lowered information processing costs, increased the quality and reliability of equipment, and increased the variety of forms and programs available. Some of the present systems are affordable by even the smaller firms in the A/E/C community, and new advances are expected to lower the costs and increase the performance of computer systems still more. Computer science will continue to improve the equipment in terms of cost and performance. It will increase both the tolerance for ambiguity and error and the media available for man-machine dialogue.

Those in the A/E/C community see these advances as vehicles for expanding their services to their clients, increasing their own productivity, and gaining new aesthetic freedoms and improved environmental quality. Clients see these advances as a means of maximizing their returns on building investments, managing their own growth over time, and reducing the uncertainty that market changes may have on their facilities.

Architects, engineers, and contractors may not always use information for the same objectives. For example, architects may use computers to expand their client services whereas clients may use computers to cut extra costs. However, they all need to share descriptions of the building projects in which they have a mutual interest. The broader integration of computers into A/E/C-client relations will necessitate formal building descriptions and representations that go beyond the traditional text and graphics.

In the broadest sense, the building description is a formal set of logical models, data exchanges, and machine configurations that: (1) reduces the uncertainty in the design and programming of buildings, (2) facilitates communication among the A/E/C-client group throughout the life cycle of the building, and (3) improves the definition of client requirements and A/E/C service delivery by making the entire experience more cumulative and testable.

Representation is a formal system of symbols that: (1) reduces data, (2) portrays interactions, (3) summarizes and communicates physical attributes, and (4) acts as surrogate measures for more subjective values. This discussion explores the formal computer-based descriptions and representations of buildings used for these purposes.

IMPLICATIONS

The need for a building description, graphic or otherwise, is derived from the need for more effective communication among the "actors" in the building process throughout the life of the building from conception to preservation or demolition. Hence, the focus here is on the computer as a medium of communication.

A building description model should not be thought of as a very detailed, very complex package of information, but rather as an historical collection of various incomplete models that are biased by and for the particular viewer (user). Advances in computer and communications technology can have some rather obvious impacts on the development and use of a building description model. They are:

1. Input/output of information,
2. Interfacing the pieces of the models,
3. Interfacing the actors in the processes,
4. Interfacing the multiple processes themselves, and
5. Encoding and archiving all of the above.

The not so obvious roles of advanced technology include the following:

1. The assemblage of all the incomplete and viewer-biased models into a complex, detailed model that, in quantity, is less than the sum of the parts and, in quality, is more,
2. Simultaneous simulations of processes in order to discover and correct the conflicts,
3. The accumulation over time of a basis for a "design language" that is acceptable and usable by all the design actors,
4. The delivery of the brain and nervous systems of the building (the delivery of the "consciousness" of the building organism), and
5. Experimental representation of the building ("walk through it, sense it, feel it").

In order for design tools to be developed within the context of advanced technology, analysis tools must be defined and developed. At least this has been the case in other industries where design tools are now beginning to emerge.

A new methodology then will emerge that embraces the building process across the full time cycle. Perhaps a new profession will emerge to take responsibility for the delivery, update, and use of the models. Whether or not some members of the architectural profession will assume this role remains to be seen. Questions of accountability and liability also will need to be studied.

The study group drew three conclusions about building description models. They are:

1. The data representations must be canonical (i.e., they must be an "authorized or accepted body of rules, principles, or standards that are universally binding") and reduced to their simplist form,
2. The models and tools must be able to be tailored to the actors who use them, and
3. The models must be managed.

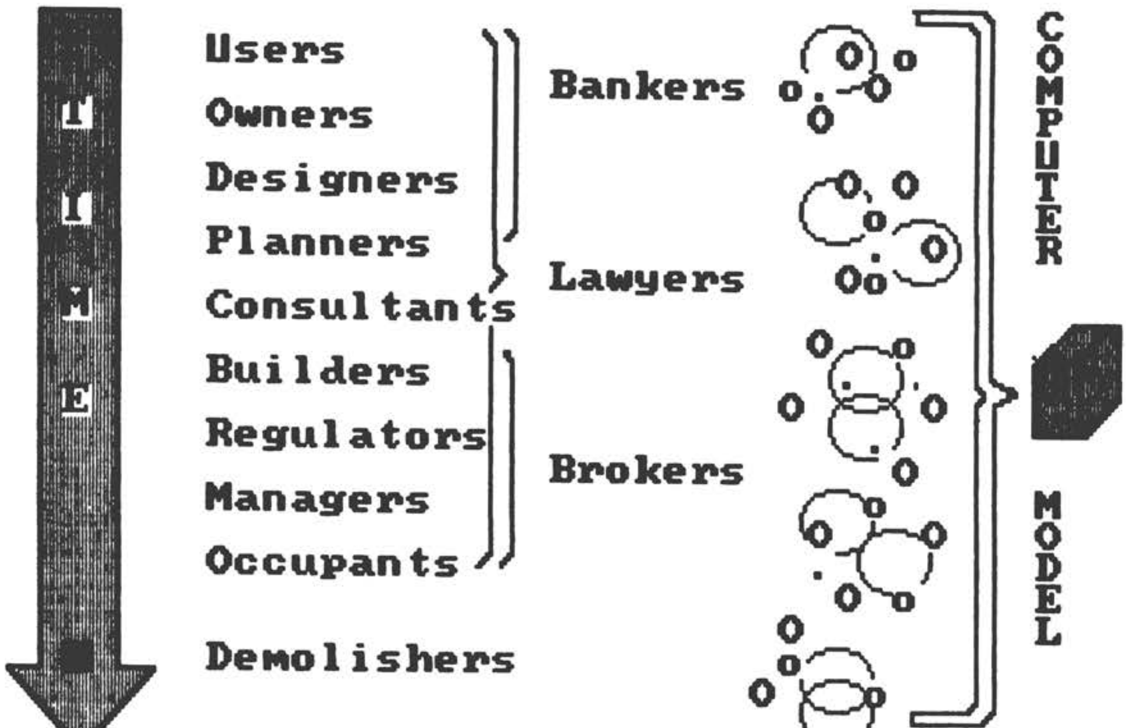
THE SEARCH PROCESS

Consensus on three broad and interacting issues emerged during the group's deliberations. They are:

1. Building cannot be viewed as a discrete activity; rather, it occurs over time. The building process has a life cycle that extends from concept formulation through demolition or reuse (Figure 3-1).
2. The building process involves participation by numerous players, each of whom brings a different view of the problem, different technical expertise, and different demands for project data representation (Table 3-1).
3. The form and representation of project description data vary with the demands of each participant and the requirements imposed by each separate phase of a project's life cycle (Table 3-2).

The notion of "project data models" also surfaced early in the group's deliberations. The project's data model is built-up over the project's life cycle. It is the body of descriptive data that is operated on (via graphic grammars, simulations, analysis algorithms, and so on), and it is the body of data from which "reports" are generated to suit various functions during the project's life (e.g., graphic views, text and tabular reports, voice instructions, holographs). Under these conditions, it seems clear that project data should be a canonical expression of project description data. Given a canonical form, key questions regarding interfaces between the building data model and individual data operators or report generators, as well as the management of the data over time, will have to be considered further. Stated another way, data transfer to and from analysis, design, and management functions and conventions for accessing relevant project data are central to the implementation of canonical project data models.

Beyond the technical implications and requirements are questions such as: What is the project data model concept? Will there emerge a



ACTORS, PROCESSES, AND MODELS OVER TIME

■ FIGURE 3-1

TABLE 3-1 Information Needs Throughout the Building Process

Information User Groups	Building Conception	Architecture Engineering	Occupancy	Demolition and Re-use
Users/ occupants			Where are things by name, attribute, and occupancy?	
Owners	Cost/schedule design reviews			
Designers (architects, engineers, planners)	User requirements, resources/ finances, context (site, climate)	Form/geometry, materials, performance of systems		
Builders		Constructability (component availability, location, schedule, context, change orders)		
Facilities Managers (operations, maintenance, modification)	Buy/rent/build, performance specifications from monitoring		Building modification, services/ equip. inventory, temporal/use records (service, maintenance), monitor building use	
Public Facilities (code officials)	Land use (density and parking)	Design code compliance	Code compliance over time, building description (fire)	
Brokers Marketeers	Register (market requirements, client profiles)		Lease hold, ownership records	

TABLE 3-2 Variations in Information Characteristics as a Function of Building Process or Activity

	Access Mode	Quantity	Source	Accuracy	Frequency of Use	Security	Time
Programming and Planning	Nontransactional	Low (statistical reduction)	Largely internal	Low	Low	Low	Historical projective
Schematic Design	Nontransactional	Low	External	Low	Low	Low	Projective
Design Development	Transactional	High	Both	Medium	High	High	Most current
Construction by Builder	Transactional	High	Both	High	High	High	Current, historical projective
Occupancy by Facility Manager	Transactional	High	Internal	High	High	High	Present, future
Occupancy by User	Transactional	Low	Internal	Low	High	Low	Current
Historical Analysis of Performance	Nontransactional	High	Internal	High	Low	High	Historical

project "data guru?" There also are questions concerning data-base ownership.

Another key issue affecting the scheme described above is how participants' diverse views of the project and the project data model should be accommodated. Table 3-2 illustrates this problem, suggesting that factors such as effective mode of data access, data quantity, data source, data accuracy and precision, and frequency of use will vary. These variations will have an effect on hardware and software developments, standards for data exchange at critical junctures between building process participants and phases, and the economic basis of computer-aided design (CAD) implementation in the building process. Thus, people concerned with conceptual problem solving during the early stages of a project are more likely to require heuristic tools that aid in problem definition and building program development. They may benefit most from developments in artificial intelligence. Similarly, architects and engineers involved in detailed design and development will require formal methods for analysis and synthesis. Finally, building managers may require tools that borrow heavily from a management information systems orientation. The progression from heuristic to analytical tools mirrors the movement of the building project from ill-defined concepts to precisely described products. Trends in "supercomputer," microcomputer, and computer network technologies and in artificial intelligence drive individual developments in these domains.

The group considered the premise that building description reflects the characteristics of the data themselves. Critical issues for future development will involve the organization of diverse data model views into a single canonical project data model and, as a result, access to canonical data through function- and time-dependent "viewports."

TRENDS IMPORTANT TO DESCRIPTION AND REPRESENTATION

The group identified several trends that will affect building description and representation. They are:

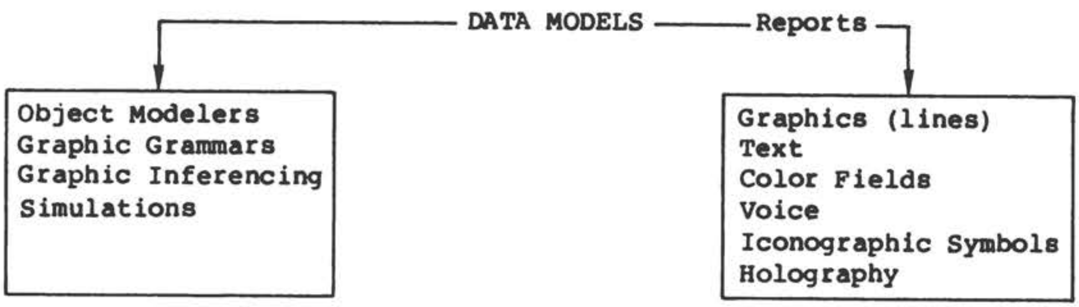
1. Computer graphics hardware will become ubiquitous.
2. Two-way voice communication with computers will become common (although the role of voice communication is not yet defined).
3. Drawings may become simply reports generated by a computer from a modeling system (drawings on demand).
4. Paper will have an ongoing role as an easy method of transporting information such as on a building site, but is not likely to be used for more than temporary storage.
5. Designers will develop procedures for layout and detailing that will lead to automatic detailing and free the project architect to concentrate on other aspects of design which may not be considered

today. They will become designers of methods for designing rather than designers of the end product.

6. The problem of design integration will continue despite automatic methods of flagging or even resolving certain inconsistencies because the logic is extremely complex and temporary inconsistencies in design are a necessary part of design development.

7. Graphic and other representations will not be limited to the physical building but will also include representations of building data for things such as simulation of traffic and analysis of performance. Designers make little use of business graphics today, but this will change.

The following diagram shows the areas of concern dealt with by the study group:



CONCLUSIONS

The group concluded that:

1. Computers offer a number of advantages in the building process in that they permit a rapid search of historic data that can also provide a form of surrogate measures of quality. Computers provide better communications and access to data, encourage more precise and accurate data, permit representations to be changed and updated more easily, allow automatic, inexpensive, and fast analysis, and assist in data reduction for easier comprehension.

2. Data models will span the building life cycle from inception to demolition and will be used by a number of actors in that life cycle.

3. CAD is a tool for improving communication between the designer and the client. Paradoxically, it is viewed by architects as an aid in selling their designs to the client and by clients as a way of

obtaining more precise design descriptions at an early stage. This permits the client to evaluate the appropriateness of design decisions. Computer representations of designs also will facilitate cost estimating and procurement.

4. In the future builders and designers may deliver a special-purpose computer with the building to maintain the model of the building during its life cycle. However, the suitability of the design data base for post-occupancy use is doubted because of the changes that occur during construction and changes that are made by occupants as they use the space. The use of computer models by users, owners, and facility managers in determining building needs (by engaging in "what if " exercises) is, however, a new and very valuable extension of current methods.

5. The long-term goal for modeling systems is to enable designers to deal in abstractions and give "detail work" to the machine. This assumes a high level of standardization and a high degree of integration. The computer, however, is a poor tool for representing imprecise and ambiguous data such as is typically found in design concepts. Furthermore, the language used in software to communicate with computers is poorly formed and unnatural to the designer. On the other hand, designers' current vocabulary is quite imprecise and inadequate for computer representation.

6. Computer hardware advances in the next 10 years probably will improve the building process from concept to demolition; however, the present state of the art is far ahead of the building process and, consequently, many impediments exist. Hardware advances are not likely to make a major impact as a result. Lower cost hardware systems and more ready access by users are more likely to be the driving factors in the building industry.

QUESTIONS REMAINING

As a result of its discussions, the building description and representation group identified a number of questions that require further analysis. They are:

1. During the life cycle of a building, who owns the data in the computer data base associated with the building?
2. What kinds of data are needed for analyses that are not ordinarily found in the building data base?
3. Computer-based design implies a new design process. How will this new process differ from the present one?
4. What better information does the architect need to produce a better design?
5. How can the diverse views of the actors (users, owners, and so on) be accommodated better in the development of the base through the various stages of the building process?

6. What is the lowest level of precision that is adequate for the data base? Does the computer impose more precision on the data than is useful?

7. Can a language be developed for codifying and expressing the performance of a building over time?

8. Are there preferred communication forms such as line graphics, text, color fields, voice, iconographic symbols, holography?

9. Will a merging of the roles of the actors in the building process make a difference in data-base design?

10. Are canonical data specifications required to permit good data exchange at critical stages (such as from designer to builder or builder to facility manager?

11. Is the loss of desired ambiguity at an early design stage that results from computer "hard edge" representations a negative aspect of their use?

12. How can the vocabulary of designers, which is quite inadequate and imprecise for computer-based communications, be improved?

13. How will the building process change as a result of this technology?

4

DATA-BASE DESIGN AND MANAGEMENT

The group studying data-base design and management consisted of: Harold Borkin, University of Michigan; Brian Bowen, Hanscomb Associates, Inc.; Louis Childers, U.S. Postal Service; Ronald King, U.S. General Accounting Office; Myron Miller, Arrowstreet, Inc.; Shirley Radack, National Bureau of Standards; and David Skar (chairman), Naval Facilities Engineering Command. It was asked to examine the major data bases currently used in designing buildings and to suggest ways in which new technological developments--hardware and software--will affect data-base formulation and use. A summary of the group's discussions is presented below.

BACKGROUND

Two ideas provided the framework for the group's discussion. They are:

1. A data base is a formalized model of information flow in an organization that is responsible for building, or is a model of information flow in the life cycle of a facility.
2. The way to get the most use from a data base is to understand how advanced technology can be used and to have a well-developed system model.

INTRODUCTION

A building is the result of the combined efforts of a fragmented industry that consists of independent entities that must come together in a closely cooperative effort. These entities include owners, regulatory agencies, designers, engineers, contractors and building operators. Each performs specific and finite services at a point in the life cycle of a building facility. Because these entities are independent, there is a continual loss of useful data about the building.

This loss usually occurs at each boundary of functional responsibility. The owner will develop his functional and economic requirements for the project and turn them over to the designer but will hold back most of the supporting data. The designer, in turn, will gather the data needed to define the project for construction and will give this information to the construction contractor in the form of drawings and specifications. These drawings, in effect, compress all of the data about the project into a simplified format that omits much information that might have been used by the contractor to construct the project better and more efficiently.

A similar occurrence takes place when the contractor turns the building over to the user. This extensive gathering of data and the resulting abbreviation of data continue throughout the project as responsibilities shift from entity to entity. Many data are lost at each transfer of responsibility. In most cases, the lost information will be useful sometime in the life of the project, but either will be gone forever or will have to be regenerated, often repeatedly, during the project's life span. An example of data that is collected on a repetititious basis is given in Table 4-1.

The advent of advanced technology for the computerized processing and storage of data, along with computer-aided designs, offers an opportunity to capture and store for later use all of the useful information about a building project. With this expanding technology, it is possible that this data base of information can be retained and managed to be drawn on, as needed, by each of the independent entities involved in the building process.

As these project data bases are assembled and made accessible to all interested parties, new relationships can be expected to form among the many independent entities now involved in the building process. New knowledge about each building and about the building process can be expected to develop. This new knowledge could be used to develop improved standards and improved approaches for building design and operation, and improved procedures for building procurement.

In developing ideas about these data bases, the group recognized two distinct types of data bases relevant to the building process. They are:

1. General data bases that consist of data relevant to many different buildings, projects, or organizations. These include the regulations, codes, design standards, engineering practices, and generally accepted knowledge applicable on a national, regional, or institution-wide basis.

2. Project data bases that include the specific data generated for an individual building project in the process of its design, construction, and use. This will be accumulated throughout the building's life. These data bases include information such as functional requirements, analysis, costs, specifications, drawings, changes, and building management and performance feedback.

TABLE 4-1 Example of Repetitious Project Data

Stage	Floor Area[a] Measured	Purpose	Needed By Whom
Feasibility	GFA	Cost estimates	Owner
	GFA	Zoning-max use	Owner
Requirements	NFA	Estimate area requirements	Owner
	FFA	Estimate area requirements	Owner
	GFA	Budget	Owner
	RFA	Financial pro-forma	Owner
Design[b]	NFA	Establishing compliance with requirements	Architect (owner checks)
	FFA	Establishing compliance with requirements	Architect (owner checks)
	GFA	Cost estimate	Architect
		Structural calculations	Engineer
		Energy analysis	Engineer
		Zoning compliance/ negotiations	Architect
	RFA	Financial pro-forma	Architect/owner
Construction	GFA	Cost check	Contractor
Operations	NFA	User assignments	Owner
	FFA	User assignments	Owner
	RFA	Lease agreements	Owner
	GFA/NFA	Operation and maintenance	Owner

[a]Abreviations for floor area measured are:

GFA Gross floor area
NFA Net floor area
RFA Rentable floor area
FFA Function floor area.

[b]Measurements repeated at each stage.

ISSUES

The group identified six issues that must be addressed so that useful design data bases can be developed. The group's general assumption was that large amounts of information are generated during various phases of the development of a building project. Much of that information is lost only to be regenerated during later stages of the process. Data-base systems that would allow collection of and access to this information are technically possible.

The questions to be answered by further analysis are as follows:

1. How can the information lost at various points in the building process be retained, reformed, and made useful to other parts of the process? What opportunities are possible by using this information?
2. What are the information needs of the entities involved in the total building process? What are the costs and benefits of making data-base systems that support these needs?
3. Can a data base be developed that will provide information on the knowledge and practices used in the building process? Such a data base would provide access to abstractions such as methods, concepts, practices, and knowledge.
4. How can information be transferred in this diverse industry? What are the interests and roles of the professional, owner, user, educator, builder, as well as the materials industry in the transfer process? Must there be agreement on information structures or can information be viewed from various perspectives?
5. What new data-base organization and technology need to be developed to solve problems unique to the requirements of the building process?
6. How can facts, rules, and processes be applied in a computer-aided building process?

CONCEPTS

As noted above, two major types of data bases are required over the facility life cycle: general data bases and project data bases. These are, of necessity, related, and each data base must be able to extract information from the other when needed.

Many of the general data bases already exist in the form of professional handbooks, product catalogues, computer programs, and the like. These existing data bases may be national, regional, institutional, or discipline-based in scope and application. However, many of these data bases exist in archival form. The usefulness of these data could be increased greatly if they were readily available in interactive form for efficient access. Examples of general data bases are:

1. Regulatory--building codes and standards (national and regional), professional standards (such as ASHRAE), and other requirements (such as handicapped access, life safety, security, and medical practice).

2. Institutional standards--standard criteria and details established by institutions for generic building types.

3. Environmental data--climatological, topographical, demographic and economics, and general statistics (such as transportation and utilities).

4. Behavioral--human factors (such as physical and psychological).

5. Technical--design, construction experience, knowledge, and techniques.

6. Construction products--information on the availability, the manufacturers, the technical characteristics, and the performance of products.

7. Legal--contracts, case law, and procurement.

8. Economic--unit costs (all levels); labor, materials, and equipment costs; productivity data; market conditions; general economic data (such as intelligence indices, interest data, and investment levels); and operations and maintenance data.

9. Construction--resources and activity data (current and planned).

10. Research--construction management and marketing (sources of potential business).

11. Services directory--contractors (subs and primes), architects and engineers, and construction managers.

The second category of data bases contains the results from all phases of the building process for a specific project. This begins at the point of identification of the need for a facility and is continuous through the life of the facility. For the purposes of this discussion, the facility life cycle is divided into six phases: requirements, design, procurement, construction, building operation, and user operation. These phases are considered to be more function related than time related. They cover all aspects of the project, from "cradle to grave," including acquisition, operation, management and renovation. These phases do not necessarily imply a time scale. Examples of the data included in project data bases, cumulative by phase, are:

1. Requirement/planning phase--functional description, space requirements, site context description, site evaluation criteria, economic feasibility model, special user requirements, codes/regulations/ legal constraints, performance requirements, management plan, marketing/selling data, budget limits, and development approach.

2. Design phase--space allocation, space organization, constructed elements, quantities/costs, equipment, population distribution, expected performance of the design configuration (such as cost and

energy use), options (left to choice of builder), maintenance and operations, training plan for operations and maintenance, and cost of design production.

3. Procurement phase--structure and procedures of procurement process, scheduling, quantities, estimated costs, sources of supply and payment, furnished items, and contract documents (from design phase to data base).

4. Construction phase--"as built" information, shop drawings, design refinements (graphic and specifications), materials bought, equipment bought, costs (actual), change orders, construction schedule (daily log of events, people, and environment), productivity, and test results.

5. Building operation phase--expenses and financing, renewal/replacement, servicing/preventive maintenance, repairs, redecoration, and training costs.

6. User operation phase--space assignments, communications assignments, furnishings and equipment, functions performed, productivity, remodeling, and income/expense model.

A comprehensive view of data use and ownership transcends the traditional organizational framework of the construction industry. The sheer number of industry players in the design and construction phases increases the difficulty of transferring data from one phase to another. It is acknowledged that the amount of information developed about a project continues to grow throughout its life, but the fragmented industry is a deterrent to collecting many of those data. Much of the information exists in archival, inextractable form; most, but not all, should be made accessible.

The study group has taken an ideal view and identified the types of data bases that are developed during each of the six functional phases. These data could be available to the facility manager in a comprehensive project data base to show a complete history of the project. One cannot, however, assume that the need of a project data base should be based on current documentation sequences of the building process. This will be submerged, modified, and made more fluid by the capabilities of automated technology and electronic media.

CONSIDERATIONS

The human, technical, and organizational considerations involved in developing, implementing, and encouraging the use of integrated project and general data bases are addressed below.

The human factors to be considered are that:

1. People in the construction industry are slow to change.
2. They perceive that innovation brings no immediate reward as it often does in other industries. Innovation often has the reverse

effect in that the first users of a new technology or approach are not always the ones to reap the benefits.

3. There are so many entities involved in construction that simple jurisdictional problems and communication gaps are inevitable.

The technical considerations are related to:

1. Technology--advances in data-base technology would appear to be substantial and, at present, pose no real problem in establishing and operating the extensive new data bases required.

2. Costs--those supplying data are not necessarily those who benefit directly from its use. Collection, maintenance, and operation can be expensive. Substantial "front-end" cost is likely to be highly visible and presents a barrier to initiation.

3. Formats and structure--no common frameworks exist within the industry today. For example, the Construction Specifications Institute may be suitable for classifying constructed elements but not for design operations or the construction process. Decisions must be made concerning how much interactive and how much archival information is needed. Current technology may permit avoidance of decisions on uniform information structure and hierarchy, permitting multiple retrieval patterns meeting the needs of different users.

4. Training--general training is needed concerning both the technology and the use of data bases and the application of data for problem solving.

Organizational concerns focus on:

1. Accessibility of data--data are available at different levels and "screens" or barriers exist in obtaining free interchange. For example, contractors are likely to resist admitting their actual costs (versus their contract costs) into the data base. Confidentiality is another issue that causes problems for free data availability.

2. Nature of the industry--the industry is conservative, slow to change, and avoids innovation, usually "borrowing" it from other industries. Time constraints are severe. No overall industry coordinating body exists to link different interest groups.

3. Liability issues--there are inevitable concerns over liability for data supplied such as whether the architect is responsible for the correctness of a schedule of quantities produced automatically on a CAD system.

4. Conflicts of interest--owners, designers, and constructors are joined by contractual links that work against free interchange of data.

5. Management of data bases--it must be determined who will operate and manage the fully integrated data base. Only the owner is involved from inception to operation, but there may be a need for a separate data base manager.

OPPORTUNITIES

Problems only provide opportunities. The advances that are occurring in data-base technology and CAD present a new opportunity to consider the creation and use of integrated data bases that would not have been possible a few years ago. Use of integrated data bases (both general and project related) will provide the following benefits:

1. Better buildings will result simply because more information, representing a better understanding of building design, procurement and performance, will be available to be drawn upon more often in planning, design, and construction.
2. Better operation will result because the accumulated project data base will provide the facility manager with a model for the facility.
3. Improved value will result because more data can be explored, providing greater economy and better quality.
4. Better communications will result and reduce conflicts and misunderstandings.
5. Project data retention will improve the knowledge base that can be drawn on to improve future projects.
6. Process time will be reduced as a result of participation of all actors in searching for data and better coordination between phases.

The use of integrated data bases also offers opportunities for innovation such as:

1. Retention of data between phases and transmission over boundaries for use by all participants involved in data creation,
2. Re-alignment of traditional industry relationships to overcome standing conflicts,
3. Overcoming industry attitudes to data interchange and use,
4. Introduction of a role for project data base management and administration, and
5. Potential for improving liability issues through improved design and rapid access to current state-of-the-art technologies.

The study group concluded that data-base management will yield new information; new insights into building design, construction, and operation; new organization of the industry; new relationships and interaction potentials; and better buildings and operations.

5

DATA-INTEGRATION CONSIDERATIONS

The group studying data integration consisted of: Alton Bradford, Naval Facilities Engineering Command; Robert Mahan, Battelle Pacific Northwest Laboratories; Leonard Simutis, Virginia Tech; Peter Smeallie, Advisory Board on the Built Environment; George Stiny, University of California, Robert Tilley (chairman), Veterans Administration; and Richard Wright, National Bureau of Standards. It was asked to study the potential for integrative approaches to the building and design process. Although it is clear that the integration of large and complex design problems is made technically feasible as a result of computers, the group was asked to consider what sort of integration would be desirable. A summary of the group's discussion is presented below.

INTRODUCTION

Computer technologies today are used principally to automate existing design and engineering technologies. As these technologies advance, they will begin to reshape the process of design. The important issues facing the industry of building today should be concerned with what the building and design process will look like in the future and how does the industry get ready for it.

The integration of project data bases will be here in 20 years. By then, it is likely that those involved in the process of building buildings will not be bound by any physical limitations of advanced technologies. Computing technologies will be greater than the ability to apply them.

For those planning long-term programs, the question should move from "how well does computing technology work?" to "how do we apply the technology?" Theory should remain ahead of the technology.

The study group decided to address the theoretical issues concerning the nature of the future building and design process and related organizational, managerial, informational, environmental, and educational issues. Their report is divided into five parts:

1. The Building and Design Process of the Future. Given the ability to perform massive computations and the integration of this advanced technology into the building and design process, how will the process change or regroup?

2. Organizational and Management Alternatives. Given the likely characteristics of the future building and design process, how will professionals organize themselves into firms, conduct work, and collaborate with colleagues?

3. Models and Information to Support Decision Making. How will this new building and design process function in terms of theory and rules?

4. The Working Environment. What changes in the existing working environment (fees, licensing, legal and contractual, and regulatory) will be required?

5. Education Issues. Will a redirection in educational programs be required, and, if so, what are the principal issues?

THE BUILDING AND DESIGN PROCESS OF THE FUTURE

As currently practiced, the building and design process consists of five main stages, each embracing a number of specific participants with identifiable roles (Figure 5-1). They are:

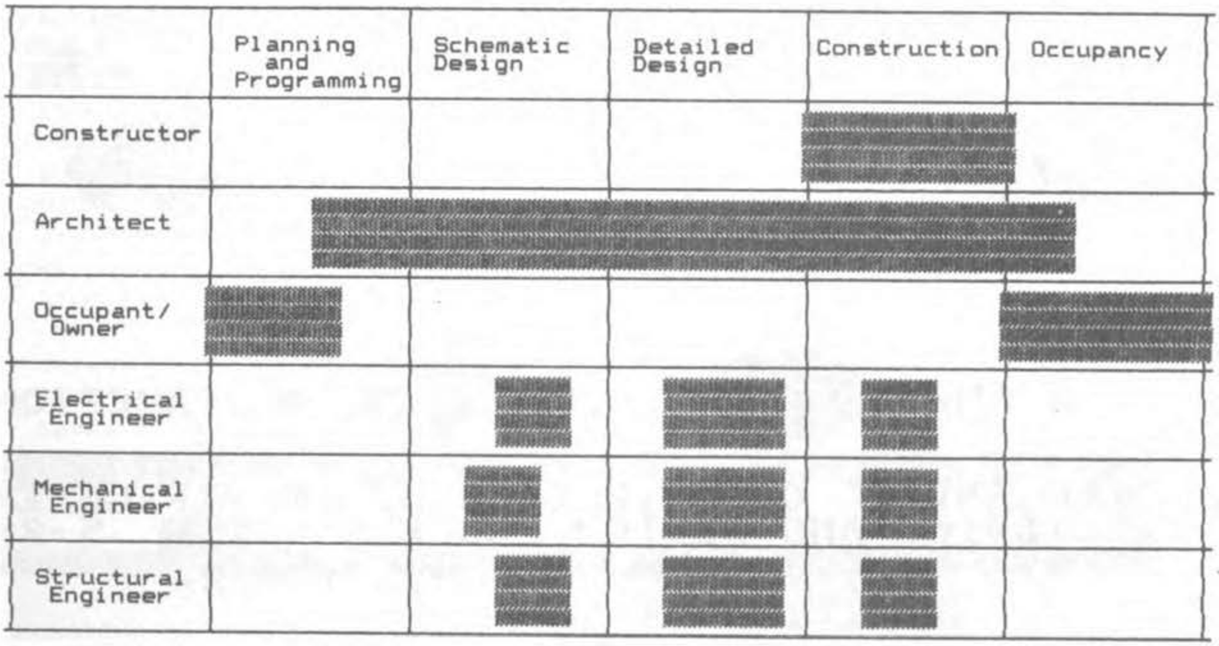
1. Programming and planning--This stage involves owners and occupants who identify functional needs and economic objective; designers who formulate performance objectives and criteria consistent with the owner and occupant requirements; regulators and public officials who identify public policy requirements; and financiers, builders, labor and manufacturers who identify resource availability and costs.

2. Schematic design--This stage involves owners and occupants who provide qualitative comments and alternatives; designers who develop and evaluate these alternatives; regulators, public officials, and the community who provide public policy comments; and financiers, builders, labor, and manufacturers who provide resource and cost critiques.

3. Design development--This stage involves owners and occupants who provide appropriate appraisals and critiques; designers, manufacturers, and builders who prepare detailed plans and specifications; financiers and insurers who approve financing; and regulators, public officials, and the community who provide needed approvals.

4. Construction--This stage involves builders, manufacturers, and labor who provide fabrication and erection; designers who oversee construction and make changes to meet contingencies; regulators who approve the facility for occupancy; and owners and occupants who accept the facility.

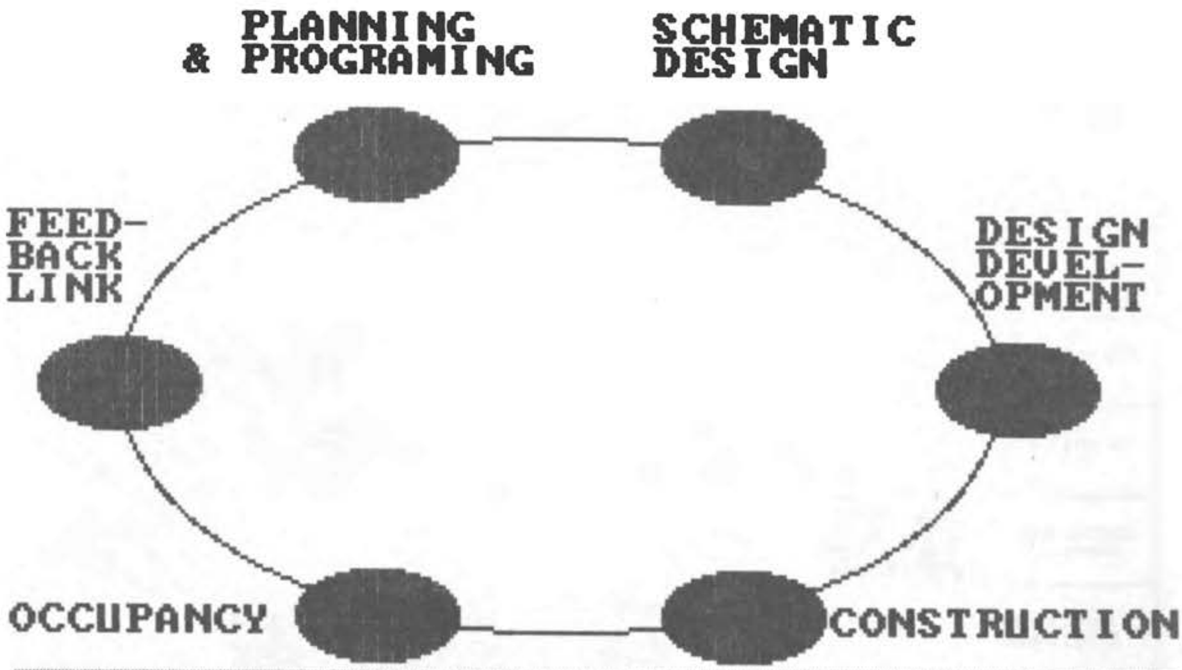
5. Occupancy--This stage involves owners and occupants who use and maintain the facility; and designers, manufacturers, and builders who provide technical support of operations and maintenance.



TRADITIONAL LINEAR BUILDING PROCESS FIGURE 5-1

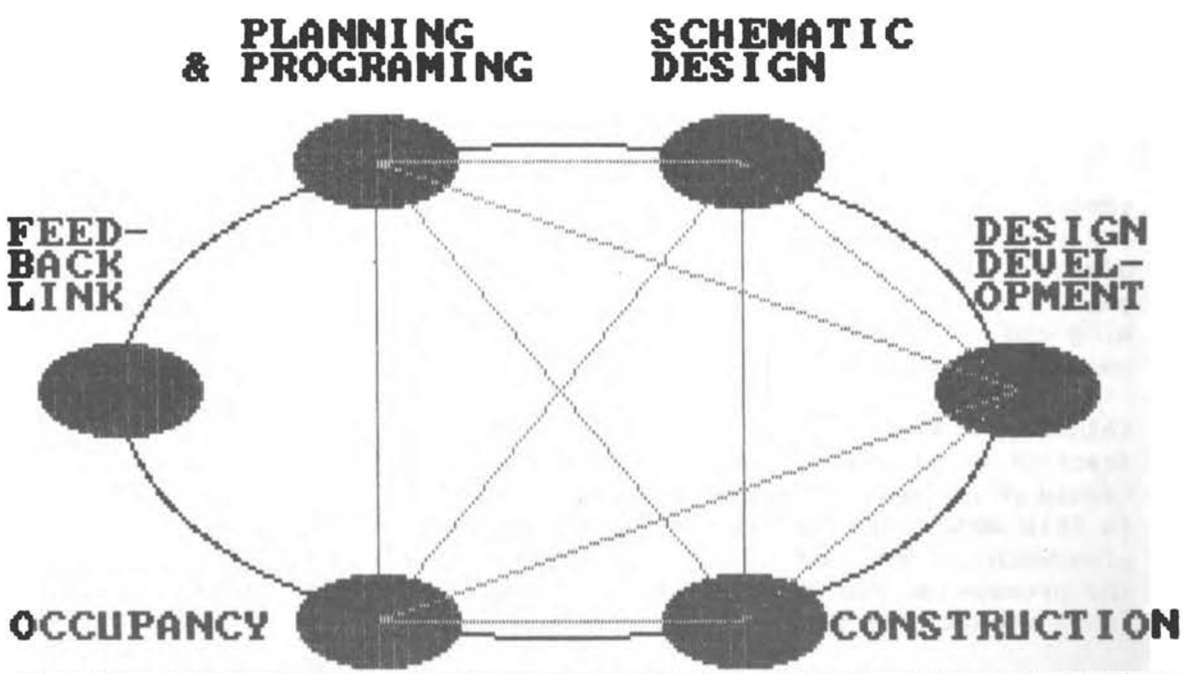
The perceived view of this process leads to the sequential organization shown on Figure 5-2. Here the process begins with programming and planning and moves in a more or less sequential fashion in the direction indicated. Each stage in the process is carried out independently of the others. With the exception of the initial programming and planning stages, each is assumed to provide the information necessary to begin the next stage.

With the introduction of computational modes of representation and thinking in the building and design process, however, a network description of that process in which stages interact in an elliptical, highly connected, nonsequential fashion becomes feasible (Figure 5-3). In this model it is assumed that the building and design process begins with information and data fixing each stage (node). The goal of the process is then to complete each stage so that no stage in the final result (the completed network) is inconsistent or conflicts with



SEQUENTIAL ORGANIZATION OF THE BUILDING AND DESIGN PROCESS

FIGURE 5-2



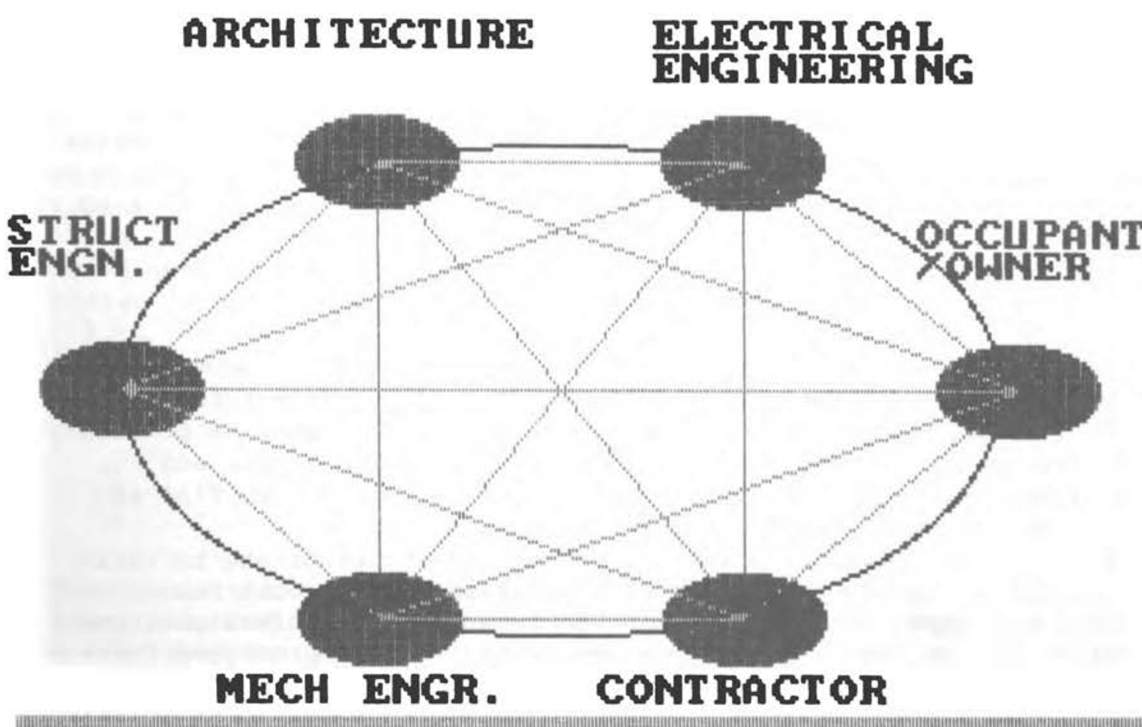
FUTURE BUILDING AND DESIGN PROCESS

FIGURE 5-3

the others. For example, constraints depending on available methods of construction, construction planning and scheduling can be used to help guide the schematic design and design development stages just as programming and planning are traditionally used alone for this purpose. Further, decisions in the schematic design stages can be used to guide programming and planning.

For this model of design to be feasible, information must be passed between stages in a coherent way. Because this information will consist of unique descriptions for each stage, a better understanding should be developed of the different types of descriptions used in the building and design process. We need to understand the formal structure of these descriptions, the operation by which descriptions of any given type can be generated or augmented to produce new descriptions and the schemes of translation by which descriptions of one type can be used to derive or constrain descriptions of another type.

The creation and manipulation of descriptions in the building and design process make it possible to expand each node in Figure 5-3 so that it is viewed as a complex but separable task (Figure 5-4). The tasks of building and design in the future will be carried out by a team or teams of people passing descriptions.



EXPANDED NODE FIGURE 5-4

MODELS AND INFORMATION TO SUPPORT DECISION MAKING

The integrated computer-aided building and design process requires that coordinated decisions be made by the various design team participants. To make these decisions, one must know the effects of such decisions on the performance of the building. One must be aware of the latitude provided for concurrent and simultaneous decisions. To accomplish this, predictive models are required to simulate building performance and ensure that correct values are given to design parameters.

Project specifications are needed to define both the requirements for and the results of design decisions. An interactive, real-time project information system is required to give each participant correct and current knowledge of the design. Design theories and rules for organizing the building and design process are required to provide a systematic and comprehensible approach for each designer. It is noted that a person can deal with only about seven variables at a time, but each designer is responsible for hundreds of decisions.

Typical Design Decision Process

The designer will have or will formulate concepts to be approved by design team management. These concepts include design objectives and functional requirements, constraints, design parameters (fixed value), and design variables. Design objectives and functional requirements, constraints, and design parameters will be taken from the integrated project information system. The design variables will be given values through the decision-making process. These values will be shared in the project information system when the decision process is completed.

Design Rules and Operating Rules

Skilled designers have personal styles and strategies for sequencing design decisions. These skills will be required for integrated computer-aided design. The large number of variables and the problem of non-linearity prevent setting all design variables as one and finding an optimal solution. Such a process is unlikely to find an initial satisfactory solution.

Research is required to develop design rules appropriate to various classes of buildings and subsystems, classified by both function and physical type. The results can be presented for professional use in forms such as expert systems or generative logical processes for sequencing the building and design process and for making specific decisions within the process. Design rules would be developed to support decisions in programming, schematic design, and design development. Similar rules, presented in instruction manuals or computer-based systems, can guide decisions by owners, occupants, and maintenance personnel in the occupancy phase.

Performance Prediction Models for Buildings and Building Systems

Models for integrated design are required to predict physical performance and the effects of design decisions on human, economic, and social performance. Extensive prior work exists in the areas of physical performance (such as structural, thermal, and mechanical). Further developments are required to address more demanding performance requirements such as indoor air quality, seismic design, and firesafety. Little information is available for the rational prediction of man-environment interaction such as aesthetics, comfort, and productivity. Constructability, maintainability, durability, and flexibility also require attention.

Information for Design Decisions

Currently available information generally lacks the structure and content required to support integrated design. Research is needed to develop the following information:

1. Properties of materials and components and their cost data in a form readily available and reliable for input to design computation,
2. Regulations, standards, and specifications in a form to compute the consistency of design variables and to abstract for contribution to project specification,
3. Project specifications to provide consistency of design variables and project information; project specifications will define the design for manufacturers, building contractors, owners, and occupants,
4. Construction data including loads, time requirements and costs to guide design decisions, and
5. Environmental, social, economic and human data to support predictions of building performance.

THE WORKING ENVIRONMENT

Changes in the existing working environment will be required by the integration of disciplines in the future building and design process. Areas requiring attention are: fee structures, licensing, legal responsibilities, contracting approaches, and the regulatory environment.

Fee Structures

The fee structure should be changed so that it provides incentives for the use of advanced technology. In the traditional system, the beneficiary of the technology is not necessarily the user. For example, technology used by architects will benefit the constructor, the facilities organization and others, but these benefits ordinarily are not recognized by the present fee structure.

The fee structure should accommodate participation across the entire design, build, and operate spectrum over the life cycle of the building. It should encourage a change in the roles of the participants such as architect, engineer, builder, and so on to provide greater interaction between participants.

Licensing

Present licensing practices do not take into consideration the notion of a highly integrated, technology-based process. The changes required should address the idea of providing visibility to those practitioners who can demonstrate skill in the application and use of the new technology. Ideas include content changes and specialty endorsements.

Legal Responsibilities

Integration blurs the questions of legal responsibility. Data bases are an example. In the well-integrated future system, many people across organizational lines will have access to the data base. Care must be taken in assigning read, write, modify, and delete privileges since these privileges can lead to actions that raise legal questions. The major requirements are to define the technical and legal role of data administration and to define clearly the legal responsibilities in view of an integrated environment.

Contracting Approaches

Contracting must recognize this new integrated environment. Present practices, particularly in the public sector, treat the process in terms of separate, independent contracts. Specific actions are needed to:

1. Provide contractual incentives for the use of advanced technology,
2. Provide for contractual terms that permit integrated responses, and

3. Change contractual evaluation (bid process) to total life-cycle analysis.

In order to evaluate properly the impact of the use of technology, the benefits of that technology and its costs over the entire life cycle of the building must be evaluated. It is clear, for example, that the design data base will be of value over the full building life.

Regulatory Environment

As the roles, responsibilities, and relationships of the participants change, the regulatory process must respond. The regulatory process should anticipate this new environment rather than react to it. Specific efforts should be started to examine and modify the regulatory process. Two generic examinations will be required: technology driven changes (software validation) and management and organization driven changes.

ORGANIZATION AND MANAGEMENT ALTERNATIVES

Given the likely characteristics of the future environment of the building and design process, it becomes clear that organizational and management alternatives must be addressed to take full advantage of (or even survive in) this future environment. These alternatives must address the manner in which professionals organize themselves into firms, conduct work and collaborate with colleagues. Profes- sionals include architects, engineers, contractors, developers and others in the building and design process. The alternatives include various structures and collaborations such as sequential, parallel and network with designer involvement throughout the life cycle.

Major characteristics of the future environment created by social, economic, political, and technological change are viewed to be:

1. Unlimited computational capability,
2. Unlimited data storage capacity and retrieval capability,
3. Increased concern about and, consequently, regulation of the building and design process,
4. Increased emphasis on using the latest technology to obtain the best design product including both office technology and material and product technology,
5. Increased emphasis on rational, factual decisions through the ability to obtain, validate, coordinate, and reduce data to a meaningful form,
6. Continued emphasis on project optimization through the minimization of acquisition time, the use of life-cycle costing, and scope alternatives to provide functionally adequate facilities, and

7. Increased need to discern the sensitivity of the design product to changes in the criteria and requirements in the total design environment and to respond to these changes.

Present Structures and Management

Present organizational structures are basically tree (branching) configurations (Figure 5-5) within which projects or facilities are managed in a linear fashion with a minimum amount of feedback or cross talk. These organizations do "leak," and based on personal effort, special management emphasis, and very opportunistic events, feedback and cross talk do occur.

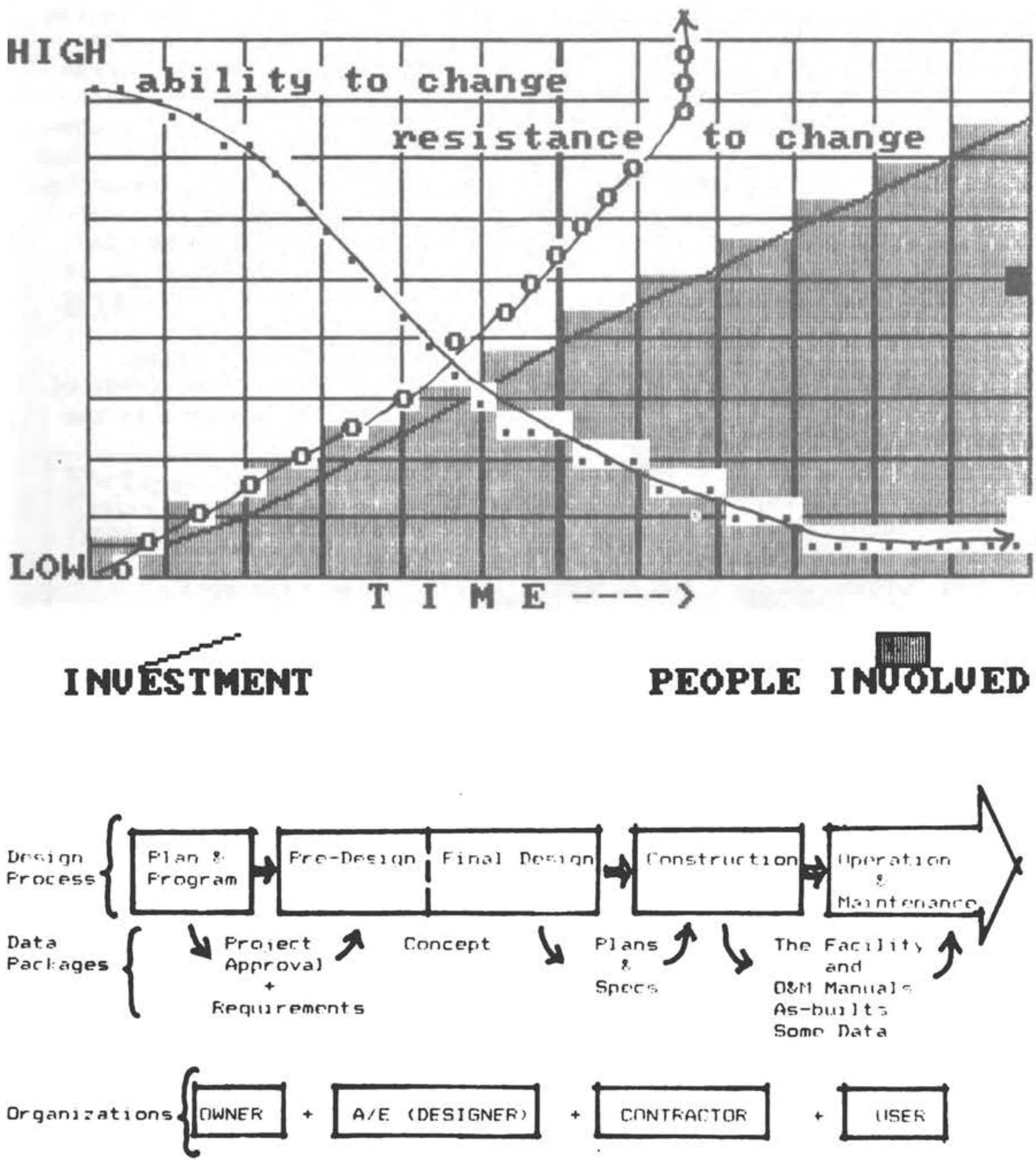
The present organizational structures and management, however, do not encourage this type of activity. In fact, when tightened up, they become more inefficient and less likely to produce the best product. This is primarily due to the sequential management of data events (decisions) and, thus, are the products of the organization. The design process progresses in a serial manner, from one organizational element to another, carrying with it its relative package of data. Iterations in this serial structuring are difficult since data and information tend to be created, changed, and destroyed. This reduces the ability to review the essential data on which a decision was based.

For example, the construction documents (plans and specifications) are passed from design to construction, but they do not carry with them the data on which the design is based or the intent of the design. If a problem arises during construction, there is a big rush to reconstruct the data to determine what went wrong. This action may correct a design or construction problem while missing completely the original intent or function of the design. This leads to dysfunctional projects, costly corrections, dissatisfied clients, and, sometimes, catastrophic failures.

The present sequentially executed building and design process does not provide for transfer of information from one function to another in a timely manner. The present organizational structure will prove to be clumsy and ineffective in using future technology and in adapting to the changing roles of the professionals.

Future Organizational Model

In the future we can anticipate a shift from how to perform computations to a comprehensive understanding of why one needs to perform computations. This will be accompanied by an understanding of the input and output, and an understanding of the interrelationships of the building systems. There will be a need to organize and manage professional activities to utilize fully the information developed during



PRESENT DESIGN PROCESS FIGURE 5-5

the life cycle of the building to produce a better design while maintaining an organizational matrix to assure a clear leadership and responsibility structure. The automation of data, its communication links and utilization, coupled with proper employment of the role-changing professional, will be the key to an organization's success or, at least, its progress in the future technological environment.

This will demand an organizational structure that assures a continuous involvement of all participants. The automation of data coupled with the proper leadership and involvement of the professionals, will be the key to the organization's success. A diagram of this building and design process is shown in Figure 5-6. The organizational and management structures could take many forms; however, it appears clear that they must provide for:

1. Development of the professionals' interpersonal skills,
2. Development of the professionals' comprehensive knowledge of this technology and its interrelationship with other systems in the building process,
3. Automation of existing practice,
4. Involvement of the owner and end-user,
5. Integration of the participants, the information, and the decision process throughout the life cycle of a project, and
6. Organizational and managerial emphasis on team work.

EDUCATIONAL ISSUES

Increased concern for the integration of the various phases of the building and design process will require significant redirection of emphasis in current educational programs. Major emphasis must be placed on the development of the following:

1. Familiarity with computer technology, both to become aware of existing applications and to prepare and position professionals to take advantage of anticipated technological innovations in data organization, data display, and data analysis capabilities,
2. Increased technical capacity to formulate and use complex modeling of building design, construction, and use,
3. Increased capacity for the exchange of technical information and increased ability to formulate and convey technical requirements for improvements in the various phases of the building and design process, and
4. Increased interpersonal communication abilities and emphasis on collaborative problem-solving approaches.

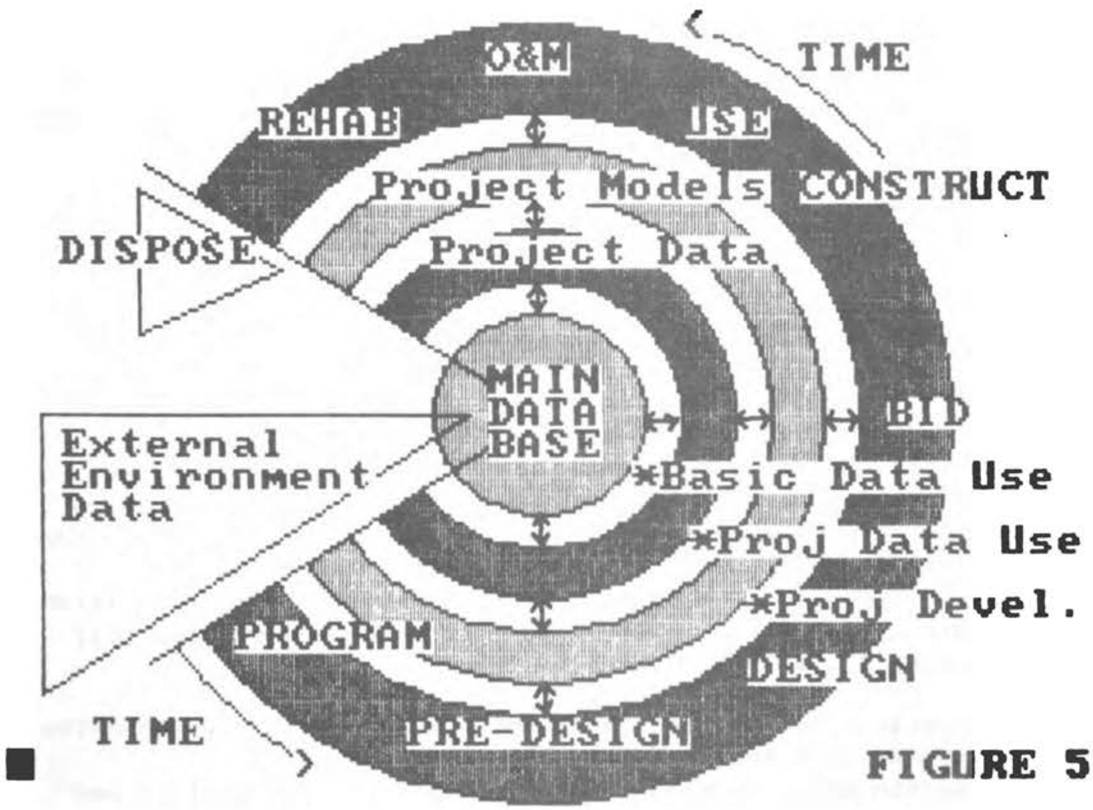


FIGURE 5-6

FUTURE DESIGN PROCESS

Currently, technical competence is defined as the ability to perform in the realm of a particular discipline or profession and to be familiar with the practice and research in a particular field. Interaction is limited to a small set of participants in the building and design process, usually those involved in the previous and next phases of the linear process described earlier. For example, those involved in programming have little incentive to be concerned with construction. Those involved with the design of mechanical systems may have no involvement in the schematic design phase which may severely constrain the options available during the detailed design phase.

An integrated approach implies that the participants will be able to exchange technical information and design parameters and to do so in ways that contribute constructively to the overall process. In order for the various professionals to take full advantage of the increased potential for collaboration provided by computer-based systems and shared data bases, the capacity to deal with the technical information of a variety of fields must be increased. This will encourage the formulation and use of more complete and more sensitive models of design, construction, and operation.

The network of interaction anticipated by a more intergrated approach requires a more detailed level of exchange of information. This exchange should be along established lines of communication such as design detail and construction, as well as in new areas such as construction considerations during the programming phase. Educational programs must be developed to facilitate the exchange of technical information for the following reasons:

1. Analytical models are likely to be computationally intensive and have complex data requirements.
2. Semantic understanding of and agreement on definitions and measurements for data commonly shared in an integrated data base will be increasingly important.

The capacity to take advantage of technological innovations must be seen as a necessary and desirable aspect of professional development. Advances such as the linkages between the design and manufacturing of building elements or the linkages between operating work schedules in a building and the larger transportation network, must be seen as opportunities that enhance rather than threaten the professional.

Educational approaches that currently emphasize individual problem-solving capabilities should shift to collaborative efforts, whether in the design studio or the engineering lab. The mathematical capability to state relationships, and the programming capability to direct the computational devices should be assumed to be central in the individual's education. A broad understanding of the operational aspects of the technology, both for analytical reasons and for reasons of professional responsibility, needs to be stressed. CAD should not be seen as a "black box" approach with a series of different boxes delivered over time by vendors. Neither should analytical models be seen as merely a process of parameter-passing between unseen (and unsupervised) computer communication links.

Competence in computer use should be viewed as a generic skill, not a subfield or specialization. The mathematical and algorithmic statement of relationships should be considered an essential professional skill as should the capacity to perform successfully as a participant in group problem-solving approaches. The educational consequences of these changes are dramatic and far-reaching. In some respects, they echo the calls for changes in professional design education first heard in the 1960s, but unlike then, the technological support for making such changes is now in place, and the environmental and societal imperatives to do so have never been more evident.

6

COMPUTER-AIDED BUILDING

The group studying computer-aided building included: John Eberhard, Advisory Board on the Built Environment; Richard Field (chairman), U.S. General Services Administration; Bertram Herzog, Herzog Associates, Inc.; Lee Nackman, IBM Research Center; Robert Pearson, Control Data Corporation; Kenneth Reinschmidt, Stone and Webster Engineering Corporation; Douglas Stoker, Skidmore, Owings and Merrill; and Richard Wromble, U.S. Department of Health and Human Services. It was asked to look at the vertical integration that might result from use of computer-aided design and computer-aided manufacturing (CAD/CAM) in the building industry. It also was asked to examine other industries, especially the computer industry itself, to see where the major new links are being made and to suggest how these advanced concepts might affect educational programs, licensing laws, and code requirements. A summary of the group's discussion is presented below.

INTRODUCTION

The building process is often characterized as the integration of subsystems. These subsystems include space, structure, mechanical, electrical, plumbing, and so on. The link between these various subsystems is the coordinating information. This information generally is in the form of drawings, specifications, memoranda, and word of mouth.

For the purposes of this discussion, the coordinating information is viewed as one of the building subsystems. Further, it is considered to be a continuum beginning at the concept initiation stage, followed by the design and building stage, and finally being used in post-occupancy management and remodeling. This continuous form of information subsystem has always existed. Individuals from various disciplines and organizations use this information in that they access it, alter it, or augment it.

In the computer-aided building process, the principal concern is how computer technology provides new ways of handling this information and the means for handling larger amounts of it. This use of computer technology provides an important opportunity to enrich and improve the designed product, the built product, and the management of its construction.

To date, computers have been used only selectively in the built environment. Examples of applications include computer-aided design (primarily geometric design), simulation, structural analysis and project management. Of these, computer-aided design has been the most visible. Computer-aided design is more than computer drafting. Drafting of drawings is only one possible method for communicating design concepts to the process of production, and it should be viewed as a method in transition that is likely to disappear in the future.

There exists an opportunity to apply computer-aided manufacturing in the building industry as it has been applied in traditional, manufacturing enterprises. Computer-aided manufacturing in the building process involves a wide range of activities: traditional, high-volume production of building components (such as nails, screws, pipes, windows, doors, and plumbing fixtures); batch processing of assemblies (such as laminated beams, steel structural members, and cabinet work for kitchens); and final field assembly and fabrication processes (such as building a brick wall, pouring concrete, and installing electrical wiring). The methods and tools used for accomplishing each of these stages in the production process require technologies that vary from ones that are labor intensive and use simple tools to ones that are capital intensive and use complex machinery.

The means to process the required information exist. It is difficult, however, to develop the interfaces between the users and producers of this information and the information pool. Further, given the organizational fragmentation and complexity of the building industry, attention must be given to the means for distributing this information for ready accessibility. Again, the computer technology exists, but the interfaces do not.

In addition, it remains to be determined whether these interfaces can be economically devised, and whether their use will be economically attractive. Assuming such interfaces are produced and that there are economic incentives for their use, there would still remain the problem of integrating the information into a computer-based and integrated continuum. In this respect, comparisons with the more established use of computers in manufacturing are inevitable. Even in manufacturing applications, however, the issues related to integration (such as integrating the design and manufacturing processes) are not very well understood. The risks associated with procedural and organizational changes brought on by the computer-based integration of the design and manufacturing processes are well recognized. Against these risks is balanced a great payoff in the total production process. This is recognized by all the advanced industrialized nations and will be given highest priority for implementation. Perceived obstacles for manufacturing include:

1. Development of analytical, operating, and control systems and their interconnections,

2. Development of a system for creating, deriving, transforming, and interpreting the information (interfaces),

3. Development of a common and usable information system, and

4. Establishment of the required communication network (distributed computing).

BACKGROUND

The industrial revolution, by the end of the nineteenth century, produced a separation between the designer of a product and the maker of the product. Before that time most products were designed and made by the same person (with most of the designs being traditional rather than newly created and original). With the evolution of the industrial process into mass-production technologies, the worker became further separated from the total production of an article as he worked only on one relatively simple task repeatedly. Computer-aided design and computer-aided manufacturing offers the potential, not the certainty, that a continuous process of designing and producing components, if not entire buildings, will again become a technological alternative.

An understanding is clearly emerging among the larger clients of the building industry, such as government agencies, that there is a need for the continuous redesign and rehabilitation of spaces in buildings as work requirements and user organizations change. This means that the concept of CAD/CAM does not have a natural terminating point when a building is completed but should continue throughout the life of the building.

It is also clear that CAD/CAM can provide an environment of "choice" for the designers, producers, and users of buildings. The user can gain special design items or styles at no penalty in economic terms. The designer may be able to have building components that respond to a variety of climatic or safety conditions or special user groups (children, the elderly, or the handicapped) on a much wider spectrum than the standard items now available from producer catalogues.

The hardware now available for computer-aided design and production (and the hardware in the development stage) essentially removes it as a constraint to what can be done. After thousands of years of development in the building field, sufficient hardware ideas for buildings exist (from prefabricated houses to precast concrete modules). Developing building hardware concepts is not a constraint. Concepts for the processes of design and production are needed at this point. These processes should be linked and continuous as opposed to fragmented disciplines, fragmented production units, and fragmented rules of building. There is an imperative for change.

CAD/CAM tends to be a cliche that has emerged in the electronics field that may not usefully serve the purposes of the building industry. It implies a separation of design and manufacturing as activities while the need is for unifying concepts. Engineering could be seen as a unified concept, especially if the original meaning of the word--the process of innovation--is considered. Architecture could be seen as a unifying concept if it is defined as "the means that society uses to bring together the knowledge base of science, the skills of engineering, and the aesthetic content of style in the resolution of the built environment."

Architecture would have to be understood as much more than just what architects do. It is also possible to use the word technology in the broadest sense to mean "the sum of the ways by which a civilization produces its goods and services." Thus, one could speak of computer-aided engineering or architecture or technology.

ISSUES OF INTEGRATION

Design in the future may become a team effort among those persons whose skills are required to identify a need, to determine the performance requirements for a solution to that need, to synthesize alternative solutions until a satisfactory one is found, and to communicate this solution into a physical manifestation. This manisfestation might be called a building. The assemblage of spaces incorporated in the solution would not be static, however, because the changing patterns of use (from year to year or even day to day) would drive redesign and remaking processes that adapt the space to meet its new demands. The data bases used for making the original alternative selections could be large and comprehensive because the memory capacity to store the data and make it accessible is not likely to be a constraint.

The production processes are not sufficiently flexible to presume an infinite choice of products at a price most people would be willing to pay. It is more likely that there will be a range of product and component choices available to the design team, with certain parameters of size, color, or performance characteristics changeable on order.

The major cost constraint in the products of advanced technology, such as the computer chips themselves, is not the production costs for making the product, but the design costs associated with changing the performance of the finished product. It seems likely that in building products this may also happen in the next few years. How to provide a computer-assisted process for this continuous and design intensive method of providing space for human use is the focus of this discussion.

LANGUAGE TRANSLATION OPPORTUNITIES IN CAD/CAM

The higher performance computer-based design systems that will be available within 10 years will provide new opportunities for language translation. The types of languages that are suggested by this capability include: (1) natural languages such as translation from foreign language to English, (2) measurement languages (such as the translation from the metric system into the U.S. measurement system, (3) software languages such as the translation of BASIC into FORTRAN, and (4) design languages such as the use of disciplines that convert general design details into specific design vocabularies. Some of these language translation opportunities are discussed below.

Natural Languages

One of the promises of the fifth generation of computers from Japan or the supercomputer being developed in the United States is the potential to understand syntax and vocabulary content of natural languages in sufficient detail to allow automatic translation.

Measurement Languages

The capability to convert from metric units to U.S. measurement standards is already available in various computer programs. The further refinement of this translation ability into CAD/CAM will allow a design developed in one measurement system to be manufactured in another. A still further development could be the introduction of conversion rules for special situations. For example, plywood is still manufactured in 4-foot widths throughout the world. Metric conversion for products that use plywood will be checked so that the dimensions are exactly, not approximately, 4 feet.

Software Languages

Although it is possible to translate FORTRAN programs into BASIC programs using informed programmers or emulator programs, there will be an opportunity for even more direct conversion of programs. The need to transport software between systems and the potential for transporting programs from one machine language to another should be possible within five years.

CAD/CAM--A CONTINUOUS PROCESS

In many businesses the link between CAD and CAM is a state-of-the-art reality and is controlled as a continuous function under a single management structure. The continuous function can be defined as the research and development, planning, design, fabrication, and operations and maintenance that are the life-cycle phases of any man-made object or process. The link from one of these life-cycle phases to the next is information, written or numeric, and expressed in a variety of ways such as text, graphics, digital code, and photographs. The strength or integrity of the linkages between the life-cycle phases depends on five factors. These are:

1. The value of the use or reuse of the information as the end product passes from phase to phase,
2. The management structure and requirement to control and affect the linkages,
3. The technology available to take advantage of the linkages,
4. The economics of the various segments of the process affecting these linkages, and
5. The socio-political environment.

To the extent that the logical information that is required to pass from one phase to the next can flow through automated processes, the linkages become more economical and practical to put into effect. Within industry these CAD/CAM linkages vary considerably. The following sections will examine these linkages in the industry of the built environment from the current state to future possibilities.

The planning phase or concept initiation phase can be characterized as the development of written design programs, numeric budget cost estimates, and graphic displays of building concepts in order to reach the decisions necessary to proceed to the next phase.

The building geometry output during concept development is used as input to the design phase. Because the architect or engineer usually is engaged to perform both these phases, the incentive to transfer the information data base from the planning phase to the design phase is high. For example, the function of developing a cost estimate can take full advantage of the stored building geometry to generate the necessary quantity survey measurements. This is an example of the information linkages occurring between these two phases and highlights the "information leverage" available under certain conditions. Most of the five factors noted above that form these linkages are present between these two phases.

The data base generated by the architect or engineer during the planning and design phases culminates in a set of drawings and specifications that pass through to the construction phase. A multitude of activities occurs during construction that do not efficiently use the design data base, yet they share common data. It can be conjectured that the reason for this is that it does not meet the stated criteria of the five factors. For example, the dimensions of the computer-generated duct work are a natural output of the completed design. However, the sheet metal subcontractor is not using the design phase data base. The subcontractor might, at a minimum, use the isometric capabilities of the stored data base to assist in meeting the shop drawing responsibilities. Many manufactured construction materials could use the design data base in machine readable form; however, the built environment industry is so fragmented that the designer has no incentive to organize the data in such a way as to be machine readable input to the manufacturing function. Many on-site, labor-intensive end products, such as plumbing trees, also could be produced in the factory by computer-operated machines that use the designer's data base.

Typically, the built environment suffers again as a facility becomes the responsibility of yet another person or department in the post-occupancy management phase. The facility manager needs and can use information generated by the planning, design, and construction phases. As-built drawings, design calculatons, shop drawings, manufacturers' information, parts lists, operations manuals, and sketches are not efficiently passed on because the process is fragmented. The building manager is heavily engaged in accommodating the daily dynamics of what goes on within the building such as repair and alterations, preventive maintenance, fire evacuation procedures, ordering of replacement parts, partition changes, and so on. However, the data base of information may not be in a form, language, or media that can be efficiently used.

The following opportunities should be explored in order to advance the integration of vertical and horizontal processes of building:

1. Substantially improve design programming,
2. Organize a joint government-private sector research consortium to establish a phased approach to information specifications,
3. Develop under government auspices a prototype high-technology building,
4. Use ABBE's Federal Construction Council or the Advanced Building Technology Council to facilitate communications and study, and
5. Explore the possibility of lease/build with developers.

Computerized Access to Manufacturers' Catalogues

Currently, some manufacturers of building components are computerizing their product catalogues. This trend undoubtedly will continue. With computer access to these data files, architects and engineers will be able to search for products that match the computerized specifications they set. Files on those products that meet the specifications can be further queried for costs, delivery times, and other information. Three-dimensional geometric models also should be stored in these product files so that an architect's or engineer's computer can extract these models and copy them into the total building model. In this way, the exact, up-to-date product dimensions and spatial relationships would be included in the complete model and carried forward into drawings, if drawings are required, without the need for transmission of vendor prints. This process would reduce the errors and delays that result when the architect or engineer must wait for vendor information. To facilitate this process, common formats for storage and retrieval of product information are needed so that all vendors could be accessed.

Computerized Ordering, Expediting, and Delivery

Construction schedule overruns are caused in part from delays in the delivery of manufacturered items. To avoid such delays, products often are ordered in advance and stored on the construction site or elsewhere, adding to inventory and interest carrying costs. Such costs might be reduced, without increasing the risk of delaying construction, by scheduling deliveries just in time to meet actual construction needs. This would require computerized placement of orders during the design process and establishment of production and delivery schedules tied to the construction schedule. Then, any changes to the construction schedule such as weather delays would be automatically tracked, and new delivery schedules computed and transmitted to the vendors. Manufacturers would no doubt charge a premium for such service, because it would disrupt their manufacturing process. Such surcharges, however, could be less than the costs of carrying inventory, particularly at congested construction sites. The computer system also could spread deliveries over time, keying them to the time-sequenced needs of each construction area. It could even schedule truck pickups at various suppliers so that all building products needed at a particular time and place in the construction process could be consolidated and delivered together. If a given product were available from a number of suppliers, the computer system could track construction requirements and place orders with those vendors who could meet the required delivery dates.

Although such practices could result in considerable savings for the owners on major building projects, they would require considerable advances in the "computerization" of architects, engineers, constructors, and material suppliers as well as improvements in communications and data-base access. Such improvements are not so much technological as organizational and administrative, and some joint organization or group would be required to agree on communications procedures.

Computerized Quantity Development and Bills of Materials

The counting or measurement of quantities based on a three-dimensional computer model is well within the existing state of the art. The benefits include reduction in the costs of and time needed for quantity takeoffs (which is important particularly in fast-track construction) and reduction in errors. Computerized quantity development, including rapid response to design changes, is one of the major by-products of CAD. Since design information on quantities is incomplete during the conceptual design phase, computerized tradeoffs must be combined with quantity estimates based on historical data or the designer's judgment.

Automated Factories, Robotics, and Numerically Controlled Machines

Expanding use of robots and automatically controlled machines in the manufacturing process will open the opportunity for the combination of custom-designed items in the mass production system. Instead of providing computerized catalogues of standard items, manufacturers could provide architects and engineers with the parameters defining the capabilities of their manufacturing equipment. The architects and engineers could then design any custom product, in any quantity, as long as the product met the manufacturing parameters, and the vendor could automatically reprogram his robots or automated machinery to make such items. Such flexibility would probably demand a premium price and would require that architects and engineers expend the effort to understand the product manufacturing process to a greater extent than they do now. Perhaps specialty designers would arise to perform this function. Also of potential difficulty is the problem of replacement of such custom manufactured items during the lifetime of the factory, perhaps many years after the computerized manufacturing system had become obsolete or replaced. Such custom manufactured items, while costly, can be obtained now usually from small specialty manufacturers who are unlikely to computerize. Whether a place for such suppliers will remain, or whether flexible, mass manufacturing systems will eliminate them economically, remains to be seen.

Construction Robots

It is technologically possible today to produce digital output from a CAD system to drive a numerically controlled machine to bend reinforcing steel, conduit, and pipe. Many more such applications are possible. One of the problems with existing robots is that they lack the ability to recognize and adapt to deviations arising from construction tolerances. A facility constructed entirely by machines could perhaps be built to much closer tolerances than is possible today, but such a possibility is highly unlikely. More likely is technological advancement by an evolutionary process, which means that automated construction machinery would have to co-exist with current practices. This does not mean that advances are not possible, only that they will be incremental. Computer-assisted excavation equipment could erect steel to closer tolerances than is now possible, automatically compensating for temperature, dead loads, and the like. Such computer-aided construction equipment would not replace construction workers and operators so much as it would help them do a better job. The key to computer-aided building, however, is continual feedback at every stage of construction. For example, the exact location of cast-in-place anchor bolts could be determined and fed back to the building model in the CAD system. The CAD system would compensate automatically for deviations and would issue the necessary corrections for setting the columns.

This process of measurement, feedback, and correction would continue for every step, every flow and every discipline on the principle that it is more practical to measure exactly where the building is than to try to build it exactly to the design dimensions. This feedback process would require substantial integration of the processes of design and construction since the design would be updated continually based on construction feedback. Normally, changes would be minor and compensation for them would be automatic. Major discrepancies, however, such as the displacement of a foundation due to a local subsurface problem might require a re-analysis of the structural system to verify design stresses. Such reanalysis and, if necessary, redesign would be done relatively easily and quickly, without delaying construction, because all the necessary information would be accessible to the computer analytical programs. By using the as-built dimensions, subsequent components such as pipe, sheet metal for ducts, and curtain walls would be cut to fit as modified on the construction site.

The ability or need to make such last-minute changes might lead to greater use of on-site fabrication where space permits. Manufactured components might be joined by adaptors or connectors fabricated to fit on the site. Such a reorganization of the construction process would mean that constructed facilities would fit together better, could be built by automated machinery (robots or computer-aided machines), and would virtually be manufactured rather than constructed. It would also accelerate the decline of the construction craftsman (i.e., a skilled person who can execute the designer's intentions by adapting the design to actual conditions without exact instructions).

It also must be recognized that any use of robotics or automated construction machinery will place greater emphasis on logistics and supply. It will not be economical to keep expensive machines waiting for material deliveries or feasible to redirect them to perform alternate tasks. Therefore, computerized control of deliveries of materials and equipment is even more critical, and this issue must be addressed first if automated equipment is to be successfully used on construction sites.

Automated Construction As-Built Information

It would be very valuable to develop improved methods for acquiring as-built information in computer-readable form. This would be useful for developing three-dimensional computer models of existing facilities. It could be used for maintenance, repair, or renovation, and for tracking construction in progress for comparison with the design data base. Digitized stereo photographs or video images could be used. The ideal system would acquire multiple photographic or digital images, digitize them automatically, process the images, and identify the image patterns as building components (such as columns, beams, walls, pipes, and furniture). Existing defense and space technologies could be adapted to this application.

The computer system might have difficulty identifying objects due to hidden objects. Therefore, a three-dimensional display system would be necessary so that a human operator could resolve ambiguities and identify components to the computer. A computer-aided system in which the computer would extract dimensional information, and the operator would identify objects, would make the best use of the capabilities of man and machine.

Elimination of Construction Drawings

Architects and engineers produce construction drawings as a means of communicating with the constructors. In some complex situations, scale models may be made. These drawings or models represent the way the designer views the facility. With the advent of three-dimensional computer models, it is now possible for the constructor to request views or pictures of the three-dimensional model on demand. The constructor could view the facility in any manner desired, from any viewpoint that would be difficult or impossible to obtain by other means. For example, the constructor could ask for an isometric projection of all the ductwork and plumbing without structural components, floors, walls, or ceilings. He could ask for views of components in any desired temporal sequence to reflect alternate sequences of construction. He could ask for dimensions or clearances that normally never appear on drawings to determine whether there was room to maneuver large components or construction equipment. The possibilities of this technology are largely unexplored, even though the capability exists now and is being used in practice.

CAD/CAM REGULATIONS

Regulations that relate to health, safety, and cultural standards can benefit greatly from the continuing development of advanced technologies in the design and construction of the built environment. Three major benefits are readily apparent.

First, it is now possible to make the built environment into true user-friendly space which is the ultimate objective of all health, safety, and culturally related codes and standards. This can be done by combining information derived from the study of ergonomics with that being developed in computer-aided design and manufacturing. For example, a better understanding of the mechanical process of pushing open a door should enable a push bar to be designed and manufactured that will not wrench a wrist or snag a jacket sleeve. Similarly, traps in a building that could impede or even imperil a handicapped person can be identified in the conceptual stages and designed out of the building. The growing alliance of CAM with CAD, coupled with ergonometric research, can result in products that will create a healthy, safe, and convenient built environment.

Second, factors relating to health, safety, and cultural needs can now be developed into performance standards. Currently, most of the standards contained in building codes relating to health and safety are of the type that allow for easy verification of compliance. They are written in quantifiable terms so that a reviewer can scale areas and distances or count the number of features required by codes. CAD makes it possible to develop software algorithms that would allow for performance to be measured and demonstrated in conceptual models of the built environment. For example, a model could be developed that would test the time it takes for occupants to evacuate a building through various routes under different emergency conditions. Interferences with other built environment functions also may be tested using the CAD data base with appropriate modeling software. For example, the effect of a fire in one part of a structure on the operation of ventilating and communication equipment in another part could be determined.

Third, incorporation of codes and standards into the CAD data base will reveal where gaps and inconsistencies exist. This type of information, if fed back to local and national code and standard-setting organizations, can result in improved codes and standards and eventually pave the way for acceptance of performance standards in new construction.

7

ADVANCING THE STATE OF THE ART

The following are brief reports from each of the seven groups that met during the evening hours of the workshop. These groups are: (1) university research, (2) government research and development, (3) private industry research and development, (4) integration of concepts in architectural practice, (5) integration of concepts into engineering practice, (6) university programs, and (7) incentives and barriers to the adoption of advanced concepts.

UNIVERSITY RESEARCH

This group exploring university research was asked to develop comments on the organization and funding of such research including some indication of what is now going on in universities and some specific ideas for a research agenda that would be appropriate to a university setting. The participants were: Harold Borkin (chairman), University of Michigan; Lee Nackman, IBM Research Center; George Stiny, University of California; and Robert Tilley, Veterans Administration. Their report is summarized below.

Opportunities

University-based research and educational programs have as their foremost objective the improvement in the quality of the built environment. Their primary means of effecting the desired improvement is through the development and transmittal of professional knowledge. There has been a growing movement among many of the schools to base educational programs on the findings of scientific research into the building process. This is evidenced by the development of graduate programs that offer the opportunity to do research in many areas of architecture and engineering. It is also evidenced by the establishment of research organizations in universities that provide research services to the building community.

The university-based research groups have been very active in the development of architectural computer-aided design. Many of the current commercial products and concepts in architectural CAD were the direct or indirect result of research begun in the late 1960s by small groups of university researchers. Currently, some groups are investigating many of the issues that are involved in the development of integrated design systems.

The research required to develop these integrated design systems is massive. It is well beyond the means of any one group or organization. It will require the shared ideas and efforts of many individuals and organizations. University research centers can provide an important setting for long-term and high-risk research efforts while also providing shorter term solutions to specific problems. This can be accomplished while providing the building profession with the human resources needed to use the technology of CAD for buildings.

Increased activity in CAD research can provide a focus for the application of many other areas of design research. The development of evaluative tools based on human performance research is one example. The incorporation of research on decision processes in alternative selection is another.

Current Research Issues

The great software development required to provide a flexible CAD environment should be the subject of research efforts by many groups of investigators. There is currently no best way; there are only approaches that look promising to various researchers. The approach taken by Charles Eastman at Carnegie-Mellon University proposes the creation of a language, called GLIDE, for the development of the integrated data base required for CAD in the building field. This approach, which is embedded in the PASCAL language as a data-base and modeling extension, is proposed as the programming environment for development. The University of Michigan uses the operating system model rather than the language approach. Just as some operating systems are appropriate for the development of computer programs, Michigan is developing an operating system that will support computer-aided designs. The ARCH:MODEL system is based on the relational data-base model and contains an interactive command monitor, relational editor, a geometric editor, graphic and non-graphic input and output routines, and a system library that is usable from high-level languages. It provides a working environment in which to develop an integrated CAD system for building.

Independent of the approach taken, there are common areas of necessary research including the following:

1. Study of the complexity of buildings and the development of models of these projects in computer data-base systems. Particular

attention must be given to the development of techniques for modeling spaces and spatial relationships. This spatial modeling is fundamental to the sucessful development of CAD for the building field.

2. Study of the effects of changes in architectural design methodology that could result from use of CAD.

3. Development of high-performance, low-cost computer analysis and simulation software that will permit the accurate prediction of the performance of buildings prior to their construction and will serve as a component of a responsive CAD system.

4. Development of design subsystems for selection and detailing of the various building subsystems, such as mechanical, structural, enclosure, and lighting systems.

5. Investigation of many computer-related questions studied including those concerning consistency of the data base as the design develops, methods for automatic production of the required drawings and reports from a data base, and improved methods for increased interaction with three-dimensional spatial models.

Barriers to University Research

Barriers to university research are:

1. The current level of support for building-related research is low.
2. There is no organization, as there is in other fields, dedicated to the continuous funding of research.
3. Although the building industry is a large segment of the economy, it does not provide research funding in proportion to other industrial sectors.
4. Federal and state funding for building research is very low, especially for long-term research.
5. Large institutional building organizations (such as the Corps of Engineers or the Veterans Administration) have difficulty funding short-term research.

Incentives for University Research

Incentives for university research are:

1. The educational value of long-term design research to those who design, produce, and manage the built environment has been established and enhanced by professional organizations.
2. The need to rebuild much of the nation's urban infrastructure in the next decades should in itself require major investments in long-term research.

3. The long-term value to the collection of organizations that belong to the Federal Construction Council of fundamental research should justify an increase in their support of CAD/CAM research.

GOVERNMENT RESEARCH AND DEVELOPMENT

The group that considered government research and development (R&D) was asked to identify research that would be appropriate for the federal laboratories and to suggest strategies for funding. The group included: Alton Bradford, Naval Facilities Engineering Command; Ronald King, U.S. General Accounting Office; C.N. Mitchell, U.S. Department of Energy; and Richard Wright (chairman), National Bureau of Standards. Its report is summarized below.

Goals

The goals of government research and development should be to:

1. Achieve benefits and avoid losses in the major changes advanced computation will make in building practices,
2. Advance the international competitiveness of U.S. building services and products,
3. Develop the knowledge and establish the priorities needed to produce more useful, safe, and economical buildings, and
4. Support educational institutions capable of preparing leaders for future generations of building practice.

Barriers and Incentives for Federally Funded Research and Development

The federal government lacks a program dedicated to building research to support advanced concepts. Individual agencies and programs have funds allocated to research, but, in general, they lack the value system, mission orientation, and scope to fund significant R&D in this area. Federal building programs also are very fragmented; consequently, the impact of funds allocated to research is greatly diluted. Current government funding philosophy does not support a meaningful research effort in the area. Discretionary funds to support private-sector research are being reduced. Federal agency staffing levels are being cut. Federal salary levels not sufficient to attract good researchers.

Incentives need to be developed to generate support for building research on the application of advanced concepts in the construction industry. International competition in the marketplace provides a strong incentive. Still, more is needed to gain congressional support.

The federal agencies alone cannot secure congressional and administration support for research funding. The building industry must join in by endorsing and supporting R&D on advanced concepts applied to the building process. Currently, such an endorsement and support are not readily apparent. Although the administration has endorsed the use of federal research money for long-term, high-risk scientific research, funds have not yet been appropriated to building research efforts. Incentives for funding research in this area must be clearly demonstrated to both the administration and the Congress to obtain the needed funding. This will require the efforts of both the building industry and the federal construction agencies. Federal agencies will need to demonstrate the necessary competency to carry out the federal responsibilities in research, and the private sector must demonstrate support for the research effort, including providing private funds if necessary.

Funding Strategies for Federal Building Agencies

The number of federal building agencies that have discretionary funds that could be used is very limited. Additionally, the competition for these funds is great. A small portion could be used for near-term R&D. It would be advantageous if this small amount of funds could be pooled. However, this is almost impossible in the present environment because of congressional funding restrictions. This means that funding for near-term research must, of necessity, be very limited and that each federal building agency will work directly with universities or laboratories to accomplish the research. It is regretable that funding is not greater and that the research better focused. An ABBE forum might provide an effective mechanism to link federal building agencies with university and industry researchers.

Funding Strategies for Long-Term Research

Long-term research will develop and verify new theories and principles for computer-aided building design. These theories and principles will provide better building performance (such as a new understanding of the effects of buildings on worker productivity) and better design and construction practices (such as new structures of design decisions to optimize interactive building systems). The long-term research will occur at boundaries between building research disciplines such as architecture and engineering and scientific disciplines such as computer science, mathematics, and psychology. Experienced building researchers are needed as principals. It meets administration policy to focus research on long-term, high-risk, high-technology efforts.

Active support for the long-term research program must be provided by the building community: design professionals, manufacturers of building products, general and specialty contractors, building owners, financiers, and individual leaders. This active support will be elicited when advantages to the professional and trade associations and the public are made clear. A possible argument is:

1. Buildings shelter and support most human activities. Their quality is vital to U.S. productivity, health, and safety.

2. Building is vital economically. It accounts for eight percent of the gross national product, and investments in buildings represent 69 percent of the nation's tangible, reproducible wealth. However, building productivity has declined since 1968.

3. International competition in building services and products is increasing.

4. The federal government under-invests in building as compared to the food and health related industries:

Industry	Central Federal R&D Per Year
Health	$4 billion in the National Institute of Health
Food	$1 billion in the Department of Agriculture
Building	$50 million in the National Science Foundation and National Bureau of Standards

A single, coordinated focus for the program is required to get effective industry support and congressional attention. This focus should be a science agency to assure a management that is supportive of the program and capable of conducting it. The program should have extramural activities to draw on and develop university and industry research expertise. It should have an in-house component so that there is sufficient expertise in the federal government to conduct the needed international, technical policy-making, measurement, and standardization activities.

PRIVATE INDUSTRY RESEARCH AND DEVELOPMENT

This group addressing R&D in the private sector was asked to deal with generic areas of research that might be supported by private industry (omitting specific projects that might be considered proprietary). It also was asked to indicate the nature of private industry interests in terms of where federal programs would be considered less appropriate and to make a distinction between long-range interests and short-term development projects. The group included: Brian Bowen, Hanscomb Associates, Inc.; Robert Pearson (chairman), Control Data Corporation; Shirley Radack, National Bureau of Standards; and David Skar, Naval Facilities Engineering Command. Its report is summarized below.

Basic research in new technology probably is not needed. Rather, basic research should concentrate on the application of existing or emerging technologies to problems and opportunities within the design and construction industry.

Due to the fragmentation of the building industry, there does not appear to be a concentration of capital that could be applied to R&D. Most companies have such a low margin on revenue earned that anything less than one percent of revenue applied to research would be trivial.

The ultimate users of the products of this industry--large developers, hotel chains, commercial firms (such as Federated Stores, McDonalds, and Safeway), large companies that build for their own account (such as IBM, General Motors, and AT&T), and the federal government--represent the best source of funding. The potential exists to pool money from a number of companies through a trade association, industry research group (such as the Electric Power Research Institute), or consortium for research using the model of the Microelectronics and Computer Technology Corporation, which was created within the electronics industry to undertake the study of generic issues.

The manner in which professional firms are paid for services is a hindrance that should be changed. A six percent fee is counterproductive to innovation. Even is a professional firm could gain exclusive access to a new productive technology, it would not necessarily gain a significant edge over its competition and still be able to generate a profit to pay for the original investment.

Potential suppliers of products to the building industry may perform R&D, but this is limited by the potential market. Many companies may not be able to afford the systems that could truly increase their productivity. If the systems get too low in price, it may not pay to market them to such a widely fragmented market as the building industry.

The following areas seem to offer potential for research by the private sector of the building industry (or, by implication, the private sector in the computer industry):

1. Demonstration projects using advanced technologies,
2. Development and validation of data bases,
3. New software development for design support, three-dimensional data-base management, three-dimensional graphics representation, expert systems for lower level subsystems design, and user interface, ease of use, training, implementation and start-up support,
4. Analysis and documentation of the phases of design and construction, and
5. Development of a systems architecture for the life-cycle model of buildings that can be used as a base for simulating or analyzing alternatives.

INTEGRATION OF CONCEPTS INTO ARCHITECTURAL PRACTICE

The group examining concept integration into architectural practice was asked to consider how to introduce practicing professionals and their firms to the use of advanced concepts. The goal was to identify ways to encourage a rethinking of professional practice in light of the potential of advanced technology. The group included: John Houston, Grafcon Corporation; Myron Miller, Arrowstreet, Inc.; Neville Powers, Applicon/Schlumberger; and Douglas Stoker (chairman), Skidmore, Owings and Merrill. Its report is summarized below.

Issues and Concerns

The primary rationale for architectural practice implementation of advanced technologies must be based on economic justification. This needs to be proven and presented to professional practitioners. Federal government or other support will be required to underwrite test cases and prototypes.

Design decision making must remain the role of the architectural designer. Significant architectural design use of the advanced technologies will not depend primarily on quantifiable supports for decision making. Graphics support to design will be a major incentive for computer use, offering benefits such as faster, more capable, and more readily modifiable two-dimensional and three-dimensional projections. The technology will inspire architects to test the consequences of design decisions including qualitative and quantitative implications. The technology must develop further to provide the graphics quality and speed required.

The integrative nature of computer systems--for continuity and growth of data bases throughout the design and construction process--should change the structure of disaggregated architectural firms and restructure work processes. Staff use should involve use of computers for development and testing of more varied design options, leading to improved building products.

Computers imply the potential new service of data-base management. Architects may have an incentive to capture some of the market for this new service as initiators of much of the data base. Additional markets exist in selling data bases to others (such as for planning and facility management).

CAD speed and adaptability to modifications will change client service expectations and billing bases. CAD services should be paid for in addition to traditional architectural services. For certain classes of projects, architects may become noncompetitive without CAD.

Architects run a non-capital-intensive operation. The capital impact of the advanced technology on architectural practice has several components: declining hardware costs, expanded marketing capabilities, lengthening learning curve for existing professionals which delays implementation, and shorter learning curve for newly trained, computer-literate professionals. The overall implication of these factors is difficult to assess.

There is a lack of strategy and organizing entities for research in architectural practice in this area. Research is required on such topics as the formal language of design and its construction for computer use and the architectural parameters that are potentially quantifiable and subject to algorithmic operations.

Recommendations

The federal construction market should provide incentives for computer technology implementation by architects by: (1) establishing positive criteria in selection processes concerning the ability to produce architectural documents on electronic media, and (2) paying an additional fee for products on magnetic tape.

The additional markets and new revenue-generation potential discussed above should involve others beyond those in the architectural profession and construction industry. Federal government and large private sector client support of prototype operations testing and implementation will be required.

Architectural education should be continuously forced to apply concepts designed to make use of the advanced technologies easier.

The architectural profession needs to develop better mechanisms to do fundamental research on architectural applications of advanced technologies. Funding support and cross-disciplinary mechanisms for such research should be developed through the efforts of the Federal Construction Council.

INTEGRATION OF CONCEPTS INTO ENGINEERING PRACTICE

The group addressing concept integration into engineering practice was given a wide range of concerns since engineering includes all other aspects of current professional practice that are not included within the field of architecture. The assumption was that this group would look at the questions emerging from the development of vertical integration of design practice and explore the barriers and incentives to new professional thinking. Some time was spent in joint meeting with the group that was exploring the same set of issues for architectural practice. The group included: Bertram Herzog (chairman), Herzog Associates, Inc.; Robert Mahan, Battelle Pacific Northwest Laboratories; and Kenneth Reinschmidt, Stone and Webster Engineering Corporation. Its report is summarized below.

The following barriers to the wider application of computer-based design in engineering practice were identified:

1. A lack of computer literacy,
2. Control of the computer use environment by computer people rather than by the practicing engineer,
3. The time spent reinventing the same programs that have been developed by other professionals, and
4. The high entry cost.

The following recommendations were made:

1. Provide the profession with computer educational programs. Personal computers are providing the major educational impetus at this time.
2. See that professionals take control of the computer environment.
3. Buy--do not develop--programs whenever possible. A serious problem exists here since the personal computer has produced a flood of "inexpensive programs." The cost to a professional of verifying the accuracy and utility of such programs often exceeds the acquistion cost. This suggests the need for a "Consumer Reports for CAD Programs" in the building field.
4. Establish financial incentives for investing in computer-aided design, perhaps through extra contract requirements for extra fees.

UNIVERSITY PROGRAMS

The group considering university educational programs was asked to explore how undergraduate and graduate education in architectural and engineering schools should change as the new concepts of design practice begin to emerge. Since today's students will likely be practicing in a professional world that is largely organized around electronic media, the group also was asked to consider whether or not major rethinking for those responsible for professional programs is in order. The group included: John Eberhard, Advisory Board on the Built Environment; Charles Eastman, Formative Technologies, Inc.; Leonard Simutis (chairman), Virginia Tech; and Fred Stahl, National Bureau of Standards. Its report is summarized below.

Incentives

Incentives for change in educational programs are as follows:

1. There is a growing recognition that manual approaches to design and information exchange are deficient compared to the relatively inexpensive technology of CAD.

2. The increasing interest of students in professional training and employable skills, their recognition of the importance of computer use in future society, and the interest of at least some universities are causing an increased emphasis on computing as a primary medium of instruction and professional preparation.

3. Increasing university emphasis on research, particularly in architecture programs, is opening up faculty exploration of technology development and transfer to design and building.

Barriers

The barriers to change are:

1. The lingering view of architectural education as a process of training in a "craft" that is passed on from generation to generation (learning from the "masters"),
2. The continuing emphasis on the idiosyncratic character of the search for appropriate design "creativity" works against generalized approaches to design and building,
3. The continuing distrust of technology transfer, particularly given the lack of a shared model of the design/build process,
4. The lack of a research tradition and of operable examples of a strong link between research and professional practice, which calls into question the applicability of previous and current research in CAD/CAM to pressing professional problems (as viewed from the practicing profession), and
5. The cost of providing data work stations for students.

The Issues of Education

The university must strive for a balance between training through current technology, on the one hand, and generic design and analysis skills, on the other. This balance will assure that design/build education continues to be concerned with anticipating and defining the profession of the future instead of merely meeting current patterns of practice and employment. In this respect, instruction and research in CAD are critical to defining and developing the professional practice of the next 20 years.

Computing must be seen as an integral part of education in architecture, engineering, and construction. It should not continue to be a curriculum option or specialization but must be made central to the medium of instruction in the design studio and engineering laboratory. Until now, computing has been seen largely as a vehicle for automating detailed tasks such as working drawings and for visual representation. It needs to be seen and taught as a central medium of communication, analysis, and synthesis.

The university must continue to develop a research mode for faculty in architecture, engineering and construction, and the faculty, in turn, must continue to develop strong ties with industry and professional organizations. Industry and professional organizations then need to develop more visible and more demonstrable evidence of support for faculty research efforts. This is particularly important in hardware-intensive fields such as CAD/CAM and computer-assisted instruction.

In the medical professions, for example, training, research, development, and practice derive from a common model of their interaction and interrelationship. Thus, professionals in each domain recognize the whole system, and the movement of new methods from R&D through training to practice is an accepted and natural process. The movement of advanced technology through the various segments of the building industry will require an analogous model of the linkages between research, training, and professional practice.

The university must give serious attention to the continuing educational needs of its own faculties and the professions they serve. The advances in CAD/CAM technology are evolving so rapidly that the professions cannot wait for a new generation of faculty to embrace the technology and to teach it with conviction and understanding. Neither can the design/build professions benefit very long from an ad hoc entrepreneurial or "self-taught" approach to CAD/CAM.

The Potential Use of CAM Experiments as a Teaching Method

The use of numerically controlled machines is common in enough industries to provide many locations where students could be taken on field visits to see actual applications of CAM and possibly CAD/CAM. If at least one laboratory in each school of engineering was equipped with CAM machinery (possibly a robot of some type), students could be engaged in experiments to design and produce simple articles. The primary lesson to be learned is to understand the various ways in which CAM requires a more disciplined approach to design. A CAD system that allows unbridled design solutions is not sufficient for the purposes of CAD/CAM. When CAD and CAM are linked, and the conjecture is that the future will find more and more links, there are constraints placed on the design alternatives. A major engineering design problem is to create CAM situations that are sufficiently flexible to increase the range of design alternatives.

INCENTIVES AND BARRIERS TO THE ADOPTION OF ADVANCED CONCEPTS

The group addressing incentives and barriers to the adoption of advanced concepts was asked to consider such national policies as tax incentives for organizations and re-education loans for individuals to help pave the way for the new concepts. It also was asked to assess the impact of advanced concept adoption on regulations (such as building codes) and licensing, insurance coverage, and employee relations. The group included: James Burrows, National Bureau of Standards; Louis Childers, U.S. Postal Service; Richard Field, General Services Administration; Mary Oliverson, Applied Research of Cambridge, Inc.; and Richard Wromble (chairman), U.S. Department of Health and Human Services. Its report is summarized below.

Fragmentation

Fragmentation among the actors involved in the entire life cycle of a built environment is a major barrier to the application of CAD/CAM technology. The industry is now compartmentalized into such areas as planning, designing, constructing, operating, and maintaining this environment. In general, each actor has responsibilities for developing information required only by the next actor. The ultimate actor, the building owner, receives information that just happens to filter through from previous actors.

An incentive for a more complete pass-through of information must come from building owners who need to recognize that: (1) information from all compartments can be made available to them, (2) this information can result in downstream dollar savings, and (3) they are paying for the generation of this information at all stages in the development of a built environment. If the downstream dollar savings offset the cost for capture of information, the owner will be motivated to require that a data base, useful for operation and maintenance, be provided as part of the completed facility or building. The Federal Construction Council should come to grips with defining specifications for data transfers between the various compartments as a means of stimulating industry awareness of the need as perceived by at least one major developer, builder, or user.

Behavioral Aspects

Behavior is a major barrier to the application of advanced technology by architects and contractors. In general, they are not attuned to making large capital outlays for computer equipment and the software necessary to CAD/CAM design and construction. There also appears to be skepticism about the benefits to be derived from this advanced technology. There may also be a certain amount of complacency to applying CAD/CAM technology by architects.

An educational effort within the industry on how the large investments can be financed and the costs recovered would be an incentive for stimulating investment in CAD/CAM technologies. Bright and highly motivated individuals also can be stimulated with university and college courses and research in CAD/CAM.

Another incentive would be to develop a healthy tension in the design and construction community based on a fear that competitors might gain an edge using CAD/CAM techniques. A way to develop this might be through a national competition and awards program for innovative uses of CAD/CAM in the built environment industry. Another would be through the stimulation of articles in professional and trade journals on CAD/CAM application experiences within the industry.

Software Limits

Software limitations are a barrier to wider use of CAD/CAM by the design professions. The current software is not capable of accommodating all of the details of a design in a manner that facilitates handling interferences or making significant changes in design, like moving a wall. In addition, the software languages are difficult to learn and to use. The output products are not easily transferred between systems.

An expanded market, reflected by increased sales of personal computers and CAD systems to architectural and design firms, would stimulate software developers to provide improved languages and expanded capabilities within CAD systems.

Investment Costs

The cost of CAD/CAM systems is a major barrier to their use. An effective CAD system costs in the neighborhood of $150,000. It is doubtful that costs will drop much in the near future.

A major incentive for CAD acquisition would be to assure firms that they would recoup their investment costs in a reasonable time. The federal government could stimulate some firms by incorporating special allowances in its fee structure to reimburse architectural and engineering firms using CAD design techniques. Firms also should be encouraged to cooperate and develop CAD/CAM service centers that would allow costs to be shared by a number of firms.

PART III

APPENDIXES

APPENDIX I

COMPUTERS IN BUILDINGS, BUILDING AND BUILDING RESEARCH

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This paper was presented at the Triennial Congress of the International Council for Building Research, Studies and Documentation (CIB) in Stockholm, Sweden in August 1983. Dr. Wright submitted the paper as background for the participants at the workshop.

INTRODUCTION

When an information processing task is well-defined, an electronic computer is about one million times faster than a skilled human being in conducting the task. Consider the implications. Compare it to transportation where an airplane is about 100 times faster than a person walking. The advance of electronic computation over human computation is two orders of magnitude greater than the advance of air transportation over walking. This new, human-controlled power is only now beginning to affect our lives and work. We must anticipate far greater effects on our lives and society than have occurred in the past century with the advent of rapid air and automotive transportation.

Electronic computation will have great effects on what we build. We will build "smart" buildings that are able to sense changes in human needs and in the external environment and modify themselves to better serve human needs. Our building practices, by which we design, construct and operate buildings, also will change as electronic computers are used to provide the information needed by decision makers in the building process. In turn, the new capabilities provided by electronic computation will change the roles of the people involved in the design, construction, and operation of buildings.

Building research produces knowledge for the improvement of building products and practices. Electronic computation will cause major changes in building products and practices. Therefore, the effective use of electronic computation in buildings and in building practices needs to be a major focus of building research. Through effective building research we can exploit the potential benefits of improved computational techniques and avoid errors and undesired side effects.

In this paper I anticipate how buildings and building practices may evolve with increasing use of the abilities of electronic computation. Suggestions are noted for the knowledge from research that is needed for the effective exploitation of the computational resource. Although it is unlikely that we can predict the future completely and correctly, this paper may stimulate research managers to test these thoughts and improve on them as they formulate their future programs of research. It may give researchers a framework for identifying how their research can respond to and support the knowledge most needed for the effective use of computers in building and buildings. These perspectives of the directions for the evolution of building technology and the knowledge barriers likely to control the rate of this evolution may be helpful to people in building practice in assessing how they can best employ electronic computers in the near future and in identification of sources of more detailed information.

Electronic computation will pervade the whole building process and will change it. A simplified view of the whole building process is shown in Figure A-1 to help us anticipate the applications and changes. All participants in the building process need to be considered since each will use electronic computation to support individual decision making. In programming, the requirements that the building must satisfy are defined qualitatively and quantitatively with participation by developers, designers, financiers, regulators, owners, and users. In preliminary design, one or more concepts to satisfy the project requirements are developed with major roles often played by designers, contractors, and manufacturers. In detailed design, plans and specifications are produced with important participation by designers, contractors, and manufacturers with review and approval by regulators. In site construction, contractors, labor, and manufacturers produce the building with oversight by designers and regulators. In occupancy, the developers, owners, users, and maintainers use and maintain the building. Eventually, as functions change or the facility becomes obsolete, renovation or removal make major changes in the building.

Three aspects of change in buildings or building practices, made possible and driven by the availability of electronic computation, seem most important. These are: automated building services, automated construction equipment, and integrated project information systems. These can be looked at from a common perspective of the process and information required for effective decision making in building. The steps are: problem defined, criteria for solution of the problem identified, alternative solutions for the problem identified, effects of each alternative solution modeled and predicted, the validity of each prediction assessed, and action taken on the best alternative.

The great information processing power of electronic computation usually is applied first to the stage of predicting the effects of

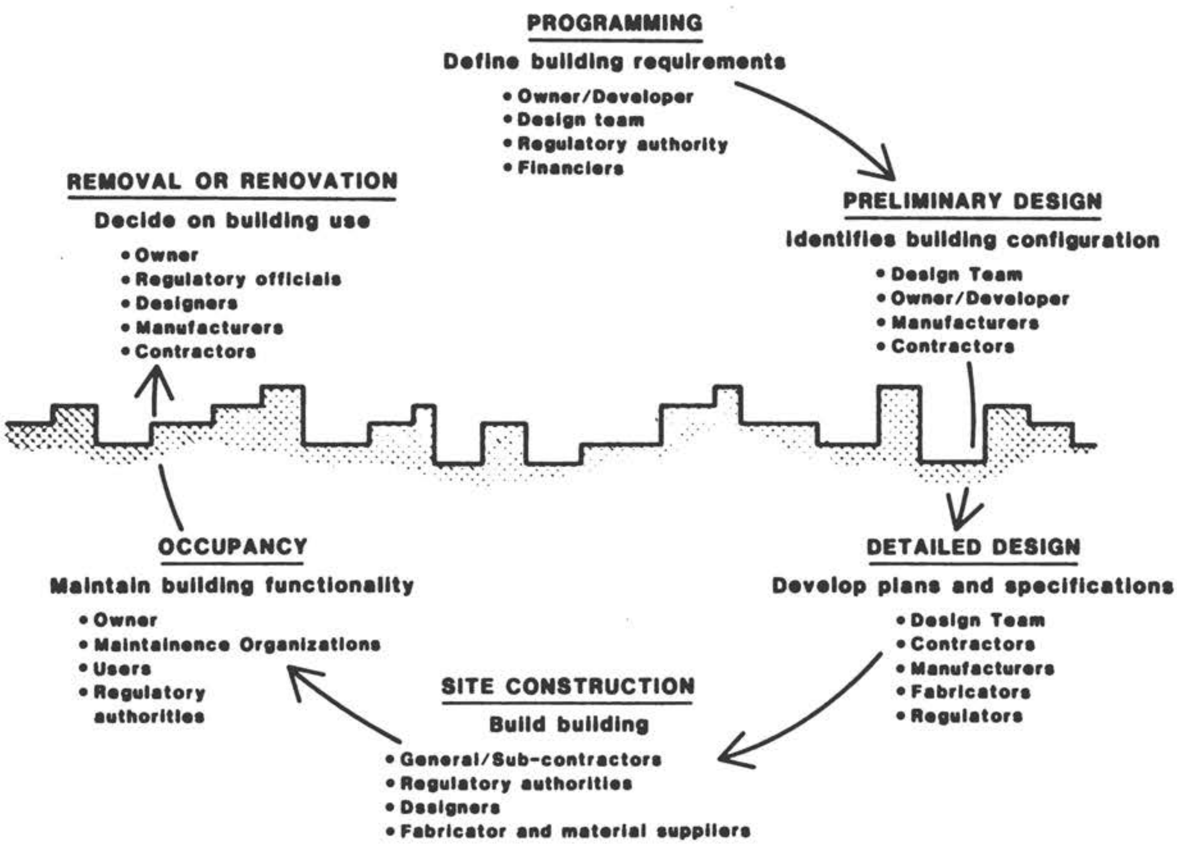

FIGURE A-1 The Building Process

each alternative solution. However, computers can assist in the information processing required for other steps of the problem-solving process. In the following sections, we will look at the potential benefits of electronic computation in automated building services, automated construction equipment, and integrated project information systems and define the knowledge needed from research in order to assure effective computer uses and correct decisions in the building process.

TRENDS IN COMPUTING

There is much literature on trends in computing (for instance Abelson and Dorfman, 1982 and Toong and Gupta, 1982). I will cite here on a few items of data for a shared perspective on the powers of computers.

TABLE A-1 General Purpose Computer Costs and Capabilities

Type	Equipment Cost $	Task[a] Time Sec.
Mainframe	10,000,000	0.1
Supermini	250,000	0.5
Mini	50,000	2.4
Micro	6,000	5.7
Human	45,000	.0

[a] 1000 Steps of Integration by Simpson's Rule

Table A-1 shows equipment costs and task capability for general purpose computers. The task, used in some bench-mark calculations at NBS, is 1000 steps of integration by Simpson's rule. Those of you with a civil engineering education a generation or so ago will relate this task to computing earthwork cross sectional areas and volumes. This task, which takes a human being 45,000 seconds with use of an electronic calculator, requires only 5.7 seconds for an inexpensive microcomputer and only 0.1 second by a large mainframe computer. Software (computer programs for particular applications) makes these general purpose computers applicable to any type of data processing to aid building decisions; relative task times will be similar to those shown here.

Special purpose computers adapted to a particular task also are important to building. A special purpose computer may control a bank of elevators in a tall building or a ventilation system. A 16-bit microprocessor chip capable of handling this type of special purpose computing costs about $50 (Toong and Gupta, 1982).

Memory represents the data storage capability for electronic computation. A megabite of memory (one million characters) amounts to about 200,000 words or about 2 books and can be available for rapid access for data processing at a cost of about $1 per month.

Computers, memory units, and input/output devices such as visual display tubes and printers are the "hardware" of electronic computation. In general, hardware costs will not be a barrier to the use of electronic computers in the building and in the building process. Rather, the computer programs, called software, that control the performance of the hardware are controlling the rate and effectiveness of computer use in building. It is more expensive to develop a computer program to conduct a structural analysis of a building than it is to buy a computer and peripheral equipment capable of using the program. Furthermore, it is more difficult and more expensive to assure the reliability of the software and to provide for its maintenance. Performance criteria, standards, and test methods for computer hardware are more advanced than those for software. An area of knowledge called artificial intelligence that we will discuss later offers great potential in improving the quality of computer software.

Graphics denote the computer hardware and software that allow man and machine to communicate in pictures as well as numbers and words. Graphics are very important for the interface between the human user and the computer. Graphics are demanding in hardware, software, and computing costs because much data processing is required for the representation and manipulation of images. This is an important field for all areas of computer use, not just for building, and it is developing rapidly. Therefore, this discussion assumes an increasingly effective graphics capability and does not give it special attention as a subject of building research.

As computer power has increased and computing cost decreased, much attention has been given to making computers more "user-friendly." An example is the use of graphical input and output to adapt the machine to human abilities. These adaptations, such as voice recognition, will continue. However, people also will change their techniques and organizations to exploit the capabilities of computers, much as we have changed our urban areas, housing, and life-styles to exploit the capabilities of automotive transportation. We in building research should seek to anticipate how building practices will change and how the roles of the various participants in the building process will change and work to provide the knowledge to make these changes beneficial.

The developing discipline known as artificial intelligence, knowledge engineering, or expert systems provides methods for modeling how experts use scientific knowledge and judgment in their decision making. By these techniques, it is possible to have the computer emulate the behavior of an expert. By these means, a technician aided by an expert system can make a decision very similar to the one an expert would make without a computer. More significantly, an expert can focus his attention on the non-routine aspects of decision making, deeply probe the most significant aspects of the situation, and provide more accurate judgments.

Data-base management denotes the software for entering, quality controlling, storing, and retrieving information. The results of a computation hardly can be better than the input made to it. Thus, information must be reliable as well as economically available to those who need it in the building process. Much computational research and development efforts are focused on the improvement of data-base management. These technologies are underdeveloped, relative to those of computer hardware and large-scale analytical computer software (Rehak and Lopez, 1981). However, data-base management technology is developing rapidly; building research will be needed to define the data-base management requirements for building information systems as described in a following section.

Electronic computation is becoming a very important tool in the building process and a very important component of the operating building. It will affect and change human roles in building. What will building roles become? The human being will remain the user served by the building and will be responsible for the control and servicing of equipment in the building (and overseeing cleaning equipment seems a more humane and satisfying endeavor than cleaning itself), for concepts and decisions in building processes such as design and construction, and for research, development and design of better building systems and building techniques.

Great, and often agonizing, changes will occur as computers are introduced in buildings and in building practices. Human skills developed at great cost that have been matters of great pride, such as skill in drawing or manual computation, will be displaced by computers and computer programs. However, we can anticipate that human roles will evolve to exploit the best human qualities in the process of building.

AUTOMATED BUILDING SERVICES

Building services are defined to include all of the dynamic systems that alter the state or environment of the building to shelter and support human activities. These include the heating, ventilating and air conditioning system, the lighting system, water supply and drainage, and security and fire safety systems.

Services are systems that include as elements: sensors to monitor the state of the environment and system, control logic to determine how the system should be changed to achieve the desired state of the system and/or environment, and actuators to achieve the change desired in the state of the system. For the heating system, the sensor would be a thermometer measuring the temperature in the space, the control logic would compare the temperature with that set by the user, and the actuator is the valve controlling the flow of heat to a radiator.

Automation of building services is not completely new. We see all of these elements in traditional service systems that do not employ electronic computation. However, electronic computation permits much more extensive automation (i.e., much reduced direct human intervention in the operation of a service system). Computer automation of a service function requires:

1. A model predicting the automated systems performance to be used directly or indirectly in the real-time process of control.
2. Performance criteria for the sensors, logic, and actuators of the automated service system. The functional strategy for the service system must satisfy the overall performance criteria for the service system. Fail-safe behavior is a key element. When an automated service function fails consequent damages must be minimized.
3. Test methods are required for overall system performance and for the essential qualities of the system components.
4. Interface standards allowing open systems are highly desirable to reduce cost, enhance reliability, and maintain independence of any one particular vendor or supplier.

Electronic computation should be an incentive to the integration of building service systems. Many components naturally belong to more than one service system (a duct may provide either hot air for heating or pressurized air for smoke control). The great data processing capability of inexpensive computers makes integration of service systems seem inexpensive. However, the complexity of logic involved with integrated service systems does make functional and fail-safe behavior difficult to achieve. Controls on doors for security must give way to controls on doors for firefighting. Again, system and component performance standards, test methods, and interface standards are needed to achieve open systems and to stimulate effective innovation, functionality, economy, and reliability for integrated, automated, building service systems.

There is an active market place in automated building service systems in the United States. Our trade journals carry advertisements for many proprietary systems, some of them integrated systems. However, in the United States we generally lack dynamic, well-documented performance models that allow a designer to predict in advance how the automated service system will perform. Moreover, criteria for this performance generally are not defined. Standards for the qualities of individual components and the interfaces of between components, and test methods for component and system performance are lacking. In these circumstances, it is not surprising to find (Dickenson, 1981) that many users, 30 to 70 percent, report disappointment in the performance of automated building service systems.

Much building research and development is needed to support the improvement of automated building services. Performance criteria for service systems should be reviewed, now that the constraints of manual control are relaxed, to determine the actual human needs for these systems. Models for the dynamic performance of service systems need to be formulated and verified to assure that the effects of control system parameters are properly represented. Functional strategies with fail-safe characteristics need to be formulated and proven. Test methods for the qualities of systems and components need to be established. Standards supporting open systems (i.e., independent procurement of sensors, control logic systems, and actuators) need to be formulated to stimulate the long-term economy and reliability of automated systems.

Automation is anticipated to greatly change the technologies of building service systems. New skills will be required to use these new techniques in the practice of building. Designers will need to understand and use new performance models and performance criteria. Installers, operators, and maintenance personnel need to learn new techniques to carry out their responsibilities for the normal functional behavior of service systems and to conduct their activities properly in emergency situations requiring manual operation or manual intervention.

AUTOMATED CONSTRUCTION EQUIPMENT

Automation and robotics for manufacturing are advancing because costs can be reduced and quality improved through automation. There are similar potentials for robotics and automation at the construction site. This section views opportunities for automation of site construction activities and identifies some of the research needed to take advantage of these opportunities.

As with automated building equipment, automation of an activity at the construction site requires sensors to identify the states of the environment and physical system, control logic to determine how that state should be changed, and actuators to effect the change. However, the environment for automation at the construction site is more severe than the environment in a factory or for an automated system of a building. Physical and environmental conditions at the site are dynamic, rather than steady-state. As each construction activity proceeds, the physical environment at the construction site changes; these changes must be reflected in the automated activities. As a simple example, the next brick goes on top of or beside the last one, not in the same place. The environment for automation is harsh. There is exposure to the natural elements, and construction components may be massive, or large volumes of materials need to be handled. Many simultaneous activities occur in construction. Automation needs to be planned to prevent interferences between these activities or to conduct them in an integrated fashion. Essentially, integration requires integrated control logic.

The potential for automated construction equipment is being realized and will continue to develop. Distinct and well-defined functions can be automated soon. Something as familiar as an automatic transmission for an earthmover is an example. Tunneling machines, lifts, and the like, show substantial degrees of automation. Equipment for complex functions will be automated more slowly. On-site materials handling is an important candidate, but such activities require development of models of the site in space and time and real-time definition of as-built conditions to allow materials to be delivered to ever-changing points of use. Some reflection on these subjects suggests that the design of an automated construction process involves the same parameters and can be equally or more intellectually challenging than the design of the constructed facility itself. This suggests that automation of construction may lead to integrated design of the construction process and the facility constructed.

The status of practice shows automation proceeding in the development of individual pieces of equipment such as tunneling machines, paving machines, grading equipment, and welding equipment. The manufacturing industry is proceeding to integrate equipment providing sequential manufactured operations. Such developments are anticipated in construction. Research for automation of construction equipment need be pursued in a number of areas:

1. Performance criteria for the control of automated equipment need to be based on tolerences for the qualities of the built elements.
2. Models need to be developed for the state of the construction site and techniques are required to make as-built information ready in real time to guide automated operations.
3. Functional models are required for the control logic of the automated systems. These models must have strategies for fail-safe behavior that will place the automated equipment in a safe configuration when some element fails to function correctly or to maintain required tolerences.
4. Interface standards are needed for sensors, control logic, and actuators that will allow open systems of automated equipment. Open systems seem desirable for economy and reliability of construction processes without undue dependence on a single supplier.

Substantial efforts will be required to translate knowledge research in automated construction practices. Designers and planners of construction activities need to learn how to design buildings to be constructed by automated techniques and how to design the automated construction techniques. Construction technicians need to learn to control and maintain novel types of equipment considering the dependence of automated equipment on electronics and computer logic as well as the more traditional mechanisms. Very substantial technician training will be required to use automated equipment effectively in construction.

INTEGRATED PROJECT INFORMATION SYSTEMS

The project information system is the mind and memory of the building process. Its present fragmentation is the cause of much loss of information, many mistakes, and much expense in building. Integrated project information systems have the potential for providing each participant in the building process with timely, correct, and economical information in a useful format (Brown, 1982). A view of such an information system appears in Figure A-2.

Note that the information system exists through the whole history of the construction process beginning with initial activities in programming to define quantitatively the owners' and users' requirements. In these activities, owners, users, and architects are principal participants. The information system continues to provide the information needed by each participant in the construction process and accepts in return the information produced by each participant's decisions. The typical activity of a participant is to take data from the information system, process it through his particular data processing techniques to provide the basis for assessing his alternative decisions, to make appropriate decisions, and to return information describing these decisions to the information system.

There are various levels of data involved in the construction project. The most important data are multi-stage and multi-user, significant through the life of the project to several users. An example would be the clear distance between structural members from the top of the floor framing to the bottom of the ceiling framing. This information would be developed early as a functional requirement and needs to be maintained throughout the life of the building for use in considering modifications and rehabilitation. Other information would be of interest only at a single stage of construction but at that stage would have multiple users. An example might be cost and performance data on several alternatives considered in design. Architects, structural engineers, mechanical engineers, and others may need these data as each carries out his share of work in exploring the alternatives. Once the decision is made on the best alternative, there may be no further need for the data describing other alternatives. Finally, many data are meaningful only at a single stage and only to a single user. An integrated project information system needs only to provide data of interest to multiple users or data required over much of the project's life.

There are challenging performance requirements for an integrated project information system. Data need be consistent (i.e., in accord

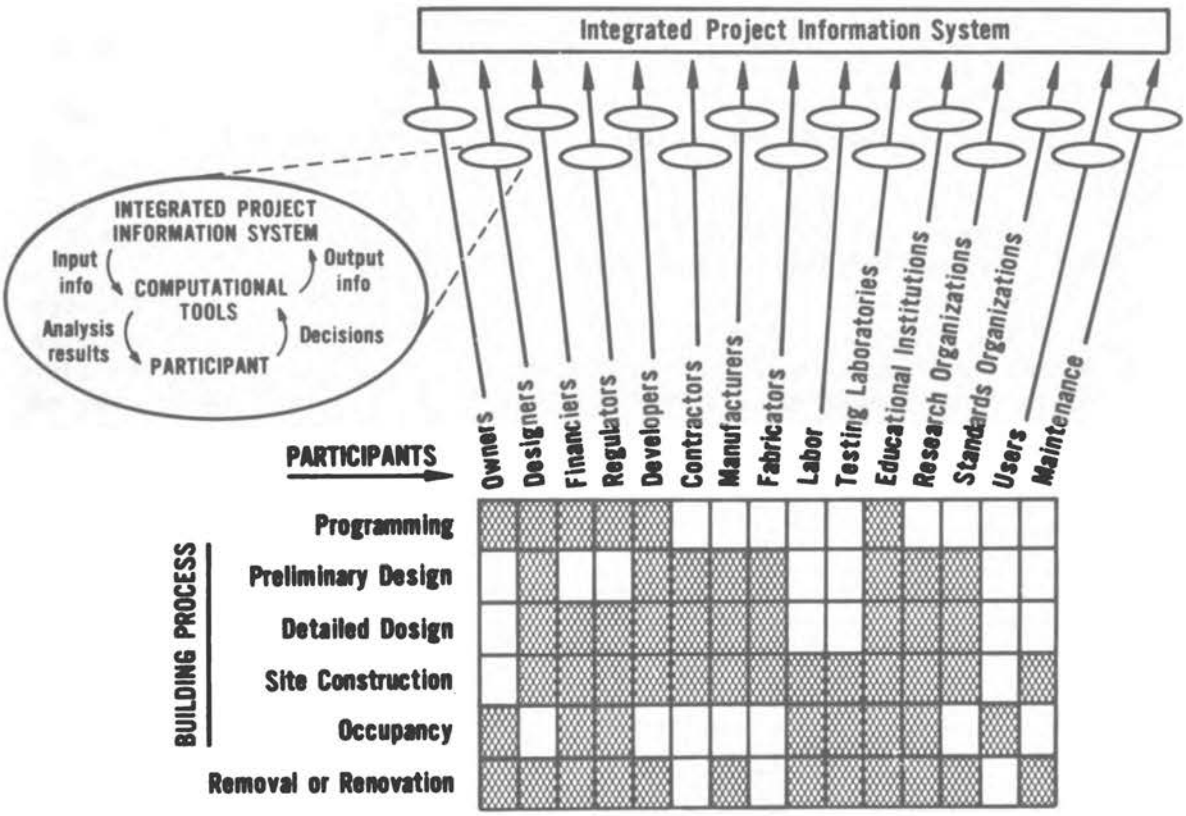

FIGURE A-2 Integrated Project Information System with project requirements and with related data). For instance, a heating duct must fit between structural members and an architectural element such as a dropped ceiling. Project data need to be accessible to those who require them to carry out their roles in the construction project. Data also need to be secure from unauthorized uses and unauthorized modifications.

The integrated project information system is seen as a project-specific body of data. It needs to interface to generic data sources such as national standards and catalogues for the properties of materials, components, and processes. The project information system also needs to interface with generic procedures for data processing used by participants in the building process. Examples of such procedures are techniques of structural analysis used to predict the response of a building to design loadings, and techniques for quantity take off used to predict the amounts of materials required for a building. Figure A-3 illustrates the relationship between the integrated project information system and generic data and procedures.

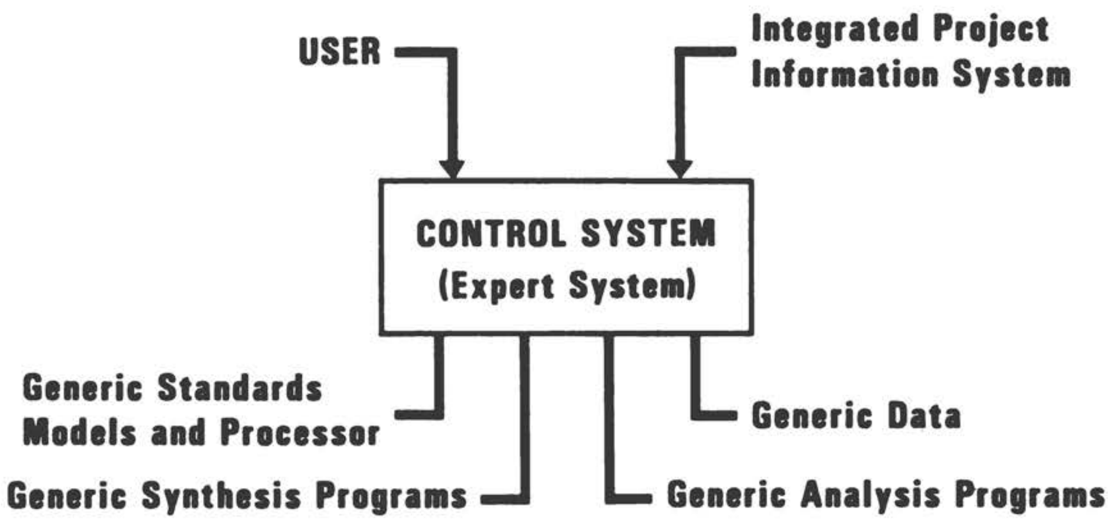

FIGURE A-3 Linking to Generic Procedures and Data

A recent NBS study (Stahl, 1983) of available computer-aided design systems showed that many generic data processing procedures are available, such as analysis of structural systems and analysis of energy performance, but few integrated project information systems are available. The National Aeronautics and Space Administration has a system called IPAD (integrated program for aerospace and design) (Fulton, 1982), the U.S. Army Corps of Engineers is developing a system called CAEADS (computer-assisted engineering and architectural design system) (Spoonamore et al., 1982), and computer service organizations are offering information systems for building design. In the few integrated project information systems available, interfaces to generic standards data and to generic data processing procedures are manually programmed on an individual, explicit basis. In general practice, project data interfaces between participants involve exchanging drawings. Therefore, the interfaces are expensive to use and often unreliable.

Much building research is needed for development of effective integrated project information systems. Data-base management systems require extension of capabilities to achieve application to construction data. For example, consistency requirements relating items of data may be in the form of agreement with applicable generic standards. As yet, data-base management systems do not accommodate use of such consistency requirements. Research is required to characterize the project data important to the various participants in a construction project, to obtain agreement on names and definitions for information used in common, and to develop data-base management procedures to make these data accessible to participants.

The project specification is a familiar concept that expresses consistency requirements for much of the project data. Techniques are needed to synthesize project specifications using desired aspects of generic specifications and project-specific criteria, to assure the consistency of the synthesized project specifications, and to express the project specification in automatically processible form consistent with the project data-base management system. This will permit the project specification to be used for maintaining consistency in the project data base.

Research can provide technical bases for interface standards for the generic data processing procedures used by the various participants responsible for design, manufacture, and site construction operations. Such interface standards would allow open systems procurement or selection of the generic data processing procedures by the individual participants. This would reduce barriers to the development of the improved modeling and synthesis computer programs.

Expert systems provide a promising approach to the analysis of complex information for decisions (Duda and Gaschnig, 1981). Expert systems combine scientific principles and expert judgment to emulate the decision that would be reached by a panel of experts. Major research efforts are required to develop and verify expert systems for the most significant decisions involved in the building process. While expert systems are a frontier research area in computer science, they are somewhat familiar in building. Our traditional norms and standards combine scientific principles and expert judgment. They can be rigorously modeled for computer application (Goel and Fenves, 1971) as a form of expert system.

Much technology transfer will be required to achieve application of integrated project information systems. Specialists in information systems and data-base management procedures will require training in the characteristics of building project information in order to use their systems to support building needs. Participants in the building process need training in real time, interactive use of integrated project information systems to gain information effectively and to document their decisions. Software engineers developing generic data processing procedures to support various participants in the building process need to learn to interface their routines to project information systems. Those responsible for maintenance of integrated project information systems throughout the project life cycle need to learn how to support the needs of the various participants. Information system managers also will need to adapt to changes in information processing techniques that will arise in the long life of a typical building.

SUMMARY AND CONCLUSIONS

The evolution of computation for building, buildings, and building research is summarized below with citation of needs and opportunities for CIB activities. The first area considered is that of computing resources for buildings and the building process:

1. Falling costs of computer hardware will stimulate and permit automation of building and buildings. Computer industry research and development will support improvements of computing hardware. Building research and development are not needed.
2. Software development costs and software quality will control the rate of effective computer use in buildings and building. Building research and development are needed for software development since software development requires expertise in building technology as well as expertise in computer science.
3. Data-base management technologies must be advanced to make feasible integrated project information systems. Advances of these technologies require computer industry research and development to improve generic data-base management technologies. Building research and development are needed to characterize effectively and define requisite building data and to develop appropriate strategies for management of these data.

4. Technologies of artificial intelligence for support of decision making will advance rapidly through computer science research. Building research and development are needed to apply these generic expert systems techniques to the development of expert systems for support of the various decision-making activities in building.

Automated building service systems will exploit advancing computational resources to provide major improvements in functionality and safety of buildings. Substantial building research is required to make automated building services functional, economical, and safe:

1. Performance requirements and predictive models are required for the logical units of automated building service systems. Such research is the role of CIB W-79, (Working Commission) Control of Building Services.
2. Expert systems need to be developed to assist in the design and use of automated building services. Building research will provide the scientific principles embodied in the expert systems, and the syntheses of experiences of building experts will provide the judgmental aspects.
3. Interface standards are required between the sensors, control logic, and actuators of individual service systems and between the logical units for integrated automated service systems. Such interface standards will promote economy, flexibility and reliability through the encouragement of open systems.

Automated construction equipment promises to improve economy, speed and safety in site operations. Technologies and research for automated construction equipment are closely related to those for automated building services. Design of the automated process will become a challenging professional activity and seems destined to become closely linked to design of the faculty itself. Equipment manufacturers will be major sponsors and participants in the research for automation of construction equipment, but substantial building design, construction and building research expertise must be involved because of the close linkage between equipment performance, the planning and design of construction operations, and the design of the facility itself. International coordination of such research might be a major activity for CIB W-65, Organization and Management of Construction. Interface standards for sensors, control logic units, and actuators within a particular construction operation and between integrated construction operations are important for the economy, flexibility and reliability of the systems. Interface standards will promote economy, flexibility and reliability by allowing alternative choices of components through open systems procurement.

Integrated project information systems have the potential for great improvements in the quality and economy of the whole construction process. Building research is required to define and characterize information requirements of the various participants throughout the whole building process:

1. The needed characterization of generic information processing technologies might receive international coordination by CIB W-57, Building Documentation and Information Transfer.

2. The needed characterization of project information requirements and information processing techniques, such as means to synthesize consistent project specifications, might receive international coordination through the activities of CIB W-74, Information Coordination for the Building Process. Interface standards will promote economy, flexibility and reliability by encouraging open systems for the development of information processing software and hardware.

Building research and development are required for artificial intelligence techniques to support professional decision making and the interfacing of elements of the project information system. Such research and development may include:

1. Techniques to develop consistent project specifications by synthesis of pertinent generic standards in project specific requirements.

2. Techniques to use project specifications in design checking, design decision making, and in maintaining consistency of data in the integrated project system.

3. Techniques for planning, designing, and scheduling that employ effectively both formal optimization techniques and expert judgment.

Technology transfer will require sustained efforts. Computer hardware evolves rapidly. Software is developed to exploit new scientific principles and to emulate better the judgment of leading experts. However, each participant must understand the performance of the aspects of the building system or building process for which the participant is responsible and the capabilities of the computing hardware and software used to assist decision making in order to use these technologies responsibly and effectively in all work.

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APPENDIX II

BIOGRAPHICAL BACKGROUND OF PARTICIPANTS

HAROLD BORKIN is an architect and professor of architecture and urban planning at the University of Michigan. He is director of several computer-aided design research projects for the U.S. Army Corps of Engineers. He is also the director for the development of the ARCH, a model computer-aided design system. Professor Borkin has authored numerous articles and papers on advanced technologies for housing and computer-aided design. He received his Bachelor of Architecture from the University of Michigan.

BRIAN BOWEN is executive vice president of Hanscomb Associates, Inc. in Atlanta, Georgia. He has experience in the United Kingdom, Canada, and the United States. Mr. Bowen is interested in computer applications in the management process for design and construction, in estimating and cost control, and in data structures.

ALTON S. BRADFORD is a registered professional engineer and a graduate of the University of Maryland. He is currently the assistant commander for engineering and design at the Naval Facilities Engineering Command (NAVFAC), Washington, D.C. His 24-year career has been dedicated to the design and acquisition of naval shore facilities, structures and systems at the NAVFAC. Mr. Bradford has worked on such projects as Byrd Station, McMurdo Station, and Pole Station, Antarctica; various projects throughout CONUS, Hawaii and Alaska; and many projects in areas such as Spain and Vietnam. During the early 1960s, Mr. Bradford pioneered the use of computers in NAVFAC by employing them in his design work and later by developing and implementing a nationwide computer access system for use by NAVFAC field divisions, including Hawaii.

JAMES H. BURROWS has been the director of the Institute for Computer Sciences and Technology, National Bureau of Standards, Department of Commerce since 1979. The Institute manages the government-wide federal computer standards program, provides technical assistance to federal agencies in the use of computer technology, and conducts related computer science research. These activities are aimed at improving economy and effectiveness in the procurement and use of computers by the federal government. Prior to 1979, Mr. Burrows was associate director, Office of Computer Resources, U.S. Air

Force. As the Air Force's senior civilian manager for data automation, he was responsible for developing and implementing policies for ADP management, operations, procurement and standards utilization. Before this he directed the development of large information systems and data management projects for the Mitre Corporation and the Lincoln Laboratory in Massachusetts. Mr. Burrows received his B.S. in engineering from the Massachusetts Institute of Technology in 1949 and his M.S. in mathematics from the University of Chicago in 1951.

LOUIS E. CHILDERS is an architect with the U.S. Postal Service. As manager, he is responsible for planning, functional design requirements and the selection, technical review and management of contracts with architect-engineer firms performing services for major postal facility projects. Previously, he was principal in an architectural practice engaged in design of educational and public facilities.

CHARLES M. EASTMAN is president of Formative Technologies, Inc. and professor of architecture and computer science at Carnegie-Mellon University. He has 15 years of research experience in architectural CAD. His primary interest is data bases for design and solid modeling.

RICHARD FIELD is currently acting assistant commissioner for design and construction at the General Services Administration. Prior to this, he was a captain in the Naval Reserve Civil Engineering Corps. Mr. Field has extensive experience in facilities development for the U.S. Navy and the Public Buildings Service of GSA. He is a mechanical engineer and holds a Master of Science in OPS research.

DENOS C. GAZIS is assistant director of the Department of Semiconductor Science and Technology at IBM Research in Yorktown Heights, New York. He served previously as director of the General Sciences Department, as technical advisor to the IBM vice president and chief scientist, as a member of the Research Review Board, and as assistant director of the Computer Sciences Department. In his various assignments, he has been involved in the review and management of a wide range of research and development activities in computer technology. He has also done research in applied mathematics, solid state physics, operations research and computer science. He has written over 100 papers and 2 books on these subjects. He was educated at Athens Polytechnic Institute, Stanford University, and Columbia University, receiving his Ph.D. in engineering science from Columbia in 1967.

BERTRAM HERZOG is president of Herzog Associates, Inc., a technical and management consulting firm specializing in engineering computation, CAD/CAM, and computer graphics. He is on the editorial board of IEEE Computer Graphics and Applications, Computers and Graphics, and CAD/CAM Digest. He was co-chairman of the SIGGRAPH Graphics Standards Planning Committee which published the Core standard. Prior to engaging in full-time consulting practice in 1979, he held positions in industry and at universities. From 1962 to 1965 he held management positions at Ford Motor Company in computer-aided engineering functions. His academic appointments have been at Cleveland State University, Case-Western University, the University of Michigan, and the University of Colorado. He has developed a network of large computers and has been director of a computing center. He has served on the boards of directors of several companies including the founding board of Computervision Corporation. Dr. Herzog received his B.S. in physics and his M.S. in engineering mechanics from Case-Western University, and his Ph.D. in engineering mechanics from the University of Michigan.

JOHN O. HOUSTON is executive vice president of GRAFCON Corporation where he manages all design, development and support of applications software at GRAFCON. Prior to this, he served as director of systems development for Graphic Constructions, Inc. From 1974 to 1978, Mr. Houston was assistant professor at Oklahoma State University where he received his Bachelor of Architecture, Bachelor of Architectural Engineering, and Master of Architectural Engineering. His background includes architecture, structural engineering, computer-aided drafting, design and engineering.

RONALD KING is project director for the General Accounting Office study of computer-aided design. He is area manager for all subsequent work on the use of computers in design. Mr. King has a degree in accounting and holds a California CPA certificate.

ROBERT E. MAHAN is manager, Information Systems Design at Battelle Pacific Northwest Laboratories. He is an adjunct lecturer in computer science at the Joint Center for Graduate Study at the University of Washington where he teaches digital design, computer architecture, and data communications. Previous positions at Battelle include manager, Electro-Optics Systems Section and associate manager, Computers and Information Systems Section. His research interests are in the areas of strategic planning, technology forecasting, and management systems. Mr. Mahan received his Bachelor and Master of Science in electrical engineering from Washington State University.

MYRON MILLER is an architect and planner, and a principal of Arrowstreet, Inc. A graduate of the Harvard Graduate School of Design, he specializes in architectural programming, urban design and planning, public information system design, development of design guidance documents, and planning and design procedures. His projects include: eight design guides for the U.S. Army and Air Force for diverse recreational and community facilities; specialized guidance for facilities for the handicapped and mentally retarded; manuals for roadway signage systems and implementation of public space improvements; community involvement procedures for mental health facilities; pedestrian mall design; and local energy programs. Mr. Miller has recently translated these architectural procedures into computer-aided design systems for the Army Corps of Engineers--the DIS/BSDS and 1391 Processor. These provide a modular space layout system for initial design, and a space program development system, for recreational and community facilities.

C. N. MITCHELL is director of project and facilities management in the Department of Energy. He is a retired rear admiral in the U.S. Navy where he has 32 years of experience, mainly with submarines. At DOE, Mr. Mitchell is responsible for independent assessments of department program and projects, and construction policy. He has several years experience in computers, graphics and computer-aided design. He received his Bachelor of Science from the U.S. Naval Academy and a Master of Science in business administration from George Washington University.

LEE R. NACKMAN is a research staff member in the Geometric Modeling project in the Manufacturing Research Center at the IBM Thomas J. Watson Research Center. His current research is in the computer systems aspects of computer-aided design, especially as applied to three-dimensional solid modeling. He is also an adjunct assistant professor of computer science at New York University's Graduate School of Arts and Science Program at Manhattanville College. Dr. Nackman received a Sc.B. degree in computer science from Brown University and a Ph.D. degree in computer science from the University of North Carolina at Chapel Hill.

MARY OLIVERSON is president and treasurer of Applied Research of Cambridge, Inc. in Lewiston, New York. She is an architect with experience in housing design, development and construction, and large-scale project planning/predesign. She also has experience in the application of computer techniques to building design, planning and modeling of the built environment including detailed knowledge of computer-aided drafting systems, and computer-aided design systems for architecture, civil and services engineering.

Prior to her current position, Ms. Oliverson worked with Skidmore, Owings and Merrill in San Francisco.

ROBERT G. PEARSON is currently the manager for product planning for CAD with Control Data Corporation where his responsibilities include the design and development coordination for micro-, super mini- and network-based CAD systems. His assignments have included large systems operating system support, and interactive graphics software development. Mr. Pearson received a Bachelor of Science and Master of Science in computer science from Purdue University.

EDWARD POPKO recently joined the Graphics System Programming Unit at IBM as software advisor for architectural, engineering and construction CAD/CAM. Since 1971 he has worked extensively with international development agencies to build computer systems for document retrieval, land use planning, and construction management. In 1979 he completed his Ph.D. research at MIT in urban studies and planning and was appointed project director of the Laboratory for Computer Graphics and Spatial Analysis at Harvard Graduate School of Design. At the laboratory, he participated in graphics systems development, taught graduate courses in computer-aided design and continued his personal interest in developing countries with research on microprocessor-based planning systems for low-income housing. Mr. Popko studied architecture at the University of Florida, the University of Detroit and the Massachusetts Institute of Technology.

NEVILLE POWERS is an architect and a consultant in computer modeling for building design and evaluation, and in architectural acoustics. A graduate of the Massachusetts Institute of Technology School of Architecture and Planning, he worked for seven years with the Cambridge, Massachusetts consulting firm of Bolt, Beranek, and Newman, Inc. before setting up his own practice. Mr. Powers conducted a comparative survey and evaluation of five large minicomputer systems to serve as local processors for the U.S. Army Corps of Engineers' CAEADS network. He recently developed and implemented computer-graphics modules, manipulation procedures, menus, and macros for the Army Community Facilities DIS/BSDA computer-aided design system using Applicon AGS/880-I hardware/software. He is now a principal applications engineer with Applicon/Schlumberger.

SHIRLEY RADACK is on the staff of the Institute for Computer Sciences and Technology of the National Bureau of Standards. She is responsible for developing reports and analyses of Institute activities which focus on the management and use of information technology. She holds a B.S. in microbiology.

KENNETH F. REINSCHMIDT has been associated with the Stone and Webster Engineering Corporation since 1975 as consultant, consulting engineer, senior consulting engineer, and manager of the consulting group. Prior to joining Stone and Webster, he was an associate professor of civil engineering and senior research associate at the Massachusetts Institute of Technology. Dr. Reinschmidt has consulted on problems in construction management, seismic analysis of nuclear piping, project management, and probabilistic fracture mechanics. He has conducted statistical analyses of nuclear and fossil power plant costs, schedules and operating experience, and has developed computer systems to optimize construction sites, to assess the economic risk of investment in synthetic fuel plants, to simulate engineering and design operations, to estimate the risk of cost overruns in construction, and to simulate construction productivity. Dr. Reinschmidt received his S.B., S.M. and Ph.D. in civil engineering from the Massachusetts Institute of Technology.

LEONARD SIMUTIS is associate dean for academic affairs, College of Architecture and Urban Studies, Virginia Tech. Prior to assuming his current responsibilities, he served as assistant dean and chairman of the Division of Environmental and Urban Studies from 1975-1982, and as director of the Computer Applications Laboratory in the College of Architecture and Urban Studies at Virginia Tech from 1973-75. He received a bachelor's degree from the University of Illinois, and M.A. and Ph.D. degrees from the University of Minnesota. His major teaching and research interests are in computer-based approaches to design and planning, with special interest in heuristic approaches employing computer graphics and information systems.

DAVID SKAR is director of the Naval Facilities Engineering Command's Engineering Systems Management Division, responsible for planning, developing and managing the use of advanced technology for engineering and design in Headquarters and its Engineering Field Divisions. This responsibility includes justifying resources, developing requirements for equipment, software, telecommunications and training, and managing system development and installation. These systems support all phases of construction contract document development, criteria development, consultation and management.

FRED STAHL is research architect with the Structures Division, Center for Building Technology, National Bureau of Standards, where he coordinates the Center's programs in computer integrated construction and conducts technical studies in this area. Current research topics include the computer-processing of building codes, standards and design criteria, construction project information systems, and expert systems applicable to building design and construction. In addition, Dr. Stahl is noted for his development of BFIRES, a computer model of occupants' responses during building fires. He has served on the editorial boards of the Journal of Architectural Research (1973-1980) and the Journal of Architectural and Planning Research (present).

DOUGLAS STOKER serves as director of computer services at Skidmore, Owings and Merrill where he is responsible for all SOM computer hardware and development of SOM computer software in the fields of architecture, engineering, space planning and interior design. Among these are SOM's in-house CAD system and the SDMS structural design system. He served as chairman of architectural and construction seminars for the 1983 National Computer Graphics Association conference. Mr. Stoker holds a Bachelor of Architecture degree from the University of Illinois, Urbana and an M.B.A. from the University of Chicago. He has done graduate work at Carnegie-Mellon University.

ROBERT F. TILLEY has been involved in the design and development of computer graphics applications for the Office of Construction of the Veterans Administration. His primary emphasis has been to find ways in which this new technology can aid in the "Design Review" process. In March 1983 his office received approval for a $4.5 million system development effort to automate the design criteria and A/E package preparation functions.

RICHARD N. WRIGHT has directed the National Bureau of Standards' Center for Building Technology, the U.S. national building research organization, since 1974. Its 110 engineers and scientists conduct field, laboratory and analytical research on building practices and on the performance of building materials, components and systems. From 1957-74 he was a member of the civil engineering faculty of the University of Illinois at Urbana. He has worked in research on computer-aided design since 1963. Recent studies focus on advanced methods for the analysis, synthesis and expression of standards, and their application in computer-aided design. He was recently elected President of the International Council for Building Research, Studies and Documentation (CIB) for the 1983-86 term.

RICHARD WROMBLE is a commissioned officer in the U.S. Public Health Service. His experience has been in the air pollution, radiation protection, and Indian health sanitation facilities construction programs. He is currently involved in developing an information management system for the Department of Health and Human Services facilities and property management programs. Mr. Wromble has a B.S. in civil engineering and an M.S. in sanitation engineering.

APPENDIX III

WORKSHOP SCHEDULE

National Research Council
Commission on Engineering and Technical Systems
Advisory Board on the Built Environment

WORKSHOP ON ADVANCED TECHNOLOGY FOR DESIGN AND ENGINEERING

National Academy of Sciences
Woods Hole Study Center
Woods Hole, Massachusetts
August 21-26, 1983

WORKSHOP SCHEDULE

This schedule is flexible; the underlying organization of the workshop relies on the participants to help create and modify the agenda as the week progresses. Therefore, this workshop schedule presents a framework that can be embellished, or even rewritten, as the workshop proceeds.

Sunday, August 21

6:00 PM - 7:30 PM	Registration. Carriage House.
7:30 - 8:00	Welcome. James Burrows. Carriage House.
	Introduction to the Workshop. John Eberhard.
8:00 - 9:00	Introduction of Participants. Self introduction of participants.
9:00 - 10:00	General Discussion.

Monday, August 22

8:30 AM- 8:45 AM	Introduction to the Day. John Eberhard. Carriage House.
8:45 - 9:45	First Keynote Address. Denos Gazis, IBM Research Center. Questions and discussion to follow.
10:00 - 11:00	Second Keynote Address. Charles Eastman, Formative Technologies, Inc. Questions and discussion to follow.

11:00 - 12:00 Noon	General Discussion. Organization of workshop.
12:00 Noon - 6:00 PM	Free Time. Unstructured time set aside for discussion, relaxation, or exploration of the region. Participants are encouraged to join others in small groups for lunch. Lunch is provided at no cost at the Study Center.
6:00 - 7:30	Reception and Dinner. Cash Bar. Clambake. Study Center.
7:30 - 10:00	General Discussion. State of the art in electronic technologies and telematics related to building design and engineering. Carriage House. Films. Possible showing of one or more films on robotics, expert systems and data bases.

Tuesday, August 23

8:30 AM - 12:00 Noon	Working Groups. Formulation of critical issues. The morning working groups are: A. Building Description and Representation B. Data Base Design and Management C. Data Integration Considerations D. Computer-Aided Building Rooms will be announced. Groups may continue working into the afternoon.
12:00 Noon - 7:30 PM	Free Time.
7:30 - 10:30	Working Groups. Formulation and dicussion of critical issues. The evening working groups are: 1. University R&D 2. Federal Government R&D 3. Private Industry R&D 4. Architectural Practice 5. Engineering Practice 6. University-Based Educational Programs 7. Incentives and Barriers

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Wednesday, August 24

8:30 AM - 12:00 Noon	Working Groups. Morning working groups reconvene. Discussion of issues. Groups may continue working into the afternoon.
12:00 Noon - 1:00 PM	Lunch. At no charge to participants. Study Center.
1:30 PM - 4:00 PM	Free Time.
6:00 - 7:30	Reception and Dinner. Cash Bar. Cook-out.
7:30 - 10:30	Working Groups. Evening working groupsreconvene. Writing session.

Thursday, August 25

8:30 AM - 12:00 Noon	Working Groups. Morning working groups reconvene. Writing session. Groups may continue working into the afternoon.
12:00 Noon - 7:30 PM	Free Time. Lunch is provided at no charge to participants at the Study Center.
7:30 - 10:00	Reports. Evening working groups present reports in plenary. Carriage House.

Friday, August 26

8:30 AM - 12:00 Noon	Reports. Morning working groups present reports in plenary. Carriage House.
	Summary Session. John Eberhard and James Burrows.
12:00 Noon	ADJOURN.