ALTERNATIVE MODELS OF ARCHITECTURAL PRACTICE:
The Impact of Computers -- 1990 and 2000

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ABSTRACT

Though many architectural firms have only recently begun to use computers, and most firms still do not use computers for design, it is likely that by the turn of the century computers will have transformed architectural practice. First this paper assesses the likelihood of change by examining the potential use of computers in architectural practice, summarizing technology forecasts for computer hardware, software, and standards. However, because there is an opportunity, architectural firms will not necessarily computerize. Next is a brief review of impediments to change and the process of organizational adaptation of new technology. Finally, the paper concludes with a number of forecasts in architectural practice in 1990 and 2000. A variety of professional practice options are defined, with the suggestion that there will be increasing experimentation and diversity within the profession. Finally, the implications of these changes are explored for architectural education.
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BACKGROUND AND OVERVIEW

Computers have been slow to penetrate the architectural profession, though they are now beginning to gain increasingly wide acceptance.

Looking back can be of some assistance in assessing where the profession is today and what the positive forces and impediments to change may be. The first section will look at computer applications in professional practice, current possibilities and limitations.

However, the field of computing is moving so extraordinarily rapidly that the past is likely to be a poor guide to the possibilities for the future. Next we will look to the future. This will include forecasts of technology changes in hardware and software, standards, and integration of applications programs. Some general comments on the absorption of new technology are next offered.

This lays the foundation for the forecast for the impact of computing on architectural firms in 1990 and the year 2000. A variety of alternatives are provided in the expectation that indeed much diversity will exist.

Finally the implications of this RAPID, technology driven change for the profession are explored from the perspective of professional education.

COMPUTER APPLICATIONS FOR PROFESSIONAL PRACTICE

Inventory of possibilities

In order to better understand the potential for computer aids in architectural practice, the types of activities architects engage in are classified and the various types of computer programs are related diagrammatically to these activities. The reader is encouraged to add other types of computer application programs that may have been omitted from this listing.
Current status

Except for a few pioneers, architects have only recently begun to use computers. A survey in 1981 found that only about 18 percent of United States architectural firms used computers. A similar survey in 1983 found that in two years the number had doubled, to about 41 percent. The most common use of computers in these firms was word processing. Relatively few firms were using computers for design and analysis at that time, though the number has been rapidly increasing.

Current constraints and limitations to greater computer usage

Most architectural firms have few employees and are likely to have limited financial and technical resources available for computing. Until recently, computing was simply not affordable for most firms. The doubling of computer usage between 1981 and 1983 reflected in large part the growing popularity of personal computers which made computing more accessible and affordable for everyone, though full function CAD workstations are still not affordable to most firms.

Prices have continued to decline and CAD has continued to gain greater acceptance in architectural firms. Applications software was also being adapted to an interactive environment and for users with little or no computer expertise.

The microcomputer programs that are available, like the mainframe programs, do not yet serve the early stages of the design process. They serve best for engineering analysis, working drawings, and specifications.

The mainframe programs also have some significant limitations that often will require substantial revision before they are suitable for most architects and exploit the advantages of the microcomputer environment.

- many of these programs were developed by the aerospace and nuclear power industries, and while relevant, they are not well tuned to the needs of architects;
- most of these programs are difficult to use and require considerable technical expertise;
- the lack of graphics, database and other standards inhibit the integration or data exchange among the various graphics, analysis, and display programs that exist, and therefore limit their benefits while increasing their costs (e.g., data entered for one program, say design, could not be used by another program, say structural or energy analysis). This creates additional problems (or lost opportunities) for architects who must share building descriptions with structural and other consultants.
There are also a number of other factors that limit the use of computer aids in architectural firms, some economic and others more cultural. The education and training of architects typically does not prepare them for understanding computing, evaluating possible computer applications, or selecting and installing computer systems within their firms. For some architects, the computer also represents a threat to the art of design and the craft of drawing. Architecture has traditionally been a labor intensive profession, and architects have had relatively little experience in investing in a more capital intensive work environment or in the introduction of new technologies. Finally, until CAD systems provide more adequate tools to serve the design process, they are not likely to directly engage the principal designers in professional firms.

In spite of all this, there is a growing interest in computers in general and CAD in particular that is clearly evident within the practicing profession, at conferences, in various professional journals, and in schools. Change is definitely on the way.

TECHNOLOGY FORECASTS

There are a variety of technological factors that will shape the role of computing in architectural practice in the future. Key factors are outlined below. These forecasts, in part, define what is technologically feasible. What is feasible and what individual professionals adapt may be two very different things though. The section following this will discuss the adoption of technology and some possible scenarios for the architectural firm in the future.

Computer hardware

The "architecture" of computing systems has changed dramatically in the relatively short history of computing. The following forecast assumes that the dominant computing environment in architectural firms in the next decade will be built around the individual workstation, sharing resources, and capable of communicating with other workstations, mini and mainframe computers within and outside the firm.

Hardware: not the limiting factor

The following brief overview will demonstrate that within a very short time the functionality and cost of computer hardware are not likely to be constraining conditions in the spread of computing in architectural practice. These forecasts are also relatively conservative in that they are based on existing technology. Major research on "Fifth Generation Computing" in
Japan, the United States, and several European countries could necessitate major revisions within a decade. If even a fraction of the promise of the Fifth Generation Computer Project is achieved, much greater change will occur than is here projected.

The Individual Workstation

The individual workstation is likely to be a "micro-mainframe", that is, a desktop microcomputer with the computational capability of today's mainframe computer, and high performance graphics. Several 32 bit (mainframe size) microprocessors are already in production today, and the prices of such powerful processors and memory are rapidly declining. The resolution of graphics displays should continue to improve and the costs decline as a result of increased production volumes, increased use and reduced cost of dedicated microprocessor graphics controllers, and lower cost memory. Already there are workstations available in the $10,000 to $15,000 price range with high resolution graphics and performance (measured in MIPS) that more than doubles that of the VAX780. A workstation has recently been announced with performance about 1/4 that of the CRAY 1/S super computer at 5 percent of the cost. By the year 2000 such supercomputer performance at a desktop workstation is easily conceivable. Performance and cost are likely to diminish rapidly as constraints that limit the use of computers in architectural firms.

Peripheral Resources

Numerous other components are required for a computing system capable of supporting an architectural practice. Storage capacity must be provided for the text, numeric, and image databases. A variety of alternatives should be available to enter these data into the system, and to produce hardcopy. Again continuing rapid performance increases may be anticipated in each of these areas.

Standards: A critical "pacing" factor

Standards are important to the architect or other end users both directly and indirectly. It is the definition and adherence to standards that permits the user

- to select the hardware most suited to needs with reasonable assurance that one component will work with another if both were purchased from the same firm at different times, or even if each was manufactured by a different company;
- to choose among application programs and other software with reasonable assurance that the selected item will work with the available hardware; and
to exchange data or in other ways make application programs work with one another—for example, allow energy or structural analysis program to utilize the building description database created in the Computer Aided design program.

Numerous hardware and software standards have already been defined by national and international organizations. The usefulness and extent of compliance with these standards varies. Areas of standards, de facto and otherwise, that have been slow to evolve and are of particular interest to architects include 3-D graphics and window environments.

Software: Further needs and opportunities

Typically computers are first used to do what had been previously been done, only more efficiently. For the most part, the various computer programs used by architects serve best in meeting the requirements for business management, engineering analysis, and documentation—drafting and specification writing. It is assumed that the next generation workstations will accommodate the full functionality of these programs. Such programs have not changed the design process. This could change. In particular, some consideration of "visual thinking", more tightly coupled, iterative design and analysis, and expert systems are relevant to changing the way design is done.

Visual Thinking

It is important to distinguish between drawing to extend one's thinking and drawing as communication (McKim 1980). Most computer graphics applications are designed to document and/or communicate spatial information. Architects and others, however, frequently use drawing and other visualization techniques, particularly in the early stages of formulating a project concept and design, as a means of "visual thinking", of creative exploration and problem solving.

Increased interest and many years of research and development are likely to be required before CAD and related computer applications are likely to fulfill their potential for this early and creative part of the design process. In the longer term, though, this may be one of the most exciting and important areas of contribution that computer aids can offer the design professions. As a first step, several CAD vendors are now developing sketching programs that will work in concert with their CAD systems. This marks an important step forward, for drawing as "visual thinking" can often be characterized as impressionistic, rapid, "freehand" sketches, often from varying viewpoints", with rarely a fully formed image—in short, just the kinds of capabilities sketch programs should have.

Better design decision making
There is also a growing body of literature on the design process that suggests that creative thinkers are flexible thinkers who move freely between modes of thinking, between "visual", verbal, and quantitative thinking (Adams 1979). More powerful computers and more efficient computational algorithms offer the promise of provided opportunities for a more tightly coupled, iterative process of design and analysis, providing tools that can help the architect better understand the consequences of alternative designs in the early stages of design decision making. This point is sufficiently important to justify a couple of examples.

The graphic simulation of the thermal behavior of buildings, or the earthquake loading, exhibited at Rensselaer two years ago, or the fire spread simulation demonstrated last year, provide almost a kinesthetic "feel" of the structural or fire safety behavior, and a qualitative understanding that would be difficult, if not impossible, to achieve through numeric calculation alone (Ozel 1985). Furthermore, the understanding pertains at the level of building systems and not simply that of individual structural elements. Such analysis could not only contribute to a better design of an individual building, but in time, a better feel for the consequences of design decisions more generally.

Expert systems

Expert systems are a particular class of computer programs that apply the methods of artificial intelligence to aid in human decision making. Though research and development work on expert systems has been going on for well over a decade, within the last couple of years the prospects for commercially viable expert systems have increased substantially. Commercial products are available today, and many expert systems are in use and have demonstrated their utility in such diverse fields as geological prospecting, medical diagnosis, and equipment maintenance, but not yet in a field directly related to architecture (Schmitt 1985, Waterman 1986). This is a new and now rapidly emerging field though, and there are many potential applications to architecture. Research is well underway in expert systems to aid, for example, in the selection of architectural materials, structural systems layout, and construction scheduling, though such systems are not now commercially available.
MICROPROCESSORS AND MEMORY—CHANGING PRICE/PERFORMANCE RATIOS

MEDIAN MICROPROCESSOR PRICE VS. TIME
1000 unit purchase

SEMICONDUCTOR MEMORY COMPONENT PRICE
PER BIT, RAM PRICE BY SPEED CLASS

DISK STORAGE—INCREASING PERFORMANCE, DECLINING PRICES

GRAPHICS DISPLAYS—HIGHER PERFORMANCE, LOWER COST
LOCAL AREA NETWORKS (LANS)—AN OVERVIEW

LOCAL AREA NETWORK provides network-wide virtual memory/virtual device access to all attached components.

SAVINGS FROM SHARED RESOURCES
- mass memory
- printers/plotters
- digitizers

SAVINGS INCREASE WITH
- number of workstations
- performance requirements
- number of shared peripherals

VIRTUAL MEMORY BENEFITS
- cost savings
- convenience
- control

LOCAL AREA NETWORKS—COSTS, RISKS, AND BENEFITS

COST/ RISK/ BENEFIT


CURRENT COST-RISK CONSIDERATIONS
- multiplicity of choices
- network architectures
- transmission media
- communications protocols
- not integrated into most computer vendor hardware architecture or system software
- high entry level of sophistication for acquisition decision
- high, rapidly declining unit connect costs ($1500 to $500 in 2 years, $125 by 1985)
- high risk for unsophisticated buyer and implementation

FUTURE PROSPECTS (NEXT 2 YEARS)
- cost-risk constraints should largely disappear
- potential benefits should greatly increase
- increasing number of workstations
- increasing demand for main memory (system and applications software)
- increasing demand for specialized/costly peripherals (printers, mass memory, communications)
As background to assessing how computing may change architectural firms, it is instructive to consider first how computing has changed other organizations.

Stages of organization change

There is a fairly well defined process of change often noted. Typically an organization first seeks to use computers to automate labor intensive tasks. Capital costs are substituted for labor costs, and economic efficiency is the driving force for justifying the change.

Whether computers are used to assist in word processing, accounting, or computer aided design, the goals and methods of implementation will strongly influence the extent of initial success. The extent to which those who will be effected by the introduction of new technology have participated in the planning, how they view the way their job is likely to change, and the adequacy of their training for the use of new technology—these and other factors will determine the extent of acceptance or resistance to the new technology (Bikson, Stasz and Mankin 1985).

If utilizing new technology simply institutionalizes inefficient office procedures (e.g. automates manual procedures without change), little gains in efficiency are likely to be achieved. On the other hand, if the introduction of new technology is utilized as an opportunity to analyze work methods, substantial gains in productivity may be achieved as the combined effect of improved work methods and the efficiencies of new technology.

Though often not recognized at the outset, the full benefits of new technology usually require substantial changes in the organization of work. Whether such changes result in more or less satisfying jobs is usually more a matter of management philosophy and goals of automation than of any inherent characteristics of the technology. Depending upon the philosophy, goals and methods of management, the use of new technology may either 'de-skill' or provide more fulfilling jobs, and employee satisfaction may be increased or decreased, with inevitable impacts upon productivity and ultimately, the acceptability and success of the new technology.

While efficiency is usually the initial objective, and lower skilled work is usually the first target of automation, in time, it is recognized that computer aids can improve the quality of decision making. Thus, in architectural firms, typically the secretarial and drafts-person jobs are the first to feel the impact of computers, but some of the most exciting possibilities
will not be realized until computer aids begin to serve senior designers directly and impact upon the quality of design.

Finally, while computers are usually justified and utilized initially for well defined tasks where efficiency improvements are expected, in time new, unanticipated uses of information technology are often discovered. This often leads to more radical revision of work methods and frequently to the provision of new and different services.

The chart below highlights these major stages typically found during the introduction on new information technologies.
The architectural firm in 1990

Following are a number of interrelated forecasts. Underlying all these forecasts is the recognition that individual architects and individual professional firms will respond in different ways. In fact, this forecast suggest that in the near and intermediate term, the increased usage of computing will result in experimentation and increased diversity in professional practice.

- With respect to the computing environment:
  -- sophisticated computer graphics workstations and software will be affordable by virtually all architectural firms;
  -- graphics standards will be well established;
  -- there will be a variety of usable software to support most of the architectural, engineering and related functions described elsewhere in this paper;
  -- software in support of the exploratory, creative design most characteristic of the early stages of the design process will be available in many Universities and research and development laboratories, but only to a limited extent in the commercial marketplace;
  -- a relatively small, but rapidly increasing, number of computer programs will be integrated or, more likely, able to exchange data--thus increasing the utility of each.

- Nearly all firms will use one or more computer applications, though many firms will not yet use computers for design.

- Increased computer usage will produce many changes in professional practice:
  -- small and medium size firms will be able to compete for, and undertake larger jobs,
  -- architectural firms of all sizes will provide more and more varied services
    .. cost, economic, market, and financial analysis
    .. engineering analysis
    .. construction management
    .. facilities management
-- some architectural firms will make substantial investments in the development and marketing of computer applications programs and/or specialized data bases, either developed originally for internal use or developed from the outset for sale

-- a larger number of integrated firms will evolve, not necessarily large firms
   .. architecture and engineering
   .. design and build

-- a few architectural firms will remain involved with a building over its life cycle, changing the way architects think about, and evaluate architecture
   .. design
   .. build
   .. sales and tenant modifications
   .. facilities management and maintenance
   .. rehabilitation

-- some corporations with large inventories of properties will choose to manage this life cycle process by creating their own in-house architectural and facilities management staffs

-- in a few firms the architectural design process will fundamentally change.

- An increasing number of engineering and construction firms will compete with architectural firms, finding that CAD systems can help them to utilize "packaged" designs without the need for architects.
- There will be an increasing, recognized need for professionals in mid-career to participate in continuing professional education programs to help adjust to new technologies and the changing environment.
- All of these changes will force changes in the law of professional liability. How this law evolves may also shape the nature of professional relationships and the reliance on computing and electronic databases.

The architectural firm in 2000.

By the year 2000 architectural firms that are not making extensive use of computing aids will no longer be competitive. Nostalgia will keep some of these firms alive, but most will not survive.
Virtually all firms will utilize computers to aid in design, and in support of nearly all activities performed.

There will be many important advances in support of the early stages of the design process. "Sketch" type programs and other programs that stimulate and support "visual thinking" will be widely available. Many design and engineering decisions will be supported by artificial intelligence "expert systems".

Artificial intelligence will be applied to design generation. Automatic design generation may be successful in a few, highly repetitive design contexts (e.g. Burger King or other chain stores)—that is, in these constrained contexts they may generate acceptable, though not exceptional design solutions.

The organization of professional practice and the types of functions performed are likely to change, for most firms, in ways that cannot be clearly predicted in advance of the substantial experimentation that is expected in the intervening years.

Concepts of information, construction documents, communications, design, and the very nature of the design process will have changed substantially, in ways that cannot now be fully anticipated.

The construction industry could be undergoing a revolution, applying new technologies for advanced materials design and production, materials handling and assembly, and construction management. These changes, many integrally tied to computing aids, could further transform the nature of architectural and related services (Moavenzadeh 1985).

**IMPLICATIONS**

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Even if the above forecasts are only partially correct, they are rich in implications for the architectural, engineering, and related professions; for that segment of the computer industry catering to these professions; and for those responsible for the education of these professionals.

The question is not whether computing technology will have a profound impact upon the architectural and related professions. It will. The more interesting questions are what will this impact be and how will it be determined? The following discussion will focus upon professional education and its role in preparing students and shaping the future of the profession.
The technology induced pace of change within the architectural and related professions provides many challenges for the professional schools. At present the major focus appears to be upon preparing students to work with CAD. While important, I believe that this is far too limited an approach. Let me briefly outline a variety of other needs that I believe should be met.

Universities should create computing environments that not only prepare students for the world that they will face, but also takes full advantage of computers to teach more effectively.

In preparing students for the future of their professions, not only should students be acquainted with CAD, but they should be able to function effectively in a relatively highly computerized environment. They should not only understand something about the technology, but they should learn to anticipate and manage change. They should be endowed with not only skills, but also human values which guide them in incorporating technology in ways that create humane environments within their own professional practice and outside in the built environment they help to shape.

Technical issues must be mastered. They are often sufficiently difficult that they command all the attention. But the computing environment also includes people, and it should be emphasized that an investment in computing is an investment in people, to help each perform more efficiently and effectively, and, yes, more creatively. Thus students must be prepared to develop the computing environment in a way that contributes to:

--- individual and organizational efficiency and quality of work,
--- individual job satisfaction and the morale of the organization,
--- "organizational learning" -- that is, preparing individuals within the organization and the organization as a whole to progress step by step towards more sophisticated and demanding computer applications.

The forecasts of professional futures are in no way deterministic. Important choices exist. It will be increasingly important to the professions that researchers define new options, that clear headed thinkers illuminate and analyze the choices, that there be experimentation in creating and demonstrating viable options, that forceful spokespersons articulate the evolving needs of the professions, and that each professional purposefully and intelligently evolves an appropriate and effective strategy for change.

There is a need for much research in a discipline and professional with very weak traditions in research. Deeper study
is needed to better understand the design process and how computers can assist in all stages of design decision making. Research is needed on how to modify and improve the design process. With the increasing use of computer-based analysis, there is a need for clearer design criteria, and the need for research on building performance, including post-occupancy studies. This challenge, then, is far from a cultural change, if indeed more research is to be undertaken, and research accomplishments are to be recognized and rewarded within the Universities and the profession.

Architects and related professionals will not be alone in confronting the need for change brought about by the computing and telecommunications revolutions. They are a part of the broader social and economic fabric that is taking new form as the information society unfolds. This newly evolving information society will provide new roles, new opportunities, new challenges, and new responsibilities for the ancient and respected profession of architecture, and for the society at large.
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